Physicochemical, microbiological, and sensory characteristics of soy sauce fermented in different regional ceramics

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Abstract Korean traditional soy sauce was fermented for 120 days in ceramics obtained from five different regions in Korea. The average internal and external temperatures of soy sauce in ceramics were 20.0 and 18.3 °C, respectively. Physicochemical, microbiological, and sensory characteristics were analyzed. Ceramics from different regions generated differences in physicochemical characteristics. Soy sauce fermented in the southwest regional ceramic, which has a low height and wide circumference, had significantly lower salt content, higher reducing sugar content, and protease activity rather than others. In descriptive analysis, soy sauce fermented in the ceramic from Seoul capital region had a lower intensity of saltiness and biting taste, whereas the soy sauce in the southwest ceramic had comparable saltiness and biting taste attributes as those in the southeast and central regions, and Jeju Island ceramics. Five regional ceramics were categorized into three groups by principal component analysis. Based on the physicochemical characteristics, soy sauces from southwest and Seoul capital regions had distinctive characteristics in comparison with the soy sauces from Jeju Island, southeast, and central regions.

Keywords Ceramic · Fermentation · Quality · Sensory evaluation · Soy sauce

Introduction Soybean fermentation for soy sauce production in Korea is back to more than 2000 years (Lee 2001). Korean soy sauce is traditionally made from a naturally fermented soybean brick (meju) by soaking for several weeks in brine solution followed by filtration in order to remove solid residues. The filtered soy sauce is re-contained in ceramic and continuously fermented in the natural environment prior to consumption. Korean traditional soy sauce is produced through fermentation by Bacillus species such as B. subtilis, B. licheniformis, B. pumilus, and B. amyloliquefaciens, which are the dominant microorganisms in meju (Cho and Seo 2007), whereas Korean mass-produced soy sauce is produced by fermenting cooked soybeans and wheat flour with Aspergillus oryzae or A. sojae like shoyu, Japanese soy sauce (Luh 1995; Jeong et al. 2004). In recent years, many people are paying attention to health and well-being which epitomize the slow food phenomena, in addition to fermentation science and a gluten-free diet (Choi et al. 2013). Slowly produced Korean traditional soy sauce could be attractive for those people. In addition, the traditional soy sauce business in Korea can stretch to the global market with their high quality.

Ceramics (onggi) traditionally and widely used in Korea to ripen and store various salted fermented foods such as soy sauce, Doenjang (Korean fermented soybean paste), kimchi and pickled fish (Seo et al. 2005, 2006). Ceramic is manufactured by forming and drying clay paste including fine sands, coating the surface with a natural ash, and firing at roughly 1200 °C in a tube kiln. The ash-glazing treatment to provide the desired barrier properties is not included in all cases (Seo et al. 2005). Koreans believe that ceramics helps produce high-quality soy sauce due to its
porosity (Park 2012). Ceramic consists of micro-pores that offer the permeation of oxygen, carbon dioxide, water, and salt during the fermentation of food, and the permeability of ceramics is mainly influenced by the clay type and ash-glazing treatment employed (Seo et al. 2005; Lee et al. 2006; Seo et al. 2006). Using ceramics for anchovy soy sauce fermentation showed higher quality than that from glass jar, stainless steel tank, and PET tank (Chung et al. 2004).

Korea has distinct food cultures in different regions—Seoul capital region, central region, southwest region, southeast region, east mountain region and Jeju Island—due to different climates, soil, types of agriculture, available natural foods, etc. (Lee 2002). Thus, ceramics varies by the region with respect to its size, shape, and porosity. The distinct features of ceramics according to geographical origins are tall and narrow circumference in Seoul capital region, similar diameters from top to bottom in the central region, narrow mouth in southeast region, narrow bottom with wide circumference and mouth in southwest region, and reddish color due to the high iron content in the soil from Jeju Island (Choi 2011). Although there are differences in ceramics originating from different regions, studies have been limited to controlling permeability for soy sauce (Chung et al. 2006). Therefore, the objective of this study was to investigate the physicochemical, microbiological, and sensory characteristics of soy sauce fermented by the ceramics from different regions in the natural environment conditions.

Materials and methods

Chemicals

Sodium carbonate, NaH$_2$PO$_4$, sulfuric acid, potassium sulfate, and cupric sulfate were purchased from Duksan Pure Chemicals (Korea). H$_2$SO$_4$, HCl, NaCl, and MeOH were purchased from SamchunPure Chemicals (Korea). D-glucose was bought from Duchefa Biochemie BV (The Netherlands). MRS agar and PDA were used from Becton–Dickinson (USA). Folin reagent, 3, 3’-dithiodipropionic acid, mercaptoethanol, and acetonitrile were purchased from Sigma-Aldrich LLC (USA).

Ceramics and fermentation conditions

Ceramics representative of five regions in Korea were collected from one of the cities of the regions where traditionally known as the capital of producing of ceramics. Geological regions, shapes, and specifications of ceramics (total height, height to convex, circumference of convex, average pore size, and porosity) used in this study are provided in Fig. 1 and Table 1. Soy sauce prepared by the Korean traditional method was purchased from Dure Foods (Korea). Soy sauce (38 kg) was placed in each ceramic (60 L) for fermentation.

Soy sauce fermentation was performed on a rooftop of the research facility located in the southeast of Seoul capital region (Yongin, Korea) for 120 days, beginning from the Korean summer season to early winter (July 27th–November 29th) in 2013. The highest internal temperature in the ceramics was 42.6 °C and the external temperature was 31.4 °C on August 20th (Fig. 2). The lowest internal temperature was recorded as −4.4 °C and was the same as the external temperature. The average internal and external temperatures were 20.0 and 18.3 °C, respectively, and the internal temperature was generally 1.6 °C higher than the external. Internal temperatures above 40 °C were recorded for 12 days between August 1 and August 26, whereas temperatures below 5 °C were recorded during the last 21 days of fermentation. All batch fermentations were carried out in duplicates.

Measurement of physicochemical characteristics

Samples were taken every 20 days and analyzed in triplicates for each batch to determine physicochemical changes. The ambient and internal temperatures were monitored using a digital thermometer (Will Science, Taiwan) attached inside the ceramics. Salinity, soluble solid contents, and pH were measured with a salimeter (Mettler ToledoGmbH 8603, Switzerland), a digital refractometer DR-103L (Bellingham + Stanley Ltd., UK), and a pH meter (Orion 3 star Benchtop; Thermo Orion, USA), respectively. Soy sauce (5.0 mL) was heated at 95 °C in a water bath and then dried at 105 °C in a dry oven until it reached to a constant weight to determine the moisture content. Water loss was expressed as the difference in moisture content at each sampling time compared to the initial moisture content. For the crude ash analysis, a 5.0 mL sample was heated at 550 °C until white-gray ash was obtained. To determine the total acidity due to lactic acid contents, 5.0 mL of soy sauce was diluted with 20 mL of distilled water and titrated using a 0.1 N NaOH solution to pH 7.0. The amounts of the 0.1 N NaOH solution were converted to 0.05 % acetic acid solution. Reducing sugar content was determined using a modified DNS method (Miller 1959; Ghose 1987). A sample (200 μL) was mixed with 600 μL DNS solution and heated at 100 °C for 5 min. Water (3 mL) was added to the reaction solution, and its absorbance was measured at 550 nm. D-Glucose solution was used as a standard.
To determine the total protein content, soy sauce (5.0 mL) was mixed with 10.0 mL of concentrated sulfuric acid and heated for 2 h in combination with a mixture of potassium sulfate and cupric sulfate at a ratio of 10:1. The decomposed sample (10 mL) was reacted with 20 mL of 30 % NaOH and then distilled. Ammonia gas was

![Fig. 1](image)

**Fig. 1** Ceramics collected from five different regions in Korea (A) and their pictures of ceramics (B)

**Table 1** Specification of ceramics from five different regions

| Region         | Total height (cm) | Height to convex (cm) | Circumference of convex (cm) | Average pore size (nm) | Porosity (%) |
|----------------|-------------------|-----------------------|------------------------------|------------------------|--------------|
| Seoul capital  | 51.2              | 30.0                  | 128.1                        | 1600                   | 14.0         |
| Central        | 46.1              | 28.2                  | 135.7                        | 116                    | 9.2          |
| Southwest      | 45.6              | 28.5                  | 143.1                        | 359                    | 10.2         |
| Southeast      | 44.2              | 26.5                  | 124.9                        | 242                    | 11.0         |
| Jeju Island    | 61.6              | 49.3                  | 140.8                        | 8800                   | 4.9          |

**Determination of total nitrogen contents**

To determine the total protein content, soy sauce (5.0 mL) was mixed with 10.0 mL of concentrated sulfuric acid and heated for 2 h in combination with a mixture of potassium sulfate and cupric sulfate at a ratio of 10:1. The decomposed sample (10 mL) was reacted with 20 mL of 30 % NaOH and then distilled. Ammonia gas was
simultaneously collected in 0.05 N H\textsubscript{2}SO\textsubscript{4} and titrated with 0.1 N NaOH.

**Determination of protease activity**

One milliliter of 25-fold diluted soy sauce mixed with 1 mL of 1 % casein solution was preheated to 37 \degree C for 2 min and then incubated at 37 \degree C for 10 min. TCA solution (0.4 M; 2 mL) was added, and the mixture was centrifuged at 9425 \texttimes g force for 5 min. The supernatant (500 \mu L) was mixed with 2.5 mL sodium carbonate, and then 500 \mu L of 2 N Folin reagent was added. After 20 min of incubation at 37 \degree C, the absorbance of the mixture was determined at 660 nm using tyrosine as a standard. One unit was defined as the amount of enzyme that produced 1 \mu g of tyrosine in 1 min at 37 \degree C.

**Total count of bacteria and identification**

The samples were serially diluted with 0.85 % NaCl and spread onto the surface of Nutrient Agar for total aerobic bacteria, MRS agar containing 0.001 % bromocresol purple for lactic acid bacteria and PDA for molds. Nutrient agar was incubated for 24 h at 30 \degree C to determine total aerobic bacterial counts. MRS agar and PDA were stored for 48 h at 30 \degree C to count the number of lactic acid bacteria and molds.

**Descriptive analysis of soy sauces**

The descriptive analysis of soy sauce was conducted with 8 trained panelists using a modified version of the method proposed by Jeong et al. (2004). The panelists had at least 10 months of experience in descriptive analyses with 93 h of basic training. A total of 10 samples were tested by presenting 25 mL in a white paper cups (60 mL) labeled with three-digit random numbers. A white disposable spoon, a standard sample, and filtered water (room temperature) were provided with each sample. Panelists dipped the white plastic spoon vertically into the sample, pulled out, and kept 5 s prior to the evaluation. The panelists took a 3-min break after rinsing their mouth using room temperature water in order to prevent carry-over effect and sensory fatigue. Taking 3-min break after rinsing, the mouth was effective in preventing carry-over effect for strong flavored sample (Seo et al. 2015). Seven attributes were determined to evaluate the sensory characteristics of soy sauce (Table 2). Attribute intensities were determined using a 16-point category scale (0–15); however, the panelists were allowed to record more than 15 points for the saltiness of the samples.

**Statistical analysis**

Analysis of variance (ANOVA) was performed to find out significant differences using the Minitab 16.1.0 program (Minitab Inc., USA). Significant differences between samples or fermentation periods were assessed with Tukey’s test at \( P < 0.05 \). Pearson’s correlation coefficient test was conducted to present the relation between salt content and physical properties of ceramics. Principal component analysis (PCA) was performed to present the relation of significantly different physicochemical characteristics of the five soy sauces using XLSTAT (Addinsoft, France).

**Results and discussion**

**Changes in physicochemical characteristics of soy sauce during fermentation**

Water loss for the soy sauce increased rapidly up to 3.1–3.8 % within the first 40 days of fermentation during the Korean summer season (Table 3). The different regional ceramics had no effect on water loss during the first 40 days \( (P < 0.05) \). Afterward, water loss continued to increase in only the southwest regional ceramic reaching to 5.8 % after 120 days of fermentation. Total water losses in the other ceramics were in the range of 4.2–4.5 %. Temperature might be one of the factors affecting water loss. Although Korean traditional soy sauce is typically fermented in ceramics on the roof top under natural environmental conditions, previous studies on its fermentative characteristics were mostly performed at constant temperature in the lab condition. Water loss during soy sauce fermentation was much lower than that from the previous study, which showed approximately 10 % water loss in Korean anchovy soy sauce fermented at 30 \degree C for 4 months (Lee et al. 2006). The average temperature of our soy sauce was 29.0 \degree C during the first 40 days and 15.6 \degree C during the other 80 days. Earlier studies by Lee et al.
(2006) and Seo et al. (2005) reported that glazing treatment on the ceramics retards water loss of soy sauce. This finding, however, disagreed with the results of our study because the ceramic from Jeju Island, which lacked of glazing treatment, showed the similar rate of water loss as the other ceramics.

The salt content of soy sauce increased rapidly to 33 % between 20 and 40 days of fermentation (Table 3). It then decreased gradually after 60 days of fermentation due to the precipitation and crystallization of salt. This decrease in salt concentration was due to precipitation during the fermentation process (Kim and Lee 2008). At the end of fermentation, the salt contents of the samples were 29.27–30.29 %. The salt contents in this study were similar to those from the 18 Korean traditional soy sauces (27.5 ± 3.6 %) (Kim et al. 1996). The soy sauce in the southwest ceramic contained significantly lower salt content (29.27 %) and larger salt crystals (>3 cm of diameter) than the others (30 % and less than 1.0 cm, P < 0.05). The salt content was strongly related to water loss (R = −0.97, P = 0.01) and the circumference of the ceramics (R = −0.77, P = 0.13) more than to porosity (R = 0.16, P = 0.80) and pore size (R = 0.04, P = 0.95). The salt content of soy sauce containing less than 20 % salt was directly proportional to the water loss due to the pores of the ceramics (Lee et al. 2006). Therefore, water loss was directly related to the salt content of soy sauce, whereas, there was no significant relation with pore size.

The total acidity of the soy sauce increased from 3.7 to 4.8–5.5 % over 120 days of fermentation (Table 3). Similar trends were also reported for Korean traditional soy sauce and mixed soy sauce containing fish and meat (Jeon et al. 2002; Lee et al. 2006; Kim and Lee 2008). The increase in total acidity was caused by increased organic acids such as lactic acid, fumaric acid, and succinic acid, which are fermentative products by microorganisms that consume sugars in meju. These organic acids contribute to the sour taste and flavor of soy sauce (Jeon et al. 2002; Choi et al. 2013). The highest total acidity at the end of fermentation was 5.5 % in soy sauce fermented in the southwest regional ceramic and the lowest was 4.8 % in the ceramic from Seoul capital region. The fermentation of soy sauce in ceramics produced higher total acidity than fermentation in glass jars (Jeon et al. 2002), but within the range (3.6–18.3 %) of Korean traditional soy sauce study (Kim et al. 1996). The production of organic acids in soy sauce would be related to the lower gas permeation (Lee et al. 2006).

The reducing sugar contents in soy sauce increased slightly over 120 days of fermentation (Table 3). An increase in reducing sugars is attributed to the catalytic action of amylase produced from Bacillus sp. in the soy sauce (Yong and Wood 1977). Soy sauce fermented in southwest regional ceramic contained the highest amounts of reducing sugars (1.56 %), followed by those in southeast region (1.34 %), central region (1.27 %), Jeju Island (1.24 %), and Seoul capital region (1.20 %) ceramics at the end of fermentation. Increasing fermentation time beyond 120 days decreased the reducing sugar contents in soy sauce (Joo et al. 1997; Kim and Lee 2008). This was attributed to consumption by fermentative microorganisms and the inactivation of amylase due to the brine solution.

### Protease activity and total nitrogen contents

Protease activity often provides indirect information on the quality of Korean soy sauce due to its close relationship with the production of a unique and desirable flavor in soy sauce (Yong and Wood 1977). Protease activity increased with time after 20 days of fermentation (Table 4) and was
correlated to the trends of bacterial growth in the soy sauce. This pattern was similar to the reports by Chung et al. (2006). The initial retardation might be explained by a long lag phase of Bacillus sp., major microorganisms of meju, due to the high brine solution. The highest protease activity after 120 days of fermentation was found in soy sauce fermented in the southwest regional ceramic (0.648 unit/mL). Since protease activity is related to the flavor of soy sauce, soy sauce in the southwest regional ceramic might have different flavors in comparison with the others.

The total nitrogen content of the soy sauce was consistent at 0.27–0.70 % during the fermentation period (Table 5). The regional ceramics did not affect the total nitrogen content when comparing day 1 and day 120 ($P > 0.05$). Jeju Island ceramic, however, showed the decreased amount of nitrogen content. It would be due to missing of glazed treatment for the ceramic (Chung et al. 2006; Lee et al. 2006). The total nitrogen contents after 120 days of fermentation showed strong negative relation with the pore size ($R = -0.89$). Therefore, permeability of

| Table 3 | Water loss, salt content, total acidity, and reducing sugar of soy sauces fermented in five different regional ceramics during 120-day fermentation |
|---------|----------------------------------------------------------------------------------------------------------------------------------|
| Day     | Seoul capital region | Central region | Southwest region | Southeast region | Jeju Island |
|---------|----------------------|----------------|------------------|------------------|-------------|
| Water loss (%) | 0.00 ± 0.00$^{Ac}$ | 0.00 ± 0.00$^{Ac}$ | 0.00 ± 0.00$^{Ac}$ | 0.00 ± 0.00$^{Ac}$ | 0.00 ± 0.00$^{Ac}$ |
| Salt content (%) | 38 Appl Biol Chem (2016) 59(1):33–41 |
| Total acidity (%) | 3.72 ± 0.05$^{Cd}$ | 3.69 ± 0.06$^{Rd}$ | 3.92 ± 1.23$^{Ad}$ | 3.59 ± 0.10$^{Rd}$ | 3.81 ± 0.05$^{Rd}$ |
| Reducing sugar (%) | 1.08 ± 0.08$^{Cd}$ | 1.10 ± 0.06$^{BCd}$ | 1.10 ± 0.05$^{Ad}$ | 1.06 ± 0.04$^{Rd}$ | 1.10 ± 0.06$^{BCd}$ |

Values with different capital letters among soy sauce fermented in difference ceramics indicate significant difference by Tukey’s test ($P < 0.05$)

Values with different lower cases among the fermentation periods indicate significant differences by Tukey’s test ($P < 0.05$)

Total acidity was converted to 0.05 % acetic acid solution
Values with different capital letters among soy sauce fermented in difference ceramics indicate significant differences by Tukey’s test ($P < 0.05$).
Values with different lower cases among the fermentation periods indicate significant differences by Tukey’s test ($P < 0.05$).

**Table 4** Changes in protease activity for soy sauce fermented in different regional ceramics for 210 days

| Day | Seoul capital region | Central region | Southwest region | Southeast region | Jeju Island |
|-----|---------------------|----------------|------------------|------------------|-------------|
| 0   | 0.151 ± 0.014$^{Ad}$ | 0.152 ± 0.010$^{Ad}$ | 0.174 ± 0.020$^{Ad}$ | 0.151 ± 0.010$^{Ad}$ | 0.148 ± 0.011$^{Ad}$ |
| 20  | 0.169 ± 0.011$^{Ad}$ | 0.157 ± 0.014$^{Ad}$ | 0.127 ± 0.034$^{Ad}$ | 0.166 ± 0.007$^{Ad}$ | 0.161 ± 0.007$^{Ad}$ |
| 40  | 0.207 ± 0.007$^{Ad}$ | 0.210 ± 0.015$^{Ad}$ | 0.194 ± 0.008$^{Ad}$ | 0.211 ± 0.014$^{Ad}$ | 0.212 ± 0.019$^{Ad}$ |
| 60  | 0.406 ± 0.031$^{Abc}$ | 0.410 ± 0.034$^{Abc}$ | 0.482 ± 0.031$^{Abc}$ | 0.425 ± 0.021$^{Abc}$ | 0.429 ± 0.037$^{Abc}$ |
| 80  | 0.377 ± 0.046$^{Ac}$ | 0.432 ± 0.059$^{Ac}$ | 0.429 ± 0.043$^{Ac}$ | 0.386 ± 0.036$^{Ac}$ | 0.379 ± 0.045$^{Ac}$ |
| 100 | 0.469 ± 0.009$^{Bab}$ | 0.494 ± 0.026$^{Bab}$ | 0.611 ± 0.010$^{Ab}$ | 0.469 ± 0.028$^{Bab}$ | 0.491 ± 0.049$^{Bab}$ |
| 120 | 0.493 ± 0.017$^{Ba}$ | 0.549 ± 0.044$^{Ba}$ | 0.648 ± 0.025$^{Aa}$ | 0.538 ± 0.022$^{Ba}$ | 0.545 ± 0.058$^{Ba}$ |

Values with different capital letters among soy sauce fermented in difference ceramics indicate significant differences by Tukey’s test ($P < 0.05$).
Values with different lower cases among the fermentation periods indicate significant differences by Tukey’s test ($P < 0.05$).

**Table 5** Total nitrogen contents (%) of soy sauce fermented in five regional ceramics during 120 days

| Day | Seoul capital region | Central region | Southwest region | Southeast region | Jeju Island |
|-----|---------------------|----------------|------------------|------------------|-------------|
| 0   | 0.266 ± 0.005$^{Aab}$ | 0.266 ± 0.005$^{Aab}$ | 0.266 ± 0.005$^{Aab}$ | 0.266 ± 0.005$^{Aa}$ | 0.266 ± 0.005$^{Aa}$ |
| 20  | 0.273 ± 0.049$^{Aab}$ | 0.399 ± 0.069$^{Aab}$ | 0.399 ± 0.129$^{Aab}$ | 0.455 ± 0.307$^{Aa}$ | 0.490 ± 0.366$^{Aa}$ |
| 40  | 0.546 ± 0.010$^{Aab}$ | 0.599 ± 0.054$^{Aab}$ | 0.595 ± 0.059$^{Aab}$ | 0.602 ± 0.089$^{Aa}$ | 0.704 ± 0.052$^{Aa}$ |
| 60  | 0.184 ± 0.211$^{Ab}$ | 0.294 ± 0.01$^{Ab}$ | 0.352 ± 0.002$^{Ab}$ | 0.259 ± 0.005$^{Aa}$ | 0.271 ± 0.007$^{Aa}$ |
| 80  | 0.320 ± 0.012$^{Ab}$ | 0.403 ± 0.099$^{Ab}$ | 0.345 ± 0.002$^{Ab}$ | 0.263 ± 0.059$^{Aa}$ | 0.289 ± 0.017$^{Aa}$ |
| 100 | 0.303 ± 0.002$^{Ab}$ | 0.322 ± 0.005$^{Ab}$ | 0.242 ± 0.03$^{Ab}$ | 0.256 ± 0.119$^{Aa}$ | 0.301 ± 0.025$^{Aa}$ |
| 120 | 0.324 ± 0.067$^{Ab}$ | 0.334 ± 0.007$^{Ab}$ | 0.278 ± 0.007$^{Ab}$ | 0.333 ± 0.000$^{Aa}$ | 0.208 ± 0.012$^{Aa}$ |

Values with different capital letters among soy sauce fermented in difference ceramics indicate significant differences by Tukey’s test ($P < 0.05$).
Values with different lower cases among the fermentation periods indicate significant differences by Tukey’s test ($P < 0.05$).

Air through the pores seemed to negatively influence the total nitrogen content, which was one of the parameters for soy sauce quality.

**Changes in microbial growth during fermentation**

The changes in total aerobic bacteria and *Bacillus* sp. during soy sauce fermentation are presented in Fig. 3. Total aerobic bacteria increased slowly during the entire fermentation period (Fig. 3A). The total aerobic bacteria counts were increased from 5.83 log CFU/mL at day 0 to 6.25–6.72 log CFU/mL at day 120. According to the results of Lee et al. (2006), the number of aerobic bacteria was increased by higher ceramic porosity. After fermentation of 120 days, the total aerobic bacteria counts were similar by showing the range within 0.5 log CFU/mL among samples and did not show any significant relationship with porosity ($r = 0.048$).

The number of *Bacillus* sp. remained unchanged till 60 days of fermentation, and then a rapid increase was observed between 60 and 80 days of fermentation (Fig. 3B). The long lag phase of *Bacillus* sp. counts might be due to high salt content. The impediment to bacterial growth in soy sauce might also result from high salt content and anaerobic conditions (Lee et al. 2006). The decrease in *Bacillus* sp. counts after 100 days of fermentation might be due to the low temperature because most *B. subtilis* and *B. amyloliquefaciens* are mesophiles. During the end stage of fermentation, the average temperature was 5.1 °C. Bacterial counts did not differ across the regional ceramics.

**Descriptive analysis of soy sauce after 120-day fermentation**

The intensities of all seven sensory attributes were similar among the soy sauces after 120 days of fermentation except soy sauce in the ceramic from Seoul capital region (Table 6). Soy sauce fermented in the ceramic from Seoul capital region had weaker salty and biting tastes compared to the others. Slightly lower biting and viscosity characteristics would be related with the lower saltiness (Christensen 1980; Koliandris et al. 2010). Soy sauce fermented in the southwest regional ceramic contained significantly...
lower salt intensity than the others. Although the saltiness in soy sauce is mainly due to salt, its intensity is affected by the synergistic interaction of salt with other flavoring compounds (Jeong et al. 2004). Soy sauce fermented in the southwest regional ceramic had significantly higher reducing sugar content, protease activity, pH values, and organic acid content, which might contribute synergistic effect for flavors of soy sauce. These results suggest that controlling the fermentation container may help produce a low sodium soy sauce with a similar intensity of salty taste.

Correlation of regional ceramics, physicochemical results, and sensory attributes

In order to present overall relation of physicochemical characteristics of 120-day fermented soy sauces, PCA was performed (Fig. 4). The PCA biplot explained 87.45% of total variations (F1 73.05 %, F2 14.40 %). Ceramics were divided into three groups. Ceramics from Jeju Island, southeast, and central regional ceramics were located on the right-top quadrant. Southwest regional ceramic was on the left side of the biplot. On the right-bottom quadrant, Seoul capital regional ceramics was loaded. Different regional ceramics influenced physicochemical characteristics of soy sauce. Jeju Island, southeast, and central regional ceramics were related with crude ash content, water content, and salt content. Southwest regional ceramic

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Table 6 Mean attribute intensities of soy sauces fermented in different regional ceramics after 120 days

| Region        | Taste         | Flavor          | Mouthfeel        |
|---------------|---------------|-----------------|------------------|
|               |   | MSG | Roasted soybean | Metallic | Biting | Viscosity |
| Seoul capital | 4.5 ± 1.0a  | 13.6 ± 1.6b | 6.2 ± 1.9a      | 4.4 ± 1.7a | 4.2 ± 1.8a | 2.7 ± 1.1b | 3.5 ± 1.2a |
| Central       | 4.5 ± 1.2a  | 15.8 ± 1.9a | 7.1 ± 1.7a      | 4.0 ± 2.0a | 4.1 ± 1.9a | 3.6 ± 1.3a | 4.2 ± 1.4a |
| Southwest     | 4.8 ± 1.2a  | 15.1 ± 1.5a | 6.9 ± 2.1a      | 4.4 ± 1.9a | 4.2 ± 2.0a | 3.6 ± 1.2a | 4.0 ± 1.5a |
| Southeast     | 4.4 ± 1.4a  | 15.0 ± 1.7a | 6.5 ± 1.6a      | 4.3 ± 1.8a | 3.8 ± 2.1a | 3.1 ± 0.9ab | 4.1 ± 1.7a |
| Jeju Island   | 4.4 ± 1.1a  | 15.4 ± 1.7a | 6.4 ± 1.8a      | 4.0 ± 1.7a | 4.0 ± 1.8a | 3.5 ± 1.4a | 4.4 ± 1.6a |

Values with different lower cases among soy sauce fermented in different ceramics indicate significant differences by Tukey’s test (P < 0.05)
was related with total acidity, protease activity, water loss, reducing sugar, soluble content, and pH. Total nitrogen content was positively related with the ceramic from Seoul capital region. Different soil and making process for ceramics seemed to influence the difference of physico-chemical characteristics of soy sauce after fermentation. Ceramics from different regions of Korea generated differences in physicochemical, microbiological, and sensory characteristics of soy sauce. While additional studies will be needed to fully analyze the relationship between the fermentative characteristics of soy sauce and various factors of ceramics, the insight gained from the current study will improve our understanding of the function of regional ceramics as a container for Korean traditional soy sauce fermentation under natural conditions. Based on the PLSR result, soy sauces were divided into three groups. Ceramic from the southwest region was positively related with many positive parameters such as reducing sugar, protease activity, sweet, and umami attributes, and negatively correlated with salt content. Further research will be conducted with the manipulation of the ceramics from the southwest region in order to find out key factors for the ceramics during soy sauce fermentation.

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