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Original article

Effects of adding radicchio (*Cichorium intybus* L.) powder to rice cakes (*Sulgidduk*) on the quality

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Summary. This study investigated the quality, antioxidant activities, and sensory properties of *Sulgidduk* (rice cakes) upon the addition of radicchio (*Cichorium intybus* L.) powder, which is known to have antioxidant and anti-diabetic effects. Radicchio powder was freeze-dried, passed through a 40-mesh sieve, and used to replace 0%, 0.5%, 1%, 2%, 3%, or 4% of the rice flour. The content of moisture in *Sulgidduk* did not significantly differ among samples ($p<0.05$). As the amount of radicchio powder increased, the pH value decreased slightly. Regarding color, the *L*-value decreased from 84.44 (control) to 45.91 (4% sample), and the *a*-value increased from -1.16 (control) to 5.20 (4% sample). The *b*-value increased from control to 2% samples, but then gradually decreased in the 3% and 4% samples. Though hardness and chewiness increased upon adding radicchio powder, the springiness and cohesiveness of the radicchio *Sulgidduk* samples were reduced when compared to these of the control samples (84.43% and 78.17%, respectively). Antioxidant activity of *Sulgidduk* increased significantly upon the addition of radicchio. For sensory evaluation, the 1% sample received the highest score (5.35) in overall acceptability. From these results, we determine that addition of 1% radicchio powder to Sulgidduk is suitable for producing the rice cake.

Key words: gantioxidant activities, quality, rice cake, radicchio, sensory evaluation

Introduction

Radicchio (*Cichorium intybus L.*), a cultivar of chicory, is a red leafy vegetable that originated in Italy (1). This plant is frequently consumed in salads in winter in Europe and the United States owing to its ability to grow well at low temperatures (2). In Korea, radicchio is cultivated in the Kangwon and Chungbook areas. Unlike other chicory cultivars, radicchio (or "red chicory") is rich in polyphenols and anthocyanin pigments (3). Anthocyanin pigments are natural purple pigments with anti-cancer and antioxidant effects (4-6). Several studies have reported that anthocyanin pigments provide health benefits, such as improved cognitive function and reduced risk of obesity and cardiovascular diseases (7-9).

Rice (*Oryza sativa* L. *ssp. japonica*) is a staple food in South Korea. However, rice consumption has been gradually reduced in Korea because of changing dietary habits associated with modernization. According to the 2014 Food Grain Consumption Survey Report from Statistics Korea, annual rice consumption per capita has undergone a continuous decline since 1981, falling from 80.7 kg in 2005 to 65.1 kg in 2014 (10). Thus, many researchers have shown interest in the development and study of various processed rice products. In particular, interest in *dduk*, Korean traditional rice cakes that use rice as a main ingredient, is increasing.

Dduk is composed of non-waxy rice, beans, and other grains cultivated under various climatic conditions in Korea (11). It is widely used in many agricul-

tural rituals and traditional festivals (12). *Sulgidduk,* a type of traditional Korean *dduk*, is made by steaming a mixture of non-waxy rice flour and sugared water. *Sulgidduk* is the standard for studies of Korean rice cakes because of its simple recipe, ease of adding ingredients, and diverse applications (13).

Moreover, investigators have sought to develop methods that can contribute to functional enhancements of *dduk* in order to meet the needs of modern society, which seeks a healthy diet and focuses on the nutritional value of food (14-16). Numerous studies have recently explored the addition of a variety of healthy functional ingredients to *Sulgidduk*, creating nutritionally enhanced *Sulgidduk* with unique colors and flavors (17-20).

The purpose of this study was to analyze the effect of adding different amounts of radicchio powder on the quality, antioxidant activity, and consumer acceptability of *Sulgidduk* when compared to the standard recipe.

Materials and methods

Preparation of Sulgidduk

White rice (produced in Gyeonggi, Korea) purchased in October 2014 was soaked in water for 24 h, dried in a sieve for 30 min, ground using a roller mill (DK 101, Donggwang Ltd, Daegu, Korea), and passed through a 20-mesh sieve to produce non-waxy rice flour. Refined sugar (CJ, Incheon, Korea) and salt (CJ, Incheon, Korea) were purchased for making the *Sulgidduk*. Radicchio (produced in Kangwon, Korea) was purchased in March 2015. Washed radicchio leaves were separated, freeze-dried using a freeze dryer (FD8508, Ilshin Biobase Co. LTD., Gyeonggi, Korea), ground using a high-speed grinder (CRT-04, Hungchuan Machinery Enterprise, Taipei, Taiwan), and passed through a 40-mesh sieve to produce radicchio powder. *Sulgidduk* samples were prepared with the ratios presented in Table 1 (21, 22). Rice flour was mixed with water until all wet lumps were broken and the rice flour was uniformly wet, and then sifted twice with a 20-mesh sieve. Radicchio powder was substituted for 0.5%, 1%, 2%, 3%, or 4% of the rice flour and mixed with sugar. The mixture was spread into an 8-inch-diameter steamer and steamed for 20 min. All samples were sealed in plastic bags and stored at room temperature (25°C) before performing quality measurements.

Table 1. Formulae for *Sulgidduk* (rice cake) containing different levels of radicchio powder

Ingredients (g)	Additional ratio of radicchio powder (%)					
	0	0.5	1	2	3	4
Rice powder	500	497.5	495	490	485	480
Radicchio powder	0	2.5	5	10	15	20
Sugar	50	50	50	50	50	50
Water	50	50	50	50	50	50
Salt	5	5	5	5	5	5

Quality analysis

Determination of moisture content and pH value

The moisture content of the *Sulgidduk* was measured using a moisture analyzer (MB35, OHAUS, Zurich, Switzerland). Five grams of each sample was taken from the central part of the *Sulgidduk*. The pH values of the *Sulgidduk* were measured by a pH meter (SP-701, Suntex instruments Co. LTD., Taipei, Taiwan). Ten grams of *Sulgidduk* sample was homogenized with 90 mL of distilled water by a homogenizer (Unidrive 1000D, CAT Scientific, Staufen, Germany) to measure pH value.

Color measurement

The surface color of the *Sulgidduk* was evaluated using a colorimeter (CR-400, Konica Minolta, Osaka, Japan) with the Hunter *L, a, b* color system. The parameters *L* (lightness), *a* (redness), and *b* (yellowness) were measured. The ΔE (total color difference) values were defined as in Eq. 1:

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2} \quad (1)$$

Where ΔL, Δa, *and* Δb are the difference of *L, a,* and *b* values between a white board (*L*: 96.90, *a*: 0.45, *b*: 1.49) and sample, respectively.

Texture analysis

Textural properties (hardness, chewiness, springiness, and cohesiveness) of *Sulgidduk* were analyzed by

a rheometer (Sun rheometer Compac-100 II, Sun Scientific Co. LTD., Tokyo, Japan). Samples were cut into a fixed size (2 cm × 2 cm × 2 cm). Operation conditions of the rheometer were as follows: No.1 Φ20 mm prove; maximum weight, 2 kg; distance, 33%; table speed, 120 mm·min^{-1}; 2 bites.

Retrogradation analysis from isothermal crystallization kinetics

Retrogradation analyses of Sulgidduk with radicchio were conducted with reference to the method of Kim & Chung (23). Hardness of *Sulgidduk* preserved at 4°C for 12, 24, 36, and 48 hours were measured by rheometer (Sun rheometer Compac-100 II, Sun Scientific Co. LTD.). Changes in hardness were analyzed by the Avrami equation described by Kim (24). The basic form of the Avrami equation (Eq. 2) is as follows:

$$\theta = \frac{(E_L - E_t)}{(E_L - E_0)} = e^{-kt^n} \quad (2)$$

Where θ is the fraction of non-crystallized material, k is the rate constant, n is the Avrami exponent, t is the storage time (hours), E_L is the maximum hardness, E_0 is the hardness at 0 hours, and E_t is the hardness at t hours.

The maximum hardness was determined by measuring the hardness of each sample stored at 4 C for 72 hours. Relationship between hardness of *Sulgidduk* and time that can be obtained from Eq. 2 is shown as follows:

$$\log \left[-\ln \frac{(E_L - E_t)}{(E_L - E_0)}\right] = \log k + n \log t \quad (3)$$

Avrami exponent (n) was calculated from the slope of the plot represented by the left side of the Eq. 3 against log t. The rate constant (k) was obtained as the graph y-intercept value. Time constant ($1/k$) was expressed as the reciprocal of the rate constant (k).

Antioxidant analysis

Preparation of Sulgidduk samples

One gram of each powdered sample was extracted for 24 hours with 10 mL of distilled water. The sample extracts were centrifuged at 3000 rpm for 10 min (Universal 32 R, Hettich, Tuttlingen, Germany) and filtered through Whatman No. 1 filter paper.

Total polyphenol and flavonoid contents

The total polyphenol content of *Sulgidduk* sample extracts was determined by using the Folin-Denis method with slight modifications as suggested by Hong et al. (25). Fifty microliters of 0.9 M Folin-Ciocalteu reagent (Junsei Chemistry, Tokyo, Japan) and 150 μL of 20% (w/v) sodium carbonate solution (Merck kGaA, Darmstadt, Germany) were added to 10 mL of sample with 790 mL of distilled water. After incubation at room temperature (25°C) for 30 min in the dark, the absorbance at 750 nm of the solution was measured using a microplate reader (Infinite 200 PRO, Tecan, Mannedorf, Switzerland). A standard curve was plotted using gallic acid (Merck kGaA, Darmstadt, Germany) by the same procedure above. The total polyphenol content was expressed as gallic acid equivalents (GAE) per 1 gram of sample.

Total flavonoid content of *Sulgidduk* was measured using the method described by Davis (26). One milliliter of sample was mixed with 150 μL of 5% (w/w) sodium nitrite (Junsei Chemistry, Tokyo, Japan) and kept into a dark room (25°C). After 6 minutes, 300 μL of 10% (w/w) aluminum chloride (Junsei Chemistry, Tokyo, Japan) was added and incubated for another 5 min. Absorbance at 520 nm was measured after 1 mL of 1 N sodium hydroxide (Daejung chemicals & metals, Gyeonggi, Korea) was added. A calibration curve was plotted using quercetin (Sigma Aldrich Corp., St. Louis, MO, USA) with the same procedure. The total flavonoid content of the samples was expressed as quercetin equivalents (QE).

DPPH and ABTS radical scavenging activity

The DPPH (2, 2-diphenyl-1-picrylhydrazyl) radical scavenging activity of the *Sulgidduk* was measured using the method of Baek et al (25). Each sample was diluted with distilled water to obtain concentrations of 100, 50, 33.3, 25, 20, and 16.66 mg/mL. Subsequently, 100 μL of 0.2 mM DPPH (Sigma Aldrich Corp., St. Louis, MO, USA) ethanol solution was added to 100 μL of each diluted sample. The solution was allowed to react at room temperature (25°C) for 30 min in the

dark. The absorbance was measured at 520 nm. Percentage inhibition was defined as in Eq. 4:

$$\text{DPPH radical inhibition (\%)} = \frac{(C_{ab} - S_{ab})}{C_{ab}} \times 100 \quad (4)$$

Where C_{ab} is the absorbance of 100 μL EtOH + 100 μL of 0.2 mM DPPH and S_{ab} is the absorbance of 100 μL EtOH + 100 μL of 0.2 mM DPPH.

IC_{50} values (the concentration of sample that is required for 50% inhibition of DPPH radicals) were calculated based on a trendline representing the concentration-response curve of each sample.

2.2´-azino-bis-3 ethylbenzothiazoline-6-sulfonic-acid (ABTS) radical scavenging activity was measured by a method suggested by Re et al (26) with slight modification. ABTS (7.4 mM; 384.30 mg; Sigma Aldrich Corp., St. Louis, MO, USA) was mixed with 66.15 mg of 2.6 mM potassium persulfate (Sigma Aldrich Corp., St. Louis, MO, USA) in 100 mL of distilled water. The ABTS radical cation was prepared by incubating the solution for 12 hours in dark room (4°C) and diluted with distilled water until the absorbance at 414 nm reached 1.4-1.5. Each sample was diluted with distilled water to obtain concentrations of 100, 50, 33.3, 25, 20, and 16.66 mg/mL. Ten microliters of samples with 200 μL of ABTS radical solution were incubated for 1 hour in a dark room at 25°C. Absorbance was measured at 414 nm. IC_{50} (mg/mL) values were estimated from the percentage inhibition of each sample by using Eq. 2.

Consumer preference test

Thirty panelists were selected for consumer preference test of *Sulgidduk*. Color, flavor, moisture, chewiness, and overall acceptability of *Sulgidduk* were evaluated using a 7-point scale method ('Strongly dislike'=1 and 'Strongly like'=7). The panelists rinsed their mouths with bottled water after tasting each sample. All samples were cut into a fixed size (2 cm × 2 cm × 2 cm) and served on a white plastic plate.

Statistical analysis

All measurements were performed in triplicate. All results obtained from measurements were analyzed by one-way ANOVA using SPSS v23.0 (SPSS InC., Chicago, IL, USA). All data are displayed as mean ± SD. Significance between the means of measured experimental values was analyzed by Duncan's multiple range test (p<0.05).

Results and Discussion

Quality analysis

The moisture content and pH values of radicchio-containing *Sulgidduk* are shown in Table 2. Moisture content of Sulgidduk ranged from 33.75-34.37% and was not significantly different among all samples. The pH value of the radicchio powder itself was 5.54 in a preliminary experiment (data not shown). The slight change in pH of radicchio-containing *Sulgidduk* is therefore likely caused by the radicchio powder, which is slightly acidic. The pH value and moisture content are factors that influence gelatinization and retrogradation of rice starch (29). It is inferred that the effect on rice starch might be minimal, since the changes in pH value and moisture content brought about by the addition of radicchio powder are insignificant.

Results of the surface color of the radicchio-containing *Sulgidduk* are shown in Table 3. The *L* values (lightness) decreased with increasing amounts of radicchio up to 3%, while the *a* value (redness) and the *b* value increased. These changes in color are likely caused by the anthocyanin components of radicchio, the main one of which is cyanidin 3-O-(6"malonyl)-glucoside (30, 31). However, the ΔE values did not appear to clearly differ at concentrations above 3% of radicchio powder added.

Unlike the results for pH value and moisture content, the textural properties of *Sulgidduk* were significantly altered upon the addition of radicchio powder (Table 4). Hardness and chewiness tended to increase initially, while the springiness and cohesiveness values of radicchio-added groups were lower than those values in the control group. These results indicate that the texture of *Sulgidduk* might become chewier and the surface may become harder when substituting high amounts of radicchio powder for rice flour. The texture of *Sulgidduk* is dependent on the ingredients added and the amount of rice starch (32). It is believed

Table 2. The moisture content and pH values of *Sulgidduk* (rice cake) containing different levels of radicchio powder

Properties	Additional ratio of radicchio powder (%)					
	0	0.5	1	2	3	4
Moisture contents (%)	33.8±2.4$^{a1)}$	32.6±1.8^{a}	34.3±2.1^{a}	34.3±1.4^{a}	34.1±1.8^{a}	34.4±1.1^{a}
pH	5.64±0.03^{a}	5.64±0.01^{a}	5.57±0.01^{b}	5.60±0.02^{b}	5.58±0.02^{b}	5.60±0.01^{b}

1)Means in each row with different superscript letters are significantly different by Duncan's multiple range test (p<0.05)

Table 3. Color values of *Sulgidduk* (rice cake) containing different levels of radicchio powder

Color values	Additional ratio of radicchio powder (%)					
	0	0.5	1	2	3	4
L	84.44±0.34$^{a1)}$	60.71±0.84^{b}	55.41±1.26^{c}	51.37±0.64^{d}	47.09±0.87^{e}	45.91±0.66^{e}
a	-1.16±0.04^{d}	3.51±0.10^{c}	4.76±0.17^{b}	4.64±0.01^{b}	5.15±0.12^{a}	5.20±0.18^{a}
b	5.66±0.41^{d}	6.11±0.24^{d}	7.24±0.18^{c}	9.60±0.07^{a}	9.44±0.23^{ab}	8.99±0.33^{b}
ΔE	13.2±0.45^{e}	36.67±0.82^{d}	42.17±1.26^{c}	46.5±0.63^{b}	50.72±0.86^{a}	51.82±0.7^{a}

1)Means in each row with different superscript letters are significantly different by Duncan's multiple range test (p<0.05).

Table 4. Textural properties of *Sulgidduk* (rice cake) containing different levels of radicchio powder

Properties	Additional ratio of radicchio powder (%)					
	0	0.5	1	2	3	4
Hardness (g·cm^{-2})	212.77±11.81$^{d1)}$	265.03±16.52^{c}	295.80±5.72^{abc}	278.03±21.51^{bc}	310.43±27.51^{ab}	324.23±20.20^{a}
Chewiness (g·cm^{-1})	242.53±8.31^{c}	266.22±18.64^{c}	293.20±19.86^{b}	348.17±15.76^{a}	338.15±9.73^{a}	322.99±12.77^{a}
Springiness (%)	84.4±4.8^{a}	76.9±0.7^{b}	84.1±4.0^{a}	72.2±0.9^{b}	76.7±6.4^{b}	73.0±2.0^{b}
Cohesiveness (%)	78.2±2.7^{a}	71.8±0.8^{bc}	75.5±3.4^{ab}	71.2±1.9^{bc}	73.4±4.8^{abc}	69.7±2.4^{c}

1)Means in each row with different superscript letters are significantly different by Duncan's multiple range test (p<0.05).

that the amount of rice starch in *Sulgidduk* and the dietary fiber contained in the radicchio (33) affected the textural properties of the *Sulgidduk*. These results are similar to results obtained by Li et al. (34) that hardness and chewiness of noodles were elevated upon the addition of superfine green tea powder, which is rich in dietary fiber content.

Retrogradation of rice starch, which occurs by recrystallization of amylose and amylopectin, causes quality deterioration in the preservation of the *Sulgidduk*. Table 5 shows the Avrami exponent (*n*), rate constant (*k*), and time constant (*1/k*), which were analyzed from the changes in hardness of the *Sulgidduk* during storage. The Avrami exponent is related to the rate of starch crystal formation during retrogradation. Low Avrami exponent and rate constant generally can be judged to mean a more flexible state, due to delayed formation of starch crystals (35). From the results, it is expected that the addition of 1% or 4% radicchio powder would delay retrogradation in *Sulgidduk*. Retrogradation of starch is affected by various additives. Especially, dietary fiber is known to randomize the arrangement of rice starch particles and bind to a part of amylose and amylopectin to prevent recrystallization

Table 5. Avrami exponent (n), rate constant (k) and time constant (T) of *Sulgidduk* (rice cake) containing different levels of radicchio powder

Properties	Additional ratio of radicchio powder (%)					
	0%	0.5%	1%	2%	3%	4%
n[1)]	1.49	1.51	1.251	1.838	1.799	1.498
k[2)]	0.077	0.057	0.048	0.096	0.08	0.042
T[3)]	12.99	17.54	20.83	10.42	12.50	23.81

[1)]n: Avrami exponent; [2)]k: rate constant; [3)]T: time constant (1/k)

of starch molecules (36-38). It is inferred that high dietary fiber content of radicchio powder may have inhibited retrogradation in *Sulgidduk*.

Antioxidant analyses

Polyphenol compounds are secondary metabolites found in fruits and vegetables that have antioxidant activity (39), and they have been reported to be effective against cancer, cardiovascular diseases, diabetes, and osteoporosis in many animal trials (40). As shown in Table 6, total polyphenol and flavonoid contents of *Sulgidduk* were directly proportional to the addition of radicchio powder. Though the steam-based cooking process used to produce *Sulgidduk* may reduce the total polyphenol content (41, 42), it is considered to be able to produce *Sulgidduk* with enhanced polyphenol content (1.5-1.7 times compared to control). According to Kaulmann's study (43), 1 g of radicchio contains 0.41 mg of polyphenol compounds, such as chlorogenic acid, kaempferol, quercetin, and gallic acid. Pereira (44) reported that the antioxidant activity of minimally processed radicchio did not significantly differ between fresh samples and those stored for three days. Therefore, experimental errors arising from the preparation time of the *Sulgidduk* sample are assumed to be minimal. A significant reduction of DPPH and ABTS IC_{50} upon adding radicchio powder indicates that the *Sulgidduk* containing radicchio was expected to have strong antioxidant properties. It is known that DPPH and ABTS radical scavenging activity varies directly with total polyphenol content (45).

Consumer preference test

The results of consumer preference test of *Sulgidduk* with radicchio are shown in Table 7. The color and flavor score decreased upon the addition of radicchio powder. The moisture content score was not significantly different among all groups. This result was consistent with the moisture content of *Sulgidduk* measured in this study. Chewiness also did not significantly change. These results were contrary to the results of the measurement of chewiness during the quality analysis. On the other hand, the sweetness score gradually declined when radicchio amount was above 2%.

Table 6. Antioxidant activities of *Sulgidduk* (rice cake) containing different levels of radicchio powder

Properties	Additional ratio of radicchio powder (%)					
	0%	0.5%	1%	2%	3%	4%
Total Polyphenol (mg GAE/g)	0.02±0.00$^{e1)}$	0.03±0.01^{d}	0.03±0.00^{cd}	0.04±0.00^{c}	0.06±0.00^{b}	0.07±0.00^{a}
Total Flavonoid (μg QAE/g)	1.16±0.09$^{e1)}$	1.30±0.03^{d}	1.54±0.03^{c}	1.59±0.07^{c}	1.96±0.04^{b}	2.34±0.07^{a}
DPPH IC_{50} (mg/mL)	244.41±20.37$^{a1)}$	188.40±17.72^{b}	160.73±7.95^{c}	123.87±7.60^{d}	93.60±5.76^{e}	77.07±5.94^{e}
ABTS IC_{50} (μg/mL)	961.10±90.77^{a}	635.03±28.91^{b}	561.49±22.86^{b}	466.66±7.82^{c}	287.30±19.65^{d}	212.28±31.27^{d}

[1)]Means in each row with different superscript letters are significantly different by Duncan's multiple range test. ($p<0.05$)

Table 7. Sensory preference score for *Sulgidduk* (rice cake) containing different levels of radicchio powder

Properties	Additional ratio of radicchio powder (%)					
	0	0.5	1	2	3	4
Color	5.45±1.28[a1)]	5.05±1.28[ab]	5.35±1.14[ab]	5.20±1.11[ab]	4.65±1.14[b]	4.55±1.43[b]
Flavor	4.50±1.00[ab]	4.45±1.28[ab]	5.25±1.16[a]	4.15±1.57[bc]	3.85±1.27[bc]	3.40±1.64[a]
Moisture	4.75±1.16[a]	4.65±0.93[a]	4.65±1.27[a]	4.40±1.10[a]	4.55±1.34[a]	4.40±1.39[a]
Chewiness	5.00±0.92[a]	4.85±1.18[a]	5.35±0.93[a]	4.60±1.23[a]	4.70±1.34[a]	4.65±1.23[a]
Sweetness	4.65±1.35[a]	4.65±1.35[a]	4.95±1.19[a]	4.20±1.24[ab]	3.60±1.10[bc]	3.30±1.42[c]
Overall acceptability	5.00±1.08[ab]	4.80±1.20[ab]	5.35±1.35[a]	4.30±1.45[bc]	3.85±1.27[c]	3.55±1.43[c]

[1)]Means in each row with different superscript letters are significantly different by Duncan's multiple range test (p<0.05).

It is postulated that the bitter taste of sesquiterpene lactones, such as lactucopicrin, in radicchio, masked the sweetness of the *Sulgidduk* (39, 40). The overall acceptability score was highest at 1% radicchio, as the 2-4% radicchio *Sulgidduk* samples received a lower score than control. This may be explained from data in which preference scores for parameters such as flavor and sweetness decreased rapidly from the 2% radicchio *Sulgidduk* samples onwards.

Conclusion

The purpose of this study was to examine the effect of radicchio powder on *Sulgidduk*. As the amount of radicchio powder increased, hardness and chewiness of the *Sulgidduk* also increased. It is assumed that these textural changes are due to the reduced volume of rice starch and additional dietary fiber contained in radicchio powder. Adding more than 3% radicchio powder produced no significant differences in total color values. Antioxidant activity of *Sulgidduk* cakes varied directly with the amount of radicchio powder. In the sensory evaluation, *Sulgidduk* samples with more than 2% radicchio powder received much lower scores in flavor, sweetness, and overall acceptability than those of control. Based on these results, proper controls of radicchio powder enrichment are needed to manufacture *Sulgidduk* according to the color measurement and sensory evaluation, although antioxidant activities were expected to improve as more radicchio powder was added to the *Sulgidduk*. Based on our results, it is recommended to substitute 1% of rice flour with radicchio powder when preparing *Sulgidduk*.

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