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*Research Article*

# Physiochemical quality characteristics of *sulgidduk* added with galangal (*Alpinia officinarum* Hance)

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**Abstract** This study was conducted to investigate the potential use of galangal, known for its various efficacy, as a functional food ingredient. The quality characteristics of *sulgidduk* added with galangal powder (GP) were analyzed to determine the optimal GP loading. The moisture content of rice flour is higher than that of GP. In *sulgidduk* with GP, the lightness (L*) significantly decreased and the redness (a*) and yellowness (b*) significantly increased with increasing amounts of added galangal, which may be due to the color of GP. Texture analysis revealed no significant differences in hardness or springiness between groups. Cohesiveness, gumminess, and chewiness were significantly lower in the GP group than in the control group. Quantitative descriptive analysis showed that the brown color, tenderness, moisture, specific odor, and bitter taste significantly increased, and the sweet taste significantly decreased with increasing amounts of GP. The consumer acceptance results showed a negative effect with increasing amounts of added GP. Appearance, flavor, texture, taste, and overall acceptability were all highest in the control group and decreased with increasing amounts of added GP. The total flavonoid content and 2,2-diphenyl-2-picrylhydrazyl (DPPH) radical-scavenging activity increased significantly with the addition of GP. It was found that up to 2% galangal addition had little effect on preference, suggesting that this amount of added GP is optimal. Based on the results of this study, it is recommended that galangal powder should be used at a concentration of 2% or less, as it has high antioxidant activity but reduces sensory properties when used in high concentrations.

**Keywords** galangal, alpina galangal, *sulgidduk*, quality characteristics



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## 1. Introduction

Galangal (*Alpinia officinarum* Hance), known as gao linang jiang or heba in China and chitrarathai in India, belongs to the Zingiberaceae (ginger) family. It has been used as a spice and folk medicine in China, Southeast Asia, and Africa and has recently been successfully cultivated in Korea (Lim and Bae, 2023). Galangal is widely used in Southeast Asian cuisine, especially in Thailand, where its unique aroma and flavor impart a distinctive taste to a variety of foods. In Thailand and Indonesia, it is used in traditional soups, such as tom-yam goong and tom-ka goong. Galangal is also used as a natural spice to replace synthetic additives and enhance functional properties (Caleja et al., 2018). Galangal has antioxidant and antimicrobial properties that have been reported to retard lipid oxidation. The addition of galangal extract to ground beef as an antioxidant shortens the induction period and inhibits oxidation (Cheah and Hasim, 2000). Therefore, galangal has great potential as a nontoxic food additive.

In the past, galangal was mainly found in Southeast Asia, but it has recently been imported to Korea in a dry form; although it is a member of the ginger family, it has a relatively mild taste that is not objectionable when added to common foods. According to the Korean Ministry of Food and Drug Safety, galangal is a common food ingredient in Korean herbal medicines and can be safely used as a food ingredient.

In addition to its use as a common food additive, galangal also has medicinal properties. Galangal has been reported to inhibit pain, inflammation, and microbial infections, and to have anti-inflammatory, anti-diarrheal, anti-obesity, and skin-whitening effects (Ding et al., 2019; Rajendiran et al., 2018). Galanin has been reported as an active constituent in galangal. Galangal has been reported to exhibit anticancer properties (Liu et al., 2014) and antibacterial activities against Helicobacter pylori (Zhang et al., 2010). The extract of galangal has been reported to effectively reduced Low density lipoprotein (LDL) cholesterol levels (Achuthan and Padikkala, 1997). It is considered to have anti-obesity potential as it can effectively reduce body weight (Xia et al., 2010). The pharmacological properties of Galangal are strongly correlated with its phytochemical constituents. The phytochemicals identified in galangal can be categorized into terpenes and phenolic compounds (Croteau et al., 2015; Yahia, 2017). The phenolic compounds mainly found in galangal include p-hydroxybenzoic acid, vanillic acid, ferulic acid, kaempferol-3-O-methylether, kaempferol, apigenin, luteolin, chrysin, 1'-acetoxyeugenol acetate, among others (Huang et al., 2018). Terpene compounds found in galangal include galangalditerpene A, galangalditerpene B, α-terpineol, 1,8-cineole, and α-pinene (Khumpir et al., 2018). In addition to its use as a food additive, anti-UV properties and reduced skin irritation have been reported for galangal extracts to protect the skin, with an efficacy of approximately SPF 15 (Rizkita and Sukardi, 2021).

Today, consumers seek foods with functional and nutritional properties. Currently, botanicals are being incorporated into foods to improve their functional properties and safely extend their shelf life. Botanicals can serve as good substitutes for toxic synthetic additives. Part of the potential of galangal as a functional food is that its main flavor component, galangin, has a distinctive flavor that is not as strong or persistent as that of capsaicin. It has been reported that this mild flavor can be used in beverages, sweets, personal care products and as an alcohol enhancer or substitute in nonalcoholic beverages (Yang and Eilerman, 1999). Despite recent research reflecting this potential that has been conducted to enhance the functional properties of biscuits, meats, and sausages (Suttisansanee et al., 2023), there are few examples of galangal being used as a functional food ingredient by direct addition to foods. Therefore, in this study, we conducted experiments on the addition of galangal to *sulgidduk* to obtain basic data for the development of foods that can be easily utilized to enhance health functionalities. We evaluated the chemical and antioxidant effects of the developed product, aiming to use galangal as a functional food ingredient.

## 2. Materials and methods

### 2.1. Materials

The dried galangal used in the experiments was purchased from Indonesia, crushed with a grinder, passed through a 40-mesh sieve, and stored in a freezer at -18℃. Rice harvested from Yeoju in 2023 and milled in January 2024 was purchased from a supermarket in Daejeon, Korea. Sugar (CJ Co., Incheon, Korea) and salt (CJ Co., Sinan, Korea) were used in the experiments.

### 2.2. Sulgidduk preparation

The percentages of *sulgidduk* containing GP are listed in Table 1. The control without GP and *sulgidduk* with 2%, 4%, 6%, and 8% (w/w) GP were compared as experimental groups. The rice was washed thrice with tap water. It was then soaked at room temperature (20-25℃) for 5 h and drained using a sieve for 30 min. The rice was ground twice in a roller mill (Samwoo-Geonggong, Chengju, Korea) and stored in a freezer at -18℃ until use.

The milled rice flour, salt, and GP were mixed and sifted through a 40-mesh sieve. Sugar was then added and the sample was sieved. Water was added up to 30% of the flour weight. The ingredients were mixed in the proportions listed in Table 1. A slotted silicon pad was placed inside a stainless steel steamer (No. 102161, Daeyoung, Seoul, Korea). A square mold (5.5×5.5×4.5 cm) was filled with the ingredients and evenly levelled. The stainless-steel steamer was covered with wet cheesecloth to increase the steam, and the ingredients were steamed for 20 min. The steamer was removed from the heat and left covered for 5 min. The finished *sulgidduk* was removed from the mold and placed on a rack to cool for 1 h before use.

### 2.3. Measurement of water content, soluble solids, and pH

The moisture content was analyzed by desiccation using a

**Table 1. Raw material composition of *sulgidduk* added with different ratios of galangal powder**

| Ingredients (g) | *Sulgidduk* added with galangal powder | | | | |
|---|---|---|---|---|---|
| | Control | 2% | 4% | 6% | 8% |
| Rice flour | 100 | 98 | 96 | 94 | 92 |
| Galangal powder | 0 | 2 | 4 | 6 | 8 |
| Salt | 1 | 1 | 1 | 1 | 1 |
| Sugar | 10 | 10 | 10 | 10 | 10 |
| Water | 30 | 30 | 30 | 30 | 30 |
| Total | 141 | 141 | 141 | 141 | 141 |

desiccator at 105℃ according to the AOAC method (1996). To determine the pH and soluble solid content of *sulgidduk*, 1 g of the sample was mixed with 19 mL of distilled water for 3 min using a vortex mixer. The sample was then centrifuged (Combi 514R, Hanil, Gimpo, Korea) at 3,061 ×*g* for 30 min. The supernatant was collected and the pH was measured (Delta 350, Mettler Toledo, Schwerzenbach, Switzerland). Dilution with distilled water was not considered separately in the measurements and the soluble solid content was expressed in degrees Brix (°Brix).

## 2.4. Measurement of color characteristics

The color characteristics of 10 g of GP and rice flour were measured using a colorimeter (CM5, Konica Minolta Sensing, Osaka, Japan) in a 60-mm Petri dish in triplicate and expressed as lightness (L*), redness (a*), and yellowness (b*). The standard white plate had an L* of 99.35, a* of -0.15, and b* of -0.48.

## 2.5. Determination of water holding capacity of rice flour and galangal powder

The water-holding capacity was determined according to the method described by Medcalf and Gilles (1965). Thirty milliliters of distilled water was added to 1 g of the sample, and the solution was vortexed twice with intermittent stirring at 15 min intervals. The supernatant was removed by centrifugation at 1,977 ×*g* for 30 min (Combi 514R, Hanil) and the sedimented precipitate was weighed. The water-holding capacity (%) was calculated as the percentage increase in weight compared to the initial weight of the sample.

## 2.6. Measurement of density of sulgidduk

The weight of *sulgidduk* prepared with different amounts of GP was measured by weighing the prepared *sulgidduk* after removing the silicone pad. The volume was measured by adding 90 mL of distilled water to a 500 mL measuring cylinder and adding 10 g of *sulgidduk*, while the density was calculated by dividing the solution weight (g) by the volume (mL).

## 2.7. Sensory evaluation

For the quantitative descriptive analysis of *sulgidduk* prepared with GP, 40 sensory evaluation panels were pre-trained and selected based on the characteristics of the test. The evaluation was conducted on an empty stomach between 3 and 4 PM. After cooling at room temperature for 1 h, the finished samples were cut into 2×2×2 cm pieces and served on white paper plates. Each sample was marked with a random number marker. The participants were pretrained to rinse their mouths with bottled water after evaluating a sample before performing a follow-up evaluation. The evaluation criteria were brown color, tenderness (tender to firm), moisture (dry to moist), specific odor, sweetness, and bitter taste. Each characteristic was rated on a nine-point item scale, with higher scores indicating greater intensity for the quantitative descriptive analysis.

And The evaluation items were appearance acceptability, flavor acceptability, texture acceptability, taste acceptability, and overall acceptability on nine-point scales, with higher scores indicating higher acceptability. Sensory evaluations were conducted after obtaining approval from the Institutional Review Board of Woosong University (approval number: 1041549-240409-SB-184).

## 2.8. Messurement of total flavonoid content

To determine antioxidant activity, the extract was prepared


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as follows. *Sulgidduk* was dried at room temperature (25℃) for 24 h and then powdered using a high-speed grinder (M 20, IKA-WERKE, Staufen, Germany). For antioxidant activity and bioactivity assays, 10 g of dry powder from each sample was stirred with 50 mL of 80% ethanol (Duksan Chemical Co., Ansan, Korea) for 1.5 h and extracted at room temperature. The extracted samples were centrifuged (Combi 514R, Hanil) at 3,515 ×*g* and 4℃ for 40 min, and the supernatant was collected and filtered through qualitative filter paper No.2 (Whatman, Maidstone, England). The final concentration of the extract was 500 mg/mL, and 80% ethanol extracts were prepared for each sample to compare differences in antioxidant activity. The samples were stored in a -20℃ freezer to prevent oxidation.

The total flavonoid content (TFC) was determined by adding 50 μL of 10% $Na_2NO_2$ (Daejung, Siheung, Korea) to 0.1 mL of the extract and reacting at 25℃ for 5 min, followed by adding 100 μL of 20% $AlCl_3$ (Junsei chemical Co., Tokyo, Japan) and reacting at 25℃ for 5 min. The reaction was mixed with 400 mL of 1 N NaOH (Samchun, Seoul, Korea) and 900 mL of distilled water, and the absorbance was measured at 510 nm using a Ultraviolet (UV) spectrophotometer (Optizen POP, Mecasys, Daejeon, Korea). A standard curve was generated using quercetin (Sigma-Aldrich, St. Louis, MO, USA) as the standard, and the TFC content of each extract was compared by converting the mean of three replicate values to quercetin equivalents (QE) (Devi and Singh, 2018).

### 2.9. Determination of DPPH radical scavenging activity

The 2,2-diphenyl-2-picrylhydrazyl (DPPH) radical scavenging activity was determined using the method proposed by Blois (1958) for 80% ethanol extracts of *sulgidduk* supplemented with galangal. First, 2.5 mL of 0.4 mM DPPH solution (Sigma-Aldrich) was added to 0.25 mL of the extract, and the absorbance was measured at 517 nm after reacting in the dark for 30 min. The DPPH radical scavenging activity was calculated from the absorbance of the sample ($A_s$) and that of the control without the added extract ($A_c$):

$$\text{DPPH radical scavenging activity (\%)} = [1 - (A_s / A_c)] \times 100$$

### 2.10. Statistical analysis

The results are presented as the mean and standard deviation of three (moisture content, pH, soluble solids, color, water-holding capacity, density, TFC, and DPPH), seven (texture), and forty (sensory characteristics) replicates. IBM SPSS statistical software (29, IBM Co., Armonk, NY, USA) was used for analysis of variance (ANOVA), Duncan's multiple range test, and analysis of significant differences between samples ($p<0.05$). The significance of the differences between GP and rice flour in terms of physicochemical parameters was determined using a student t-test.

## 3. Results and discussion

### 3.1. Physicochemical properties of rice flour and galangal powder

The results of measuring the physicochemical properties of rice flour and GP are shown in Table 2. The moisture content of the rice flour was 36.70%, which was 3.5 times higher than that of the GP (10.47%; $p<0.001$). The pH of the rice flour was 7.60 and that of the GP was 6.87, indicating that the pH of the rice flour was relatively higher ($p<0.01$). The pH of typical rice flour was approximately 6.5, which may be affected by the mineral content of the rice and the pH of the water during soaking. The low pH of the GP was attributed to the high content of phenolic compounds. GP contains large amounts of phenolic acids, flavonoids, and lignans, including weakly acidic phenolic acids (Das et al., 2020) and acidic polysaccharides (Wen et al., 2024).

The soluble solids content of rice flour was 0.1 °Brix, which was similar to the results of a previous study that determined a value of 0.0 °Brix (Jang and Han 2023), while that of GP was 2.7 °Brix ($p<0.001$). The higher soluble solids content of GP was attributed to the influence of monosaccharides, such as glucose, fructose, and galactose, contained in galangal (Wen et al. 2024).

As a result of colorimetry, the lightness (L*) was 93.48 for rice flour and 54.09 for GP. The redness (a*) was -0.33 for rice flour and 8.59 for GP, indicating that the redness of GP was higher. Finally, the yellowness (b*) was 3.98 for rice flour and 23.55 for GP, indicating that the yellowness was also significantly higher in galangal ($p<0.001$). The color characteristics of galangal were attributed to its inherent color and the enzymatic and nonenzymatic reactions that occurred during the drying process. The water-holding capacity of GP was 559.88% compared to 147.14% for rice flour, which was significantly higher by 3.8 times ($p<0.001$). The high water-

**Table 2. Moisture content, pH, soluble solids, color values, and water holding capacity of rice flour and galangal powder**

| Sample | Rice flour | Galangal powder | Significance |
|---|---|---|---|
| Moisture content (%) | 36.70±2.81[1)] | 10.47±0.19 | ***[2)] |
| pH | 7.60±0.05 | 6.87±0.02 | ** |
| Soluble solids (°Brix) | 0.10±0.01 | 2.73±0.06 | *** |
| Color property | | | |
| Lightness (L*) | 93.48±0.02 | 54.09±0.03 | *** |
| Redness (a*) | -0.33±0.01 | 8.59±0.02 | *** |
| Yellowness (b*) | 3.98±0.01 | 23.55±0.03 | *** |
| Water holding capacity (%) | 147.14±2.93 | 559.88±16.92 | *** |

1)All values are means±SD (n=3).
2)** and *** mean that the values within the same row are significantly different at $p<0.01$ and $p<0.001$, respectively.

holding capacity of galangal may be due to its high fiber content, which is similar to that of arrowroot flour with a high fiber content (Yeom and Suh, 2018).

## 3.2. Physicochemical properties of sulgidduk with galangal powder

A comparison of the physicochemical properties of *sulgidduk* prepared using GP is shown in Table 3. Because of the difference between the moisture contents of GP and *sulgidduk* (Table 2), it was expected that the moisture content of *sulgidduk* would decrease as the amount of added GP increased; however, no significant difference in moisture content between the groups was found. Although there was no difference in the water content of the *sulgidduk* recipe, rice flour and GP may have absorbed water while steaming in a steam-filled steamer for 20 min. The higher water-holding capacity of GP may have contributed to the lack of significant differences in moisture content among the groups. These results are similar to those of a previous report (Yeom and Suh, 2018) that showed no difference in moisture content among the groups of *sulgidduk* despite the high difference in moisture content between rice flour and arrowroot flour in arrowroot-flour-added *sulgidduk*. This may have been due to the adsorption of water during steaming owing to the high

**Table 3. Moisture content, pH, soluble solids, color values and density of *sulgidduk* added with different ratios of galangal powder**

| Sample | *Sulgidduk* added with galangal powder | | | | | F-value |
|---|---|---|---|---|---|---|
| | Control[1)] | 2% | 4% | 6% | 8% | |
| Moisture content (%) | 44.77±1.56[2)a] | 45.98±0.42[b3)] | 45.41±0.39[b] | 45.48±0.47[b] | 45.47±0.34[b] | 0.89[NS4)] |
| pH | 7.27±0.02[a] | 7.17±0.01[b] | 7.14±0.01[c] | 7.11±0.01[d] | 7.09±0.01[d] | 100.80***[5)] |
| Soluble solids (°Brix) | 0.90±0.10[c] | 0.83±0.06[c] | 1.27±0.06[b] | 1.30±0.10[b] | 1.47±0.06[a] | 37.39*** |
| Density (g/mL) | 1.25±0.01[a] | 1.26±0.00[a] | 1.16±0.09[b] | 1.08±0.07[bc] | 1.00±0.00[c] | 15.11*** |
| Color property | | | | | | |
| Lightness (L*) | 81.47±2.52[a] | 68.90±1.45[b] | 65.06±0.60[c] | 62.69±0.69[d] | 61.39±0.40[d] | 139.52*** |
| Redness (a*) | -1.27±0.06[e] | 3.68±0.32[d] | 4.89±0.19[c] | 5.74±0.14[b] | 6.51±0.13[a] | 1,062.49*** |
| Yellowness (b*) | 10.59±0.19[d] | 18.27±0.19[c] | 20.24±0.50[b] | 20.67±0.92[a] | 21.37±0.15[a] | 1,105.83*** |

1)Not added with galangal powder.
2)All values are means±SD (n=3).
3)Means with the different superscript letters in the same row are significantly different by the Duncan's multiple range test at $p<0.05$.
4)NS, not significant.
5)Significant at ***$p<0.001$.


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fiber content of the supplement, which offset the difference in moisture content among the groups. In addition, the significantly higher moisture content of the GP supplement groups, which had a lower moisture content than rice flour, was attributed to the higher water-holding capacity of GP. It has been reported that dietary fiber holds water by adsorption and absorption, and that the particle size, chemical composition, and structure of dietary fiber influence its water-holding capacity. Galangal has been reported to have a higher dietary fiber content than other herbs (Suttisansanee et al., 2023). The high dietary fiber content of galangal may have contributed to its high water-holding capacity.

The pH of *sulgidduk* prepared with different amounts of GP was the highest in the control group at 7.27 and decreased significantly with increasing amounts of GP ($p<0.001$). These results were attributed to the fact that GP had a significantly lower pH than rice flour (Table 2), which was attributed to the acidic substances contained in galangal, such as gallic acid, syringic acid, cinnamic acid, and galangal acetate (Ajobair, 2022), which resulted in a lower pH than rice flour.

The soluble solids content of *sulgidduk* prepared with different amounts of GP showed a control value of 0.90 °Brix, but as the amount of GP increased, the soluble solids content was significantly higher than that of the control at 4% and greater ($p<0.001$). Because the soluble solids content of GP was significantly higher than that of rice flour (Table 2), it was expected and confirmed that the soluble solids content of *sulgidduk* increased with increasing amounts of GP. These results showed a similar trend to those of *sulgidduk* with *Borisu* (Kim and Nam, 2021) and *sulgidduk* with *Corni fructus* powder (Kim et al., 2013), where the sugar content was increased by the additives. It has been reported that increasing the steaming time of *sulgidduk* increases the sensory perception of sweetness (Kim, 1987), but no study has confirmed this change by mechanically measuring the change in soluble solids content. In addition, the soluble solids content of the raw material was found to increase by steam heat treatment of persimmon leaf extract (Chung et al., 2023), suggesting that the steaming method when producing *sulgidduk* may have contributed to the increase in soluble solid content. However, the exact factors responsible for this change require further study.

Density measurements of *sulgidduk* prepared with different amounts of GP addition showed that the control was 1.25 g/mL, while the addition of 2%, 4%, 6%, and 8% of GP resulted in values of 1.26, 1.16, 1.08, and 1.00 g/mL ($p<0.001$). The density values decreased significantly with the increasing addition of GP, which was attributed to the fact that GP interfered with the binding between rice starches, resulting in a decreased density. It has been reported that as the ability of food particles to hold water increases, intramolecular bonds become weakened and the density is reduced. In this study, galangal dietary fiber may have absorbed excess water and reduced intermolecular bonding, resulting in a decreased density (Jorien et al., 2015).

### 3.3. Color properties

When the GP content was increased from 0% to 8%, the *sulgidduk* changed from bright white to light brown, as measured by colorimetry (Table 3). As the amount of added GP increased, the lightness (L*) of the *sulgidduk* surface decreased significantly ($p<0.001$), and the redness (a*) and yellowness (b*) increased significantly ($p<0.001$). These results are consistent with the characteristics of GP, which has a lower lightness and significantly higher redness and yellowness than rice flour (Table 2). The results of increased redness (a*) were similar to those for ground beef with galangal (Cheaf and Abu Hasim, 2000). Galangal rhizomes are characterized by a yellow to dark reddish-brown color. Galangal has been reported to contain rutein and alpha and beta carotene (Suttisansanee et al., 2023). This result of decreased lightness and increased redness and yellowness due to additive changes in chromaticity is similar to those of *sulgidduk* with acorn powder (Woo et al., 2016) and *sulgidduk* with caraway (Jang and Han, 2023).

### 3.4. Texture properties

The texture measurement results of *sulgidduk* prepared with different amounts of GP are shown in Table 4. Table 4. Compared with the control group, the hardness of the GP addition group showed no significant differences among the groups. Considering the tendency of starchy foods to soften with increasing water retention (Yeom and Suh, 2018), the lack of a significant difference in the moisture content of *sulgidduk* in this study (Table 3) may have contributed to the lack of a difference in the hardness of *sulgidduk* among the groups. Springiness refers to the degree to which the deformation caused by an external force returns to its original state when the force is removed; there was no significant difference

**Table 4. Texture profile properties of *sulgidduk* added with different ratios of galangal powder**

| Sample | *Sulgidduk* added with galangal powder | | | | | F-value |
|---|---|---|---|---|---|---|
| | Control[1)] | 2% | 4% | 6% | 8% | |
| Hardness (g/cm²) | 1,166.63±149.78[2)] | 1,042.65±85.02 | 1,003.74±186.17 | 1,060.85±98.76 | 1,074.95±107.03 | 1.71[NS4)] |
| Adhesiveness (g) | -542.93±402.01[b] | -239.17±48.82[a] | -230.55±95.71[a] | -158.69±28.72[a] | -121.69±25.53[a] | 6.34[**] |
| Springness (%) | 0.48±0.09 | 0.43±0.02 | 0.46±0.02 | 0.44±0.02 | 0.44±0.02 | 1.50[NS] |
| Cohesiveness (%) | 0.45±0.01[a3)] | 0.42±0.03[b] | 0.40±0.03[b] | 0.38±0.02[c] | 0.37±0.02[c] | 27.70[***] |
| Gumminess (g) | 524.19±73.15[a] | 436.21±43.24[b] | 407.44±91.87[b] | 405.80±45.87[b] | 394.56±50.52[b] | 5.51[**] |
| Chewiness (g) | 251.65±60.72[a] | 188.65±15.36[b] | 185.02±37.32[b] | 178.82±20.30[b] | 173.38±22.53[b] | 6.54[***] |

[1)]Not added with galangal powder.
[2)]All values are means±SD (n=7).
[3)]Means with the different superscript letters in the same row are significantly different by the Duncan's multiple range test at p<0.05.
[4)]***Significant at p<0.001, **Significant at p<0.01, *Significant at p<0.05.

between the GP-added group and the control group. This was similar to the results of moringa-supplemented *sulgidduk* (Choi and Kim, 2015), in which springiness was not affected by the additive. Cohesiveness decreased significantly with increasing amounts of GP compared with the control. Cohesiveness is the ability of a food to maintain its shape, and the decrease in cohesiveness with added GP is consistent with the previously measured decrease in density due to weakened inter-starch forces with increasing amounts of added GP. This suggests that the decrease in starch content with the addition of GP weakened the binding force between particles, making it difficult to maintain its shape (Jang and Han, 2023). These results are similar to those reported for *sulgidduk* with the addition of asparagus powder (Zhang et al., 2016). Gumminess, which is the energy required to chew food to a swallowable state, was 524.19 g in the control but was significantly lower with the addition of GP, ranging from 394.56 to 436.21 g ($p<0.01$). These results were similar to those of *sulgidduk* supplemented with almonds (Baek et al., 2018). The chewiness of the GP samples was significantly lower than that of the control. From these results, it can be inferred that lower cohesiveness leads to lower chewiness because of the inability to maintain a lump shape and increased crumbling into the powder form (Onyango et al., 2011). These results are similar to those of decreased cohesiveness and chewiness in *sulgidduk* supplemented with persimmon powder (Kim et al., 2006). The addition of both green tea (Kim and Park, 1998) and ginseng (Lee, 2008), which are commonly used functional materials, have resulted in decreased hardness and springiness, which contradicts the results of this study.

## 3.5. Sensory properties

### 3.5.1. Quantitative descriptive analysis

The results of the quantitative descriptive analysis of *sulgidduk* with the addition of GP are shown in Table 5. The inherent brown color of galangal increased, and the inherent odor increased significantly ($p<0.001$) as the amount of added galangal increased. The firmness significantly increased and moisture was reduced as the amount of GP increased, while sweetness significantly decreased and bitterness significantly increased. The fact that the evaluators perceived less sweetness despite the same amount of sugar being used to make *sulgidduk* may be due to the bitter taste of galangal offsetting the sweetness, which is similar to the results for arrowroot-powder-added *sulgidduk* (Yeom and Suh, 2018).

### 3.5.2. Consumer acceptance

The results of the consumer acceptability test for *sulgidduk* containing GP are presented in Table 6. The addition of GP negatively affected consumer acceptability. Appearance preference was highest in the control group and decreased significantly as the amount of added galangal increased ($p<0.001$). As the amount of added galangal increased, the galangal swelled and the particle size increased, resulting in an increase in the visually observed galangal particle size and uneven color, suggesting a decrease in appearance acceptability. Flavor and taste acceptability were also highest in the control group and decreased significantly with galangal addition. The increase in specific odor and bitter taste with the addition of GP was attributed to its negative effect on taste acceptability. Galangal


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**Table 5. Quantitative descriptive analysis results of *sulgidduk* added with different ratios of galangal powder**

| QDA | *Sulgidduk* added with galangal powder | | | | | F-value |
|---|---|---|---|---|---|---|
| | Control[1)] | 2% | 4% | 6% | 8% | |
| Brown color[2)] | 1.33±1.14[3)e] | 4.13±1.45[d4)] | 5.28±1.26[c] | 6.63±1.41[b] | 7.43±1.26[a] | 133.34[***5)] |
| Tenderness | 3.75±2.15[d] | 4.68±1.64[c] | 4.78±1.70[bc] | 6.05±1.52[a] | 5.55±1.90[ab] | 9.69[***] |
| Moisture | 6.75±1.63[a] | 5.63±1.55[b] | 4.68±1.82[c] | 3.53±2.05[d] | 3.90±1.66[d] | 22.49[***] |
| Specific odor | 3.20±2.21[c] | 3.78±1.76[c] | 5.73±1.91[b] | 6.00±1.96[b] | 7.60±1.41[a] | 36.34[***.] |
| Sweet taste | 5.63±1.89[a] | 5.05±1.43[ab] | 4.23±1.73[c] | 4.53±1.54[bc] | 3.95±1.85[c] | 6.22[***] |
| Bitter taste | 1.80±1.65[d] | 3.30±1.90[c] | 4.73±2.00[b] | 5.78±2.14[a] | 6.20±2.36[a] | 32.25[***] |

[1)]Not added with galangal powder.
[2)]1 weak ↔ 9 strong.
[3)]All values are means±SD (n=40).
[4)]Means with the different superscript letters in the same row are significantly different by the Duncan's multiple range test at p<0.05.
[5)]***Significant at p<0.001.

**Table 6. Consumer acceptance of the *sulgidduk* with different ratio of galangal powder**

| Consumer acceptance[1)] | *Sulgidduk* added with galangal powder | | | | | F-value |
|---|---|---|---|---|---|---|
| | Control[2)] | 2% | 4% | 6% | 8% | |
| Appearance | 8.10±1.08[3)a] | 5.55±1.85[b4)] | 5.05±1.78[bc] | 4.50±2.40[cd] | 4.18±1.80[d] | 29.01[***5)] |
| Flavor | 7.58±1.57[a] | 5.55±1.55[b] | 5.15±1.87[bc] | 4.43±1.82[cd] | 3.85±2.05[d] | 25.58[***] |
| Texture | 7.75±1.26[a] | 5.50±1.57[b] | 4.25±1.92[c] | 3.80±2.17[cd] | 3.35±2.11[d] | 37.05[***] |
| Taste | 7.70±1.38[a] | 5.45±1.40[b] | 4.40±1.88[c] | 4.00±2.02[c] | 3.18±1.92[d] | 40.33[***] |
| Overall acceptability | 7.88±1.26[a] | 5.68±1.23[b] | 4.70±2.05[c] | 3.45±1.97[d] | 3.00±1.60[d] | 55.13[***] |

[1)]Sensory score: 1 very bad ↔ 9 very good.
[2)]Not added with galangal powder.
[3)]All values are means±SD (n=40).
[4)]Means with the different superscript letters in the same row are significantly different by the Duncan's multiple range test at p<0.05.
[5)]***Significant at p<0.0001.

acetate is reported to be a major component responsible for the brilliant and pungent flavor of galangal (Lin et al., 2016). It is often used as a spice powder for meat products, bitter beer, berries, and chicken in limited amounts because of its wasabi-like flavor. Texture acceptability was highest in the control group, which was speculated to be due to the increase in coarse particles with the increase in GP, and the different particle properties (e.g., particle shape, size, and distribution) from rice flour particles reduced texture acceptability; a similar trend was observed in *sulgidduk* with added arrowroot powder (Yeom and Suh, 2018). In terms of overall acceptability, the control group showed the highest acceptability, which decreased significantly with GP addition. This suggests that the appearance, aroma, texture, and taste of galangal negatively affect the overall acceptability. Only the 2% addition group showed average (score of 4.5 out of 9) to high acceptability. The lower acceptability compared to the control was similar to that of galangal-supplemented sausages (Poltorak et al., 2019), suggesting that the inherent spicy taste of galangal may have reduced acceptability. However, the lower acceptability of the galangal-supplemented group compared to the control group may also be due to unfamiliarity. During early childhood, humans tend to prefer familiar foods. The acceptance of unfamiliar foods is low, although various techniques can be used to improve their acceptance, such as manipulating environmental, situational, exposure-based, and communication-based factors (Motoki et al., 2022).

### 3.6. Total flavonoid content

TFC results are listed in Table 7. The TFC of the 80%

**Table 7. Total flavonoid content of 80% ethanol extracts of *sulgidduk* with different ratio of galangal powder**

| | *Sulgidduk* added with galangal powder | | | | | F-value |
|---|---|---|---|---|---|---|
| | Control[1)] | 2% | 4% | 6% | 8% | |
| Total flavonoid content (mg quercetin equivalents/g) | 15.65±0.31[2)d] | 14.39±0.91[d3)] | 26.64±2.06[c] | 44.00±4.51[b] | 53.83±4.94[a] | 91.68[***4)] |

[1)]Not added with galangal powder.
[2)]All values are means±SD (n=3).
[3)]Means with the different superscript letters in the same row are significantly different at $p<0.05$ by the Duncan's multiple range test.
[4)***]Significant at $p<0.0001$.

ethanol extract of the samples was expressed as QE. The TFCs of the control and 2% added GP samples were 15.65 and 14.3 mg QE/g, respectively, while the 4% added GP sample significantly increase to 26.64 mg QE/g, which was a significant increase of 6% and 8%, respectively. The TFC in the 60% ethanol extract of galangal was 2.34 mg QE/g. Flavonoids are secondary metabolites with scavenging properties against most oxidizing molecules. They have shown a strong therapeutic effect owing to their antioxidant activities. Galangal has been reported to contain a variety of flavonoids, such as alpinone, pinobanksin-3-acetate, catechin, galangin, kaempferol, quercetin, and kumatakenin, which have enabled its therapeutic use (Devi et al., 2018). Based on these results, it was suggested that the TFC increased with the addition of galangal. The 2% added GP group was not significantly different from the control group in TFC, which is likely due to the fact that rice also contains a significant amount of flavonoid compounds (Shin et al., 2022). Therefore, the similarity in TFC between the control group and the low-dose (2%) supplemented group was similar to that of caraway-added sulgidduk (Jang and Han, 2023).

### *3.7. DPPH radical scavenging activity*

The results of the DPPH radical scavenging activity assay are shown in Fig. 1. The DPPH assay was used to determine the free radical-scavenging capacity of the galangal extracts. The purple-colored solution of DPPH free radicals was decolorized to yellow-colored hydrazine when supplemented with different concentrations of GP. The degree of decolorization increased with increasing concentrations of the extract of the *sulgidduk* with GP. At a concentration of 125 mg/mL, the extracts inhibited 27%, 38%, 64%, 81%, and 82% in the control group and 2%, 4%, 6%, and 8%, respectively (Fig. 1). The highest scavenging activities were observed in the 6% and 8% added GP groups, and those of the GP-supplemented groups were significantly higher than that of the control. The DPPH radical-scavenging activity of galangal of the 60% ethanol extract group showed 92.4% activity at a concentration of 18 mg/mL, and the IC50 value was 8.51 mg/mL, indicating the high antioxidant capacity of galangal (Devi et al., 2018).

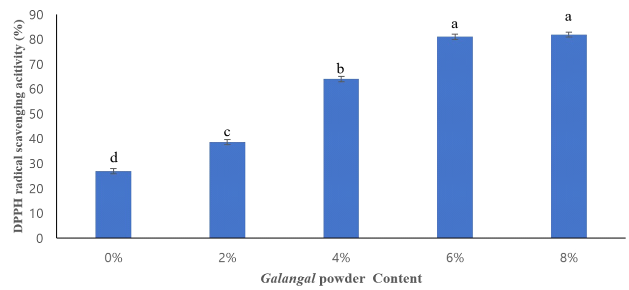


**Fig. 1. DPPH radical scavenging activity of 80% ethanol extracts of *sulgidduk* with 0, 2, 4, 6, and 8% *galalgal* powder.** [a-d]Values with different letters on the bars are significantly different by Duncan's multiple range test ($p<0.05$).

It has been reported that a higher flavonoid content results in a higher antioxidant activity (Kim et al., 2004). In this study, we speculated that the antioxidant activity of *sulgidduk* supplemented with GP was enhanced by the various polyphenolic and flavonoid components contained in galangal. In caraway *sulgidduk* (Jang and Han, 2023) and arrowroot-powder-supplemented *sulgidduk* (Yeom and Suh, 2018), the DPPH radical-scavenging capacity tended to increase with increasing amounts of additives, indicating that the antioxidant activity of *sulgidduk* can be enhanced using additives with high antioxidant activities.

## 4. Conclusions

This study collected basic research data on *sulgidduk* supplemented with GP to develop functional foods containing GP. The quality characteristics of *sulgidduk* with added GP were analyzed to determine the optimal GP loading. The


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moisture content of rice flour is higher than that of GP. In *sulgidduk* with GP, the lightness (L*) significantly decreased and the redness (a*) and yellowness (b*) significantly increased with increasing amounts of added galangal, which may be due to the color of GP. The lightness decreased, and redness and yellowness increased with the addition of GP. No significant differences in hardness or springiness were observed upon GP addition. Sensory analysis revealed increased brown color, specific odor, and bitterness, while sweetness and moisture decreased. Consumer acceptance decreased with increasing GP content, but up to 2% added GP had minimal impact. The antioxidant activity increased with increasing GP, while the consumer acceptance decreased. As a result of adding GP to rice cake, changes in physicochemical properties were confirmed, but a decrease in consumer acceptance was observed, and the level that could minimize this was found to be 2% GP. However, in order to make GP easier to use, it is necessary to research further GP to create more effective functional ingredients, including the following topics; to reduce the bitter taste and strong aroma; to understand the characteristics of GP; to develop ways to use GP in more diverse ways; and to develop a method to store and distribute GP easily.

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## Conflict of interests

The authors declare no potential conflicts of interest.

## Author contributions

Conceptualization; Data curation; Formal analysis; Methodology; Validation; Writing: Kim H.

## Ethics approval

This research was approved by IRB from the Woosong University (No. 1041549-240409-SB-184 & 09 April 2024).

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