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*Research Article*

# Effects of chestnut powder content on the quality characteristics and antioxidant activity of rice muffins

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**Abstract** This study examined the effects of chestnut powder content (2.5%, 5%, 7.5%, and 10%) on the antioxidant activity and quality characteristics of rice muffins. With the increasing chestnut powder content, the total polyphenol content, flavonoid content, antioxidant activity (determined by radical scavenging activity and reducing power), hardness, gumminess, chewiness, and overall acceptability (determined by sensory evaluation) increased, whereas the moisture content, pH, specific volume, and cooking loss decreased. Regarding color, chestnut powder content was negatively correlated with L and b and positively correlated with a. Notably, overall acceptability abruptly decreased to its minimum at 10%. Thus, adding powder at loadings of <7.5% improved the antioxidant activity and acceptability of rice muffins. Our results can be used as preparatory data for developing a rice muffin model.

**Keywords** chestnut powder, rice powder, muffin, sensory evaluation, antioxidant activity

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## 1. Introduction

Chestnuts are the fruits of *Castanea crenata*, a tree of the Fagaceae family showing strong adaptability to the environment of Korea (Ahn, 2017). Compared with other fruits, chestnuts have high starch and low moisture contents and therefore find numerous applications in medicine, gastronomy, and food production (Joo, 2013). Moreover, chestnuts feature approximately four-fold higher contents of vitamin $B_1$, $\beta$-carotene, and carbohydrates than rice and are rich in essential amino acids, e.g., valine, leucine, isoleucine, and phenylalanine. Given that the dietary fiber content of chestnuts (2.0-4.7%) is similar to that of brown rice, the former are a reliable source of dietary fiber (Ahn, 2017; Seo et al., 2009). Chestnut pericarp and pulp contain antioxidants, e.g., gallic acid, coumarin, and catechin; moreover, chestnut-derived products have been reported to prevent the proliferation and promote the apoptosis of gastric cancer cells and exhibit antithrombosis activity (Jhee, 2016). However, chestnut consumption is declining because of the lack of manpower, reduced cultivation, and difficulty in creating new demand for peeled or whole chestnut products. Hence, advanced processed-food industrialization is necessary to reinvigorate the chestnut industry in Korea (Lee et al., 2016). Previous studies have investigated the process suitability and quality characteristics of chestnuts to enable their consumption in the form of chestnut-powder-containing processed foods, such as beef patties (Jo et al., 2021), chestnut paste jellies (Jhee, 2016), and chestnut cookies (Joo, 2013). However, the effect of chestnut powder incorporation on food bioactivity remains underexplored.

Rice is the main raw material for the production of gluten-free confectionaries, as it contains

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smaller starch particles than other cereal grains and lacks gluten (Ju et al., 2006). Moreover, rice contains 6-8% protein, ~3% fiber, and ~3% lipids and is rich in minerals (Ca, P, K, Mg, Na, and Fe) and vitamin B complexes, including vitamins $B_1$ and $B_2$ (Shin et al., 2022). Despite these advantages, rice consumption in Korea is decreasing because of the shift to a westernized diet and the resulting development of instant and ready-to-eat foods, including bread and meat products (Kim et al., 2022). According to the Korean Statistical Information Service (KOSIS), annual rice consumption has decreased from 65.1 kg per person in 2014 to 56.4 kg per person in 2023 (KOSIS, 2024) and is expected to decrease further, which, together with steady rice production, may result in rice oversupply (Kim et al., 2022). Thus, rice consumption has to be increased through the development and popularization of rice-based processed foods (Park et al., 2019).

Among the recently developed rice-based processed foods, such as rice muffins, rice cookies, rice pound cakes, and rice scones (Choi et al., 2023; Kim et al., 2020; Nam et al., 2023; Park, 2021), rice muffins offer the benefits of production simplicity and are used as a meal replacement. In contrast to wheat flour, rice flour has a low gluten content and can therefore be easily mixed with other materials to prepare a wide range of products (Bae and Jung, 2013), as exemplified by quick-bread rice muffins produced from different rice cultivars (Kim et al., 2012), English muffins with differently milled rice (Choi et al., 2015), and muffins produced using different types of rice powder (Chu et al., 2023). However, only few studies have explored the quality characteristics and antioxidant effects of rice muffins produced using bioactive additives.

To bridge the abovementioned gap, we herein analyzed the quality characteristics and antioxidant activities of rice muffins with varying contents of chestnut powder and performed a consumer sensory evaluation to provide basic data for the development of nutritional processed foods based on rice and chestnuts.

## 2. Materials and methods

### 2.1. Materials

Chestnut powder was purchased from Gongju Chestnut Food-Related Agricultural Association Corporation (Gongju, Korea), and soft rice powder was purchased from Haessalmaroo (Daedoo, Gunsan, Korea). Eggs (Seyang Co., Anseong, Korea), butter (Lotte Food Co., Cheonan, Korea), sugar (CJ CheilJedang, Incheon, Korea), and milk (Seoul Milk, Seoul, Korea) were purchased from Nonghyup Hanaro Mart. The Folin-Ciocalteau reagent, tannic acid, diethylene glycol, quercetin, 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical, potassium ferricyanide, 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS), and ferric chloride were obtained from Sigma-Aldrich Chemical Co., while potassium persulfate, sodium hydroxide, and sodium carbonate were obtained from Daejung Chemicals. All other reagents were of Grade I.

### 2.2. Muffin preparation

The mixing ratios and chestnut powder loadings used to prepare rice muffins were determined in a pilot study using the method of Kwon et al. (2011) (Table 1). The butter was double-boiled at 65℃, and egg white was placed in the mixing bowl of the dough maker (GF-0519H, M.Y.K Electrical Co., Dongguan, China) for 1.5 min of kneading at level 3. Next, sugar was added in five separate portions, followed by 3 min mixing to create the meringue. The meringue was supplemented with egg yolk, and the molten mixture (30 g) was added to butter. The resulting dough was mixed with sieved chestnut powder, rice flour and baking powder and supplemented with milk. The dough was partitioned into 70 g specimens, which were placed on a muffin tray and baked in an oven (FDO-7103, Daeyung Bakery Machinery Co., Ltd., Seoul, Korea) preheated to top and bottom temperatures of 180 and 170℃, respectively, for 25 min. The thus produced muffins were cooled at room temperature for 60 min.

### 2.3. Determination of total polyphenol/flavonoid content and antioxidant activity

#### 2.3.1. Sample preparation

A 10 g muffin sample was treated with 70% ethanol (90 mL) and stirred at 160 rpm in a shaking incubator (SI-900R, Jeio Tech, Kimpo, Korea) at room temperature for 24 h. The dispersion was filtered, and the filtrate (muffin extract) was used for subsequent analyses.

#### 2.3.2. Total polyphenol content

Total polyphenol content was measured using the method of Swain and Hillis (1959). The muffin extract (150 μL) was

Table 1. Formula of rice muffins prepared with chestnut powder

| Ingredients (g) | CON | 2.5% | 5% | 7.5% | 10% |
|---|---|---|---|---|---|
| Rice flour | 300 | 275 | 250 | 225 | 200 |
| Chestnut powder | 0 | 25 | 50 | 75 | 100 |
| Butter | 200 | 200 | 200 | 200 | 200 |
| Sugar | 200 | 200 | 200 | 200 | 200 |
| Egg | 200 | 200 | 200 | 200 | 200 |
| Milk | 90 | 90 | 90 | 90 | 90 |
| Baking powder | 6 | 6 | 6 | 6 | 6 |
| Salt | 4 | 4 | 4 | 4 | 4 |
| Total | 1,000 | 1,000 | 1,000 | 1,000 | 1,000 |

mixed with distilled water (2 mL) and Folin–Ciocalteau reagent (2 N, 150 μL), and left in the dark for 3 min, supplemented with sodium carbonate (1 N, 300 μL), and left in the dark for 60 min. Subsequently, absorbance at 725 nm was measured using a spectrophotometer (DU-800, Beckman Coulter Inc., Seoul, Korea). Total polyphenol content was quantified in terms of tannic acid equivalents (mg TAE/100 g), based on a calibration curve derived from tannic acid.

### 2.3.3. Total flavonoid content

Total flavonoid content was determined using a modification of the method of Um and Kim (2007). The muffin extract (100 μL) was mixed with 90% diethylene glycol (1 mL) and sodium hydroxide (1 N, 100 μL), and the mixture was left in a 37℃ water bath for 60 min. Subsequently, absorbance at 420 nm was measured using the abovementioned spectrophotometer. Total flavonoid was calculated in quercetin equivalents (mg QE/100 g), using a calibration curve based on quercetin.

### 2.3.4. DPPH radical scavenging activity

DPPH radical scavenging activity was measured using a modification of the method of Lee et al. (2007). The muffin extract (4 mL) was treated with DPPH (0.15 mM, 4 mL), and the mixture was shaken and left in the dark for 30 min. Subsequently, absorbance at 517 nm was measured using the abovementioned spectrophotometer. Ethanol was used as the control in lieu of a more appropriate reference, and DPPH radical scavenging activity was calculated as

$$\text{DPPH radical scavenging activity (\%)} = 100 \times [1 - (\text{Sample absorbance} / \text{Control absorbance})].$$

### 2.3.5. ABTS$^+$ radical scavenging activity

ABTS$^+$ radical scavenging activity was measured using the method of Siddhuraju and Becker (2007). A mixture of potassium persulfate (2.45 mM) and ABTS$^+$ (7.0 mM) solutions was left in the dark for 16 h, diluted with ethanol, and calibrated to an absorbance of 0.70±0.02 at 734 nm. The final ABTS$^+$ solution (900 μL) was mixed with the muffin extract (100 μL), and absorbance at 734 nm was measured using the abovementioned spectrophotometer. Ethanol was used as the control in lieu of a more appropriate reference, and ABTS$^+$ radical scavenging activity was calculated as

$$\text{ABTS}^+ \text{ radical scavenging activity (\%)} = 100 \times [1 - (\text{Sample absorbance} / \text{Control absorbance})].$$

### 2.3.6. Reducing power

Reducing power was measured using the method of Oyaizu (1986). A mixture of the muffin extract (2.5 mL), 1% potassium ferricyanide (2.5 mL), and sodium phosphate buffer (pH 6.6; 0.2 M, 2.5 mL) was kept in a 50℃ water bath and then centrifuged (Combi-514R, Hanil, Daejeon, Korea) at 1,935 ×*g* for 10 min. The supernatant (500 μL) was mixed with distilled water (500 μL) and 0.1% ferric chloride (500 μL). Absorbance at 700 nm was measured using the abovementioned spectrophotometer.

## *2.4. Determination of quality characteristics*

### 2.4.1. Water content

Water content was measured using a water analyzer (MJ33, Mettler Toledo, Zurich, Switzerland) for samples (0.5 g) collected from the muffin center.

### 2.4.2. pH and color

For pH measurement, a muffin sample (5 g) was mixed with distilled water (45 mL). The mixture was homogenized using a Stomacher device (HG400V, Mayo International SR., Milano, Italy) and filtered. The filtrate pH was measured using a pH meter (FEP-20, Mettler Toledo). The experiment was repeated seven times, and the result was expressed as the corresponding mean±standard deviation. A colorimeter (CR-400, Konica Minolta Co., Osaka, Japan) was used to determine the L (lightness), a (+red/-green, redness), and b (+yellow/-blue, yellowness) values. The standard white plate was set at L=94.65, a=0.43, b=4.12.

### 2.4.3. Specific volume and cooking loss

The weight of freshly baked muffins was measured after 60 min cooling. Volume measurements were performed using the seed displacement method. The measured weight and volume were used to calculate the specific volume, while cooking loss was calculated from the weights of the baked muffins and original dough.

Specific volume (mL/g)
= Muffin volume (mL) / Muffin weight (g)

Cooking loss (%)
= 100 × [(Muffin weight before baking - Muffin weight after baking) / Muffin weight before baking].

### 2.4.4. Textural properties

Textural properties (hardness, gumminess, chewiness, adhesiveness, springiness, and cohesiveness) were measured for 2 cm×2 cm×2 cm samples using a texture analyzer (TA-XT2, Stable Micro System, Ltd., Haslemere, UK) through a two-bite test. The conditions were as follows: plunger diameter=75 mm, strain=70%, pretest speed=2.0 mm/s, test speed=1.0 mm/s, trigger force=5.0 g, posttest speed=1.0 mm/s.

### 2.4.5. Sensory evaluation

Sensory evaluation was performed by 25 panelists that were recruited from the general public and informed of the tested items and study objective. The freshly baked muffins were cooled at room temperature for 30 min, cut to dimensions of 2 cm×2 cm×2 cm, and placed on white polyethylene plates, each of which was assigned a three-digit random number. Preference was evaluated based on appearance, flavor, taste, texture, and overall acceptability using a seven-point scale, with higher scores indicating higher preference levels. Additionally, the strength of individual characteristics was evaluated on the same scale to test the chestnut flavor and muffin moistness, bitterness, and astringency. The test was performed with the approval of the Institutional Review Board (IRB) of Kongju National University (Approval No. KNU_IRB_2023-112).

## *2.5. Statistical analysis*

Data were expressed as means±standard deviations calculated using the SPSS 25.0 software (SPSS Inc., Chicago, IL, USA). One-way analysis of variance was used to determine the significance and Duncan's multiple test post-hoc for group differences was set at $p<0.05$. Pearson correlation analysis was used to probe the correlations of antioxidant activities.

# 3. Results and discussion

## *3.1. Antioxidant activity*

### 3.1.1. Total polyphenol and flavonoid contents

Fig. 1 shows the total polyphenol and flavonoid contents of rice muffins. The total polyphenol and flavonoid contents of chestnut powder were 9.20 mg TAE/100 g and 4.85 mg QE/100 g, respectively. The control and 2.5%, 5%, 7.5%, and 10% groups had total polyphenol contents of 45.08, 67.56, 89.92, 107.65, and 122.50 mg TAE/100 g, respectively, and total flavonoid contents of 3.29, 10.43, 17.10, 25.17, and 34.94 mg QE/100 g, respectively. Thus, total polyphenol and flavonoid contents increased with the increasing chestnut powder content ($p<0.001$). Similarly, the total polyphenol content was reported to increase with the increasing chestnut powder content of chestnut cookies (Joo, 2013) and sweet bean jellies (Jhee, 2016). According to Lee et al. (2008), the chestnut pericarp and pulp extracts contain catechin and gallic acid, which explains the increase in the total polyphenol content with the increasing chestnut powder content. Lee (2001) showed that chestnuts have a flavonoid content of 0.89 mg/g, which explains the positive correlation between the chestnut powder loading and flavonoid content observed

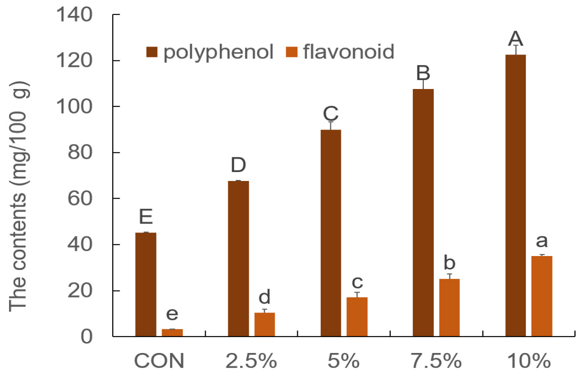

**Fig. 1. Total polyphenol and flavonoid contents of rice muffin with various levels of chestnut powder.** Values (mean±SD, n=3) with different letters ($^{a-e}$) ($^{A-E}$) on the bar of polyphenol (mg TAE/100 g) and flavonoid (mg QE/100 g) contents indicate significant differences by Duncan's multiple range test ($p<0.001$).

herein. Thus, functional muffins can be prepared by increasing the loading of the polyphenol- and flavonoid-rich chestnut powder.

### 3.1.2. DPPH/ABTS$^+$ radical scavenging activity and reducing power

The DPPH/ABTS$^+$ radical scavenging activities of the control, 2.5%, 5%, 7.5%, and 10% groups were 3.45%/2.66%, 31.79%/33.62%, 56.47%/50.35%, 77.26%/68.22%, and 84.48%/79.42%, respectively, increasing with the increasing loading of chestnut powder ($p<0.001$; Fig. 2). Similarly, Joo (2013) reported a positive correlation between the DPPH radical scavenging activity and chestnut powder content of chestnut cookies. Dinis et al. (2012) ascribed the DPPH and ABTS$^+$ radical scavenging activities of chestnuts to the presence of polyphenolics, which explains the ABTS$^+$ radical scavenging activity trend observed herein. Jang et al. (2012) observed a positive correlation between DPPH/ABTS$^+$ radical scavenging activities and polyphenol content, which implies a correlation between the two activities. The reducing power of the control, 2.5%, 5%, 7.5%, and 10% groups was 0.01, 0.75, 0.94, 1.15, and 1.33, respectively, i.e., increased with the increasing chestnut powder content ($p<0.001$; Fig. 3). According to Yoon (1991), chestnut pulp extract contains phenolics, including ferulic, salicylic, caffeic, sinapic, and *p*-coumaric acids, which explains the reducing power trend observed herein. Thus, the increase in the antioxidant activity with the increasing chestnut power content was ascribed to the high content of bioactive substances in the chestnut pulp.

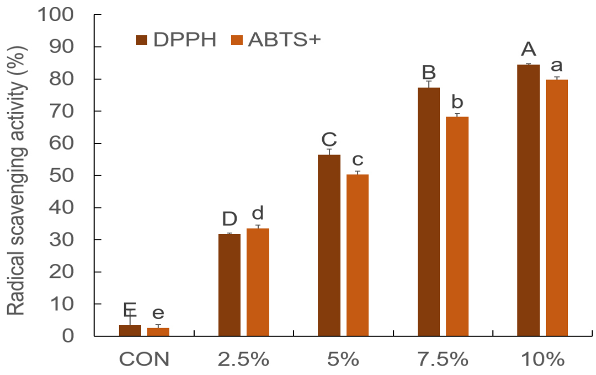

**Fig. 2. DPPH and ABTS$^+$ radical scavenging activities of rice muffins with various levels of chestnut powder.** Values (mean±SD, n=3) with different letters ($^{a-e}$) ($^{A-E}$) on the bar indicate the significant differences among DPPH or ABTS$^+$ radical scavenging activities by Duncan's multiple range test ($p<0.001$).

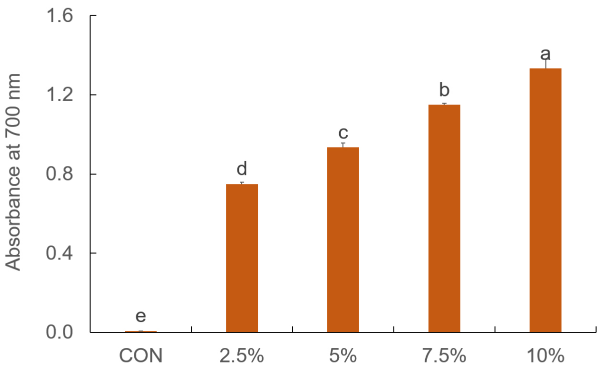

**Fig. 3. Reducing power of rice muffins with various levels of chestnut powder.** Values (mean±SD, n=3) with different letters ($^{a-e}$) within reducing power indicate significant differences by Duncan's multiple range test ($p<0.001$).

### 3.1.3. Correlations across antioxidant activities

The correlations among DPPH/ABTS$^+$ radical scavenging activities and reducing power as well as total polyphenol and flavonoid contents were probed using Pearson correlation analysis. The results of this analysis at a significance level of $p<0.01$ are presented in Table 2, revealing a positive correlation of the DPPH and ABTS$^+$ radical scavenging activities with the total polyphenol and flavonoid contents ($r=0.898-0.993$). Kim et al. (2019) reported a stronger correlation between DPPH/ABTS$^+$ radical scavenging activities and phenolic content. Polyphenols are well-known antioxidants, which explains the positive correlation between antioxidant activity and polyphenol content observed herein.

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Table 2. Correlation coefficient between the contents of antioxidant, antioxidant effects by DPPH-ABTS$^{+}$ radical scavenging activities and reducing power from rice muffins prepared with chestnut powder

| | Polyphenol | Flavonoid | DPPH | ABTS$^{+}$ | Reducing power |
|---|---|---|---|---|---|
| Polyphenol | 1 | | | | |
| Flavonoid | 0.940$^{**1)}$ | 1 | | | |
| DPPH | 0.971$^{**}$ | 0.946$^{**}$ | 1 | | |
| ABTS$^{+}$ | 0.987$^{**}$ | 0.949$^{**}$ | 0.993$^{**}$ | 1 | |
| Reducing power | 0.987$^{**}$ | 0.898$^{**}$ | 0.968$^{**}$ | 0.980$^{**}$ | 1 |

[1] Significant differences among groups by linear regression analysis and correlation coefficient at $^{**}p<0.01$.

## 3.2. Quality characteristics

### 3.2.1. Moisture content and pH

The moisture content of the control, 2.5%, 5%, 7.5%, and 10% groups was 26.33%, 26.33%, 25.16%, 24.55%, 22.86%, and 21.52%, respectively, decreasing with the increasing chestnut powder content ($p<0.001$; Table 3). This trend was ascribed to the fact that the moisture content of the chestnut powder (1.8%) was considerably lower than that of the rice powder (11.86%). The same trend was observed in a study on muffins with added nectarine (Kim and An, 2021) and jujube (Kim and Lee, 2012) powders. Go et al. (2023) reported that the addition of the supplementary material affects the moisture content and properties.

The pH of the control and chestnut powder (2.5-10%) groups was 7.25 and 6.80-7.19, respectively, decreasing with the increasing chestnut powder content ($p<0.001$; Table 3). This trend was ascribed to the fact that the chestnut powder had a lower pH (6.61) than the rice powder (6.85). Joo (2013) ascribed the low pH of the dough used to prepare chestnut-powder-containing cookies to the low pH of this powder. Similarly, the addition of dandelion powder (Kim, 2022) and brown rice powder (Jung and Cho, 2011) was reported to induce a pH decrease.

### 3.2.2. Specific volume and cooking loss

The specific volume of the control, 2.5%, 5%, 7.5%, and 10% groups was 2.38, 2.40, 2.20, 2.15, and 1.84 mL/g, respectively, i.e., decreased with the increasing chestnut powder content ($p<0.001$; Table 3). In the study of Kim and An (2021) on muffins with added nectarine powder, the specific volume was reported to decrease with the increasing nectarine powder content because of the resulting changes in protein content and starch gelatinization. In the study of Cho and Kim (2014) on muffins with added barley sprout, the muffin volume decreased with the increasing fiber content. Given that the fiber content of chestnut powder (2.0-4.7%) is similar to that of brown rice, we concluded that the specific volume of the muffins in this study decreased with the increasing chestnut powder content under the influence of dietary fiber. In previous studies on blueberry muffins (Hwang and Ko, 2010), muffins with added yacon powder (Lee and Lee, 2014), and muffins with coffee ground powder (Kim et al., 2016), the muffin specific volume was reported to decrease with the increasing additive loading, in agreement with the results obtained herein.

The cooking loss of the control and 2.5%-10% groups was 13.44% and 13.73%-11.28%, respectively, decreasing with the

Table 3. Moisture content, pH, specific volume and baking loss rate of rice muffins prepared with chestnut powder

| | CON | 2.5% | 5% | 7.5% | 10% | F-value |
|---|---|---|---|---|---|---|
| Moisture content (%) | 26.33±0.47$^{a1)2)}$ | 25.16±0.53$^{b}$ | 24.55±0.14$^{b}$ | 22.86±0.54$^{c}$ | 21.52±0.73$^{d}$ | 40.432$^{***}$ |
| pH | 7.25±0.05$^{a}$ | 7.19±0.02$^{a}$ | 7.04±0.03$^{b}$ | 6.89±0.04$^{c}$ | 6.80±0.03$^{d}$ | 104.019$^{***}$ |
| Specific volume (mL/g) | 2.38±0.02$^{a}$ | 2.40±0.03$^{a}$ | 2.20±0.09$^{b}$ | 2.15±0.09$^{b}$ | 1.84±0.10$^{c}$ | 28.098$^{***}$ |
| Baking loss rate (%) | 13.44±0.19$^{a}$ | 13.16±0.35$^{a}$ | 13.73±0.20$^{a}$ | 11.92±0.57$^{b}$ | 11.28±0.81$^{b}$ | 14.233$^{***}$ |

[1] All values are mean±SD (n=7).
[2] Different superscript letters ($^{a-d}$) within the same row indicate significant differences by Duncan's multiple range test ($p<0.05$) $^{***}p<0.001$.

increasing chestnut powder content ($p<0.001$; Table 3). In the study of Lee and Lee (2013) on sponge cakes with cinnamon powder, cooking loss was attributed to increased vapor pressure resulting from heat penetration into the dough during baking and gas release due to the expansion of the liquid at low boiling point. In another study on sponge cakes with yam powder (Lee et al., 2001), cooking loss decreased with the increasing yam powder loading, in agreement with the results obtained herein. This behavior was attributed to the higher water absorption capacity of yam powder compared with that of flour. The water absorption capacity of chestnut powder (2.97-3.01; Seo et al., 1999) was reported to exceed that of common rice powder (1.058-1.077; Lee, 2013). In agreement with the results obtained herein, a decrease in cooking loss with the increasing additive content was observed in studies on muffins with jujube powder (Kim and Lee, 2012), broccoli powder (Shin et al., 2008), and kamut powder (Yoon et al., 2021).

### 3.2.3. Color

Table 4 presents the L, a, and b values of the rice muffins. The L (lightness) value ranged from 55.16 to 80.34 and decreased with the increasing chestnut powder content ($p<0.001$). The a (+redness/-greenness) and b (+yellowness/-blueness) values ranged from -3.46 to 7.17 and 17.80 to 23.62, respectively, increasing and decreasing, respectively, with the increasing content of chestnut powder ($p<0.001$). Oh et al. (2011) reported that the color change induced by chestnut powder addition was largely influenced by the pigments contained therein, which darkened due to pH changes and heat during baking. Likewise, the color values (L, a, b) of chestnut and rice powders in this study were (72.89, 3.62, 21.60) and (95.03, -0.75, 3.82), respectively, indicating a decrease in L, increase in a, and decrease in b with the increasing chestnut powder content. Similar results were obtained in a study on sweet bean jellies containing chestnut powder (Jhee, 2016).

### 3.2.4. Textural properties

Table 5 presents the textural properties of the rice muffins. The hardness of the control and 2.5%-10% groups was 686.07 and 748.70-1,376.74 g, respectively, increasing with the increasing chestnut powder content ($p<0.001$). In a study on muffins containing jujube powder (Kim and Lee, 2012), hardness increased with the decreasing water content, which is precisely what was observed herein. A study on rice sponge cakes with green tea powder (Lee and Hwang, 2016) reported that the suppression of air bubble formation and expansion at high additive contents resulted in decreased volume and, hence, higher density. Herein, the increase in muffin hardness with the increasing chestnut powder content was ascribed to the concomitant decrease in volume and water content. In studies on muffins containing apple pomace powder (Kim et al., 2019), barley sprout powder (Cho and Kim, 2014), and coffee ground powder (Kim et al., 2016), the muffin hardness also increased with the increasing additive content. The gumminess (296.96-459.83 g) and chewiness (229.25-325.24 g) of our samples increased with the increasing chestnut powder content ($p<0001$). Go et al. (2023) observed an increase in gumminess and chewiness with increasing hardness. Kim (2022) reported that with the increasing additive content, the size of muffin pores decreased to increase the hardness and, hence, gumminess and chewiness, which agreed with the results of this study. The adhesiveness was -4.23 to -1.80 g s for the chestnut powder groups and -2.41 g s for the control group, decreasing with the increasing chestnut powder content ($p<0.001$). The springiness and cohesiveness were 0.71-0.83 and 0.33-0.47, respectively, decreasing with the increasing chestnut powder content ($p<0.001$). In a study on muffins containing brown rice powder (Jung and Cho,

**Table 4.** Color values of rice muffins prepared with chestnut powder

| | CON | 2.5% | 5% | 7.5% | 10% | F-value |
|---|---|---|---|---|---|---|
| L value[1)] | 80.34±0.74$^{a}$[2)3)] | 67.00±3.28$^{b}$ | 61.74±0.75$^{c}$ | 57.59±0.87$^{d}$ | 55.16±0.64$^{e}$ | 609.972$^{***}$ |
| a value | −3.46±0.07$^{e}$ | 3.17±1.55$^{d}$ | 5.45±0.16$^{c}$ | 6.61±0.12$^{b}$ | 7.17±0.17$^{a}$ | 586.001$^{***}$ |
| b value | 23.62±0.53$^{a}$ | 18.43±1.32$^{b}$ | 18.57±0.45$^{b}$ | 18.33±0.48$^{b}$ | 17.80±0.54$^{c}$ | 162.722$^{***}$ |

[1)] L, lightness; a, redness/greenness; b, yellowness/blueness.
[2)] All values are mean±SD (n=5).
[3)] Different superscript letters ($^{a-e}$) within the same row indicate significant differences by Duncan's multiple range test ($p<0.05$) $^{***}p<0.001$.

**Table 5.** Texture characteristics of rice muffins prepared with chestnut powder

| Item | CON$^{1)}$ | 2.5% | 5% | 7.5% | 10% | F-value |
|---|---|---|---|---|---|---|
| Hardness (g) | 686.07±78.98$^{d1)2)}$ | 748.70±86.41$^{d}$ | 1,023.35±183.62$^{c}$ | 1,136.91±121.00$^{b}$ | 1,376.74±283.15$^{a}$ | 53.025$^{***}$ |
| Gumminess (g) | 296.96±42.13$^{d}$ | 350.43±47.42$^{c}$ | 395.62±86.07$^{bc}$ | 409.78±66.82$^{b}$ | 459.83±127.79$^{a}$ | 12.651$^{***}$ |
| Chewiness (g) | 229.25±32.39$^{b}$ | 289.28±39.59$^{a}$ | 310.56±65.95$^{a}$ | 314.01±49.16$^{a}$ | 325.24±80.43$^{a}$ | 10.836$^{***}$ |
| Adhesiveness (g·sec) | −2.41±0.84$^{ab}$ | −1.80±0.76$^{a}$ | −2.72±0.82$^{b}$ | −3.59±1.21$^{c}$ | −4.23±1.93$^{c}$ | 14.785$^{***}$ |
| Springness | 0.77±0.02$^{c}$ | 0.83±0.02$^{a}$ | 0.79±0.02$^{b}$ | 0.76±0.02$^{c}$ | 0.71±0.03$^{d}$ | 79.115$^{***}$ |
| Cohesiveness | 0.43±0.02$^{b}$ | 0.47±0.04$^{a}$ | 0.39±0.03$^{c}$ | 0.36±0.03$^{d}$ | 0.33±0.03$^{e}$ | 63.837$^{***}$ |

[1] All values are mean±SD (n=20).

[2] Different superscript letters ($^{a-e}$) within the same row indicate significant differences by Duncan's multiple range test ($p<0.05$) $^{***}p<0.001$.

2011), springiness and cohesiveness decreased with the increasing additive content, in line with our results.

### *3.3. Sensory evaluation*

The results of sensory evaluation are presented in Table 6. Preference with respect to muffin color and appearance was the highest for the 5% group, decreasing at higher chestnut powder contents (p<0.01). Preference with respect to flavor increased with the increasing chestnut powder content, decreasing at contents of ≥7.5%, albeit insignificantly (p>0.05). Preference with respect to taste was highest for the control and 5% groups and lowest for the 10% group, although no significant difference was detected (p>0.05). Preference in terms of textural properties was the highest for the 5% and 7.5% groups, followed by the 2.5% and control groups, and was the lowest for the 10% group (p<0.05). Overall acceptability increased with the increasing chestnut powder content but was the lowest for the 10% group (p<0.01). Hong and Hwang (2011) reported that the sweetness of steamed rice cake significantly increased with the increasing chestnut powder content. Additionally, Joo (2013) reported that although preference increased with the increasing chestnut powder content because of the concomitant increase in sweetness, it decreased at excessively high additive contents. In this study, likewise, the overall acceptability was high at chestnut powder contents below 10%. The flavor score ranged from 1.42 to 6.13, increasing with the increasing chestnut powder content (p<0.001). The moistness score ranged from 2.83 to 5.63, decreasing with the increasing chestnut powder content, in line with the concomitant decrease in water content (p<0.001). The bitterness score ranged from 1.83 to 5.75, increasing with the increasing chestnut powder content, and was the highest for the 7.5% and 10% groups (p<0.001). In summary, chestnut powder contents of ≤7.5%

**Table 6.** Sensory evaluation of rice muffins prepared with chestnut powder

| | | CON | 2.5% | 5% | 7.5% | 10% | F-value |
|---|---|---|---|---|---|---|---|
| Acceptability | Appearance | 4.88±1.03$^{abc1)2)}$ | 4.71±1.20$^{bc}$ | 5.58±1.21$^{a}$ | 5.13±1.33$^{ab}$ | 4.13±1.92$^{c}$ | 3.676$^{**}$ |
| | Flavor | 4.67±1.050 | 4.88±1.19 | 5.13±1.26 | 5.00±1.41 | 4.29±1.73 | 1.406$^{NS}$ |
| | Taste | 4.88±1.30 | 4.63±1.53 | 4.88±1.39 | 4.79±1.38 | 3.92±1.69 | 1.830$^{NS}$ |
| | Texture | 4.75±1.39$^{ab}$ | 4.63±1.84$^{ab}$ | 5.38±0.88$^{a}$ | 4.92±1.50$^{a}$ | 3.96±1.76$^{b}$ | 2.780$^{*}$ |
| | Overall preference | 4.46±0.98$^{ab}$ | 4.79±1.47$^{a}$ | 5.33±1.05$^{a}$ | 5.13±1.62$^{a}$ | 3.83±1.86$^{b}$ | 4.070$^{**}$ |
| Intensity | Odor of chestnut | 1.42±0.88$^{c}$ | 3.17±1.34$^{b}$ | 4.71±1.37$^{a}$ | 5.38±1.13$^{a}$ | 6.13±1.26$^{a}$ | 57.989$^{***}$ |
| | Moistness | 5.63±1.58$^{a}$ | 5.29±1.00$^{a}$ | 4.54±1.10$^{b}$ | 4.08±1.10$^{b}$ | 2.83±1.46$^{c}$ | 17.992$^{***}$ |
| | Bitterness of chestnut | 1.83±1.34$^{c}$ | 2.58±1.41$^{bc}$ | 3.29±1.43$^{b}$ | 4.46±1.50$^{a}$ | 5.75±1.51$^{a}$ | 27.786$^{***}$ |

[1] All values are mean±SD (n=20).

[2] Different superscript letters ($^{a-c}$) within the same row indicate significant differences by Duncan's multiple range test ($p<0.05$) NS, non significant $^{*}p<0.05$ $^{**}p<0.01$ $^{***}p<0.001$.

Rating scale: 1 (week or bad) ↔ 7 (good or strong).

were determined to be suitable for the production of high-quality rice muffins with enhanced levels of functional compounds and preference values.

## 4. Conclusions

Rice muffins with chestnut powder contents of 2.5%, 5%, 7.5%, and 10% were prepared and evaluated in terms of antioxidant activities and quality characteristics to facilitate the development of rice-based processed foods. The total polyphenol and flavonoid contents, as well as DPPH and $ABTS^+$ radical scavenging activities, increased with the increasing content of chestnut powder, which implied a positive correlation across DPPH and $ABTS^+$ radical scavenging activities and reducing power. Thus, chestnut powder was concluded to be suitable for functional food production. Water content, pH, cooking loss, specific volume, color, and textural properties were assessed as quality characteristics. With the increasing chestnut powder content, water content, pH, specific volume, cooking loss, L and b values, adhesiveness, springiness, and cohesiveness decreased, whereas the a value, hardness, gumminess, and chewiness increased. For the tested items of preference, the appearance score was the highest for the 5% group; the flavor and taste scores did not vary significantly, and the food texture score was the highest for the 5% and 7.5% groups. The overall acceptability score increased with the increasing chestnut powder content but was the lowest for the 10% group. Flavor and bitterness increased with the increasing chestnut powder content. Thus, chestnut powder contents of ≤7.5% enhanced the preference score and functional compound content of rice muffins. The findings of this study are expected to help increase rice consumption and develop nutritional rice-based processed foods.

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### Conflict of interests

The authors declare no potential conflicts of interest.

### Author contributions

Conceptualization: Choi JH, Ahn HD. Methodology: Choi JH, Ahn HD, Hwang JM, Kim Y, Kim S, Choi HY. Formal analysis: Choi JH, Ahn HD, Hwang JM, Kim Y, Kim S. Validation: Kim I, Choi HY. Writing - original draft: Ahn HD. Writing - review & editing: Choi JH, Choi HY.

### Ethics approval

The sensory evaluation was carried out with the approval of IRB of Kongju National University (No. KNU_IRB_2023-112).

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