Physicochemical Characteristics and Antioxidant Capacity of Rice Cake (*Sulgitteok*) Supplemented with Lyophilized *Sedum sarmentosum* (*Dolnamul*) Powder

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Abstract

This study was performed to increase the availability of *Sedum sarmentosum* (*Dolnamul*) and to improve the nutraceutical value of rice cakes (*sulgitteok*). The contents of crude protein, mineral, dietary fiber, water holding capacity, and hardness significantly and directly increased with lyophilized sedum powder (SP). Pore ratio and expansion rate decreased in samples containing more than 10% SP compared to the control. In a sensory evaluation, a positive correlation was detected between overall acceptability and taste ($R^2=0.99$, $p<0.01$), and color ($R^2=0.72$, $p<0.05$). Total polyphenol contents of the SP-treated groups were significantly elevated, accompanied by an increase in radical scavenging ability estimated by the 1,1-diphenyl-2-picrylhydrazyl (DPPH) assay. Replacing 10% of the rice powder with SP efficiently improved the antioxidant and nutritional values of *sulgitteok* as well as its the sensory quality.

Key words: *Sedum sarmentosum* (*Dolnamul*), rice cake (*sulgitteok*), antioxidant, sensory quality

INTRODUCTION

Rice, an essential food resource in Korea, is used for making traditional Korean foods such as rice cakes, alcoholic beverages, and sauces. Various traditional Korean rice cakes (*tteok*) can be produced, and they are consumed as a celebratory food on special occasions. Generally, *tteok* are divided into four categories; steamed, pounded, boiled, and pan-fried. *Sulgitteok*, considered as the most important basic form for other varieties of steamed *tteok*, is shaped into a single lump and made of rice flour. In order to increase the nutraceutical, physicochemical, and sensory values, and to extend the shelf-life of rice cakes, various subsidiary ingredients are added to *sulgitteok* (1-3).

Sedum sarmentosum (*Dolnamul*) is a type of perennial herb consumed as an ingredient in salads and *baechu kimchi*, a kind of kimchi. In addition, sedum has been used as a folkloric plant in Asia, including Korea and China, for many centuries (4). Unfortunately, the preservation period of sedum is very short due to significant moisture retained and perishable tissues (5). Thus, to increase the availability of sedum, minor efforts have made to produce juices and jellies, although the nutraceutical values have not been reported (6,7).

The consumption of antioxidants leads to a reduction in oxidative stress that can induce the development of human disease, such as cancer and cardiovascular disease (8). Antioxidants derived from vegetables are effective and have reduced interference with the body's ability to use free radicals (9). Therefore, the use of natural antioxidants present in plant food has attracted considerable interest due to their presumed safety and nutritional value (10).

Recently, sedum extracts have been reported to be comparable to butylated hydroxytoluene (BHT) in antioxidant capacity (11-13). Therefore, this feasible study was performed to improve the nutraceutical value of traditional Korean rice cakes (*sulgitteok*) with the addition of *Dolnamul*. Also, we show that *Dolnamul* is a natural antioxidant source that can be used in the food industry.

MATERIALS AND METHODS

Plant materials and preparation

Fresh *Sedum sarmentosum* Bunge leaves (general edible portion) were harvested in Seoul, Korea, in January 2009. A voucher specimen (No. DBP-090131) was deposited in the Herbarium at the Research and Development Center of the DBIO Incorporation (Daejeon, Korea).

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Table 1. Formulas for the *sulgitteok* prepared with various concentrations of lyophilized sedum powder

Experimental groups ¹⁾	CO	SS-1	SS-2	SS-3
Rice powder (g)	100	95	90	80
Sugar (g)	10	10	10	10
Salt (g)	1	1	1	1
Water (g)	20	20	20	20
Lyophilized sedum powder (g)	0	5	10	20

¹⁾Experimental groups: CO, control (*sulgitteok* made of rice flour); SS-1, 5% (w/w) of lyophilized sedum powder-containing group; SS-2, 10% (w/w) of lyophilized sedum powder-containing group; SS-3, 20% (w/w) of lyophilized sedum powder-containing group.

The sedum was washed and immediately freeze-dried. Lyophilized sedum leaves were powdered and passed through sieves to obtain uniformly sized particles of 0.5 mm.

Production of *sulgitteok*

Rice (*Oryza sativa*, *Chuchung*) was purchased from Nonghyub (Hanaro-mart) in Daejeon, Korea. The rice was washed five times and soaked for 8 hr at room temperature ($23 \pm 2^\circ\text{C}$). Milling was performed at commercial facilities (two times), and the sifted powder was used in the production of *sulgitteok*. The *sulgitteok* formulas are presented in Table 1. The powdered rice and lyophilized sedum powder were mixed well, and steamed for 20 min. The *sulgitteok* was used for analysis after cooling for 2 hr at room temperature.

Analyses of general composition

Moisture contents of *sulgitteok* were determined by a moisture analyzer (MS-70, A&D, Tokyo, Japan). Lyophilized *sulgitteoks* were ground in a food mixer (HMF-3100S, Hanilelectric Co., Seoul, Korea), for analysis of general composition. Crude protein, fat, ash, and dietary fiber were determined by Association of Official Analytical Chemists (AOAC) 984.13A-D, AOAC 920.39A, AOAC 942.05, and AOAC 985.29 standards, respectively (14). Reducing sugar was assessed by the Somogyi-Nelson method (15). For the determination of mineral contents, HNO_3 was added to 0.1 g of lyophilized *sulgitteok* powder in order to decompose organic compounds, and the final volume was adjusted to 100 mL. The concentration of inorganic elements was determined by inductively coupled plasma mass spectrometry (ICP-MS; Optima 4300DU, VG elemental, Perkin Elmer, Norwalk, CT, USA) as previously described (16).

Determination of physicochemical characteristics

Volume, pore ratio, and expansion rate of *sulgitteok* were assessed as previously reported (16). Twenty mL of distilled water was added to 1 g of sample, mixed

for 30 min ($25 \pm 1^\circ\text{C}$), and centrifuged for 10 min (900 g); the supernatant was discarded. The water holding capacity (WHC) was obtained by the following equation.

$$\text{WHC (\%)} = \frac{\text{Precipitate (g)} - \text{Sample (g)}}{\text{Sample (g)}} \times 100$$

The chromaticity of *sulgitteok* ($3 \times 3 \times 3$ cm) was measured using a color meter (JX 777, Minolta, Tokyo, Japan), and expressed as Hunter's L^* , a^* , and b^* color values. The hue angle (h°) and chroma (C^*) were calculated as $h^\circ = \arctan b^*/a^*$ (deg) and $C^* = [(a^{*2} + b^{*2})^{1/2}]$, respectively.

The textural properties of *sulgitteok* ($3 \times 3 \times 3$ cm) were obtained from the texture profile analysis (TPA) using a Texture Analyser (TA-XT2, Stable Micro Systems, Godalming, Surrey, UK). The operational parameters of the texture analyzer were as follows: pretest speed, 10.0 mm/s; test speed, 5.0 mm/s; posttest speed 10.0 mm/sec; sample area, 3.0 mm²; distance (strain), 90.0%, force threshold, 20.0 g; contact force, 5.0 g; and probe, P10 (10 mm DIA cylinder aluminium).

In order to examine the surface structure of *sulgitteok*, 5 g of rice cakes was dehydrated by a graded series of ethanol (30, 50, 70, 80, 95, and 100%). The dehydrated samples were dried in a critical-point dryer (BAL-TEC, CPD 030, Los Angeles, CA, USA), and coated with gold in an ion-sputter (Hitachi E-101, Hitachi, Tokyo, Japan). The specimens were examined with a scanning electron microscope (Hitachi S-2350, Hitachi).

Antioxidant activities

One hundred grams of lyophilized and grinded *sulgitteok* were extracted with 3 L of ethyl acetate at room temperature ($20 \pm 3^\circ\text{C}$) for 12 hr. To increase the extraction yield, this procedure was repeated twice. The solvent extracts were concentrated with a rotary vacuum evaporator at $35 \pm 1^\circ\text{C}$. The total polyphenol content (TPC) and antioxidant activities of *sulgitteok* were measured by DPPH assays as previously described (11). Butylated hydroxytoluene (BHT) was used as a positive control.

Sensory evaluation

A panel of 12 members (6 males and 6 females, ages 20's to 40's) evaluated the shape, color (internal and external), flavor, taste, texture, and overall acceptability (the level of preference from the customer's viewpoint) of the *sulgitteok*. The samples were presented randomly using a table of sampling digits, and higher point indicated a higher sensory quality (1 to 5 points).

Statistical analysis

All analyses were carried out in triplicate, and the data are expressed as the means $\pm$ standard deviation (SD).

Table 2. General composition of *sulgitteok* prepared with various concentrations of lyophilized sedum powder

	CO ¹⁾	SS-1	SS-2	SS-3
Moisture (%)	39.77 ± 0.04	39.37 ± 0.29	39.40 ± 0.46	39.71 ± 0.25
Protein (g) ²⁾	4.96 ± 0.09 ^{ad)}	5.66 ± 0.18 ^b	6.55 ± 0.07 ^c	8.18 ± 0.19 ^d
Fat (g)	2.09 ± 0.04 ^a	2.19 ± 0.07 ^b	2.36 ± 0.03 ^c	2.64 ± 0.06 ^d
Ash (g)	1.01 ± 0.02 ^a	1.58 ± 0.05 ^b	2.20 ± 0.02 ^c	3.40 ± 0.08 ^d
Sugar (g)	67.35 ± 1.28 ^a	64.93 ± 2.04 ^{ab}	64.67 ± 0.71 ^{ab}	62.43 ± 1.38 ^b
Dietary fiber (g)	4.96 ± 0.09 ^a	5.50 ± 0.17 ^b	6.23 ± 0.07 ^c	7.53 ± 0.17 ^d
Ca (mg) ³⁾	9.53 ± 0.18 ^a	178.31 ± 5.61 ^b	352.20 ± 3.79 ^c	696.38 ± 15.44 ^d
P (mg)	71.31 ± 1.35 ^a	87.26 ± 2.74 ^b	106.02 ± 1.14 ^c	141.37 ± 3.13 ^d
Fe (mg)	0.88 ± 0.02 ^a	2.66 ± 0.08 ^b	4.52 ± 0.05 ^c	8.18 ± 0.18 ^d
Na (mg)	11.01 ± 0.21 ^a	21.46 ± 0.67 ^b	32.57 ± 0.35 ^c	54.30 ± 1.20 ^d
K (mg)	204.08 ± 3.88 ^a	313.36 ± 9.84 ^b	432.47 ± 4.65 ^c	663.20 ± 14.70 ^d

¹⁾Groups are the same as in Table 1.

²⁾g/100 g of *sulgitteok* (dry weight).

³⁾mg/100 g of *sulgitteok* (dry weight).

⁴⁾Different letters in a row denote values that were significantly different (p<0.05).

One-way analysis of variance (ANOVA) and Duncan's multiple range test were performed for significant differences. The p-values less than 0.05 were considered statistically significant. One-way ANOVA, Pearson's correlation, and simple linear regression analyses were conducted using SPSS (ver. 14, SPSS Inc., Chicago, IL, USA).

RESULTS AND DISCUSSION

General composition

The general compositions of *sulgitteok* prepared with lyophilized sedum powder (SP) are presented in Table 2. The moisture contents slightly decreased in proportion to the SP supplementation, but significant differences were not detected among the samples (p<0.308). The crude protein concentrations of the SP-treated groups were higher than the control group by approximately 15 ~40%. However, the reducing sugar contents slightly decreased in the SP-treated groups, and a significant difference was detected between the control and SS-3.

The crude fat contents of the SP-treated groups were significantly greater compared to the control group. Based on the principle of crude fat determination, components such as pigments and polyphenols could be extracted by diethyl ether. Chlorophylls, carotenoids, and other pigments might be higher in the sedum powder than the rice powder; thus, the crude fat concentrations of the SP-treated groups significantly increased in ac-

cordance with the SP supplementation.

The dietary contents were 6.4 g/100 g and 23.11 g/100 g dry weight of rice powder and sedum powder, respectively. Thus, the dietary fiber concentration of *sulgitteok* significantly increased in proportion to the SP addition.

The ash concentrations of the SP-treated groups were significantly higher than that of the control group, and thus inorganic elemental analysis was performed. Compared to the control group, the contents of calcium, phosphorous, iron, sodium, and potassium were significantly elevated with the increasing SP supplementation. These results indicated that sedum powder substituting for a portion of the rice powder in production of *sulgitteok* could improve the nutritional value of rice cakes.

Pore ratio and expansion rate

As the amount of SP increased, the pore ratio (PR) and the expansion rate (ER) of *sulgitteok* decreased (Table 3). No significant differences were detected between the control and SS-1 groups, or between SS-1 and SS-2 in PR and ER assessments. Compared to the control group, the PR and ER significantly decreased in SS-3. The images of the surfaces of the *sulgitteok* are presented in Fig. 1. Pores formed evenly in the control group, but the pore size diminished in SS-3.

Generally, the PR and ER of rice cakes could be increased in conformity with starch gelatinization, and subsequently hindered by the addition of dietary fiber (17).

Table 3. Physical properties of *sulgitteok* prepared with various concentrations of lyophilized sedum powder (%)

	CO ¹⁾	SS-1	SS-2	SS-3
Pore ratio	160.51 ± 9.56 ^{a2)}	145.57 ± 12.65 ^{ab}	143.75 ± 15.57 ^{ab}	128.71 ± 15.65 ^b
Expansion rate	208.21 ± 12.98 ^a	193.84 ± 8.57 ^{ab}	176.62 ± 9.61 ^{bc}	172.31 ± 5.59 ^c
Water holding capacity	26.44 ± 1.09 ^a	36.09 ± 1.49 ^b	38.27 ± 1.11 ^b	41.01 ± 1.46 ^c

¹⁾Groups are the same as in Table 1.

²⁾Different letters in a row denote values that were significantly different (p<0.05).

Fig. 1. Scanning electron micrographs of *sulgitteok* prepared with various concentrations of lyophilized sedum powder (Magnification ratio: $\times 40$): Groups are the same as in Table 1.

As described in Table 2, the dietary concentrations of the SP-treated groups were higher than the control. Thus, it was considered that the addition of sedum powder in the production of *sulgitteok* led to a decline in the PR and ER via the inhibition of starch expansion during steaming.

Water holding capacity

The water holding capacities (WHC) of the SP-treated groups were significantly increased from approximately 25 ~ 35% (Table 3). Previously known, WHC increase is induced by the addition of a high concentration of sugar and/or dietary fiber-containing ingredients (18). Thus, Pearson's correlation coefficients among the SPS, WHC, and dietary fiber concentration were calculated (Table 4). Highly positive correlations were found between SP addition and WHC, between SP addition and dietary fiber concentration, and between dietary fiber concentration and WHC. Therefore, the increase of WHC in the SP-treated groups was a result of the increase of dietary fiber concentration due to SP addition.

Table 4. Pearson's correlation coefficients between the sedum powder concentration, water holding capacity, and dietary fiber concentration of *sulgitteok* prepared with lyophilized sedum powder

	Sedum powder	Water holding capacity	Dietary fiber
Sedum powder	1.000	0.993 ^{a1)}	0.862 ^a
Water holding capacity	0.993 ^a	1.000	0.836 ^a
Dietary fiber	0.862 ^a	0.836 ^a	1.000

¹⁾Superscript letter means significantly correlated between categories ($p < 0.01$), analyzed by simple linear regression analysis.

Texture analysis

Previously reported, subsidiary ingredients affect the texture properties of rice cakes (19), and thus the textural characteristics of *sulgitteok* were determined by texture profile analysis (TPA; Table 5). The hardness of the SP-treated groups was significantly higher than the control. These results suggested that the high hardness values of the SP-treated groups were the result of the low ER of starch (Table 3); however, no significant differences were detected between the control and SS-1, or between SS-2 and SS-3. Gumminess and chewiness were slightly increased in proportion to the SP supplementation, but significant differences were not detected ($p = 0.185$ and $p = 0.178$ for gumminess and chewiness, respectively). Based on the principle of TPA, gumminess and chewiness, calculated from the hardness value, increased with hardness. The springiness and cohesiveness values of the SP-treated groups did not significantly differ from that of the control group ($p = 0.698$ and $p = 0.899$ for springiness and cohesiveness, respectively).

Chromaticity

Compared to the control, the values of lightness (L^*), greenness (a^*), and yellowness (b^*) of the SP-treated groups were significantly changed (Table 6); the lightness values of SP-treated groups decreased by approximately 15% ~ 30%, yellowness declined by approximately 13% ~ 60%, and greenness darkened approximately 9-18 fold. The yellowness of SS-1 was not significantly different from the control.

Table 5. Texture analyses of *sulgitteok* prepared with various concentrations of lyophilized sedum powder

	CO ¹⁾	SS-1	SS-2	SS-3
Hardness (g/cm ²)	576.23 $\pm$ 6.99 ^{a2)}	587.85 $\pm$ 13.11 ^a	649.84 $\pm$ 21.89 ^b	656.83 $\pm$ 28.18 ^b
Springiness ³⁾	1.028 $\pm$ 0.018	1.019 $\pm$ 0.035	1.035 $\pm$ 0.009	1.009 $\pm$ 0.039
Cohesiveness	1.004 $\pm$ 0.065	0.989 $\pm$ 0.075	1.043 $\pm$ 0.071	1.012 $\pm$ 0.134
Gumminess	422.48 $\pm$ 10.19	427.93 $\pm$ 10.11	453.11 $\pm$ 27.51	460.63 $\pm$ 32.99
Chewiness	563.35 $\pm$ 13.59	570.61 $\pm$ 13.48	604.19 $\pm$ 36.69	614.21 $\pm$ 43.99

¹⁾Groups are the same as in Table 1.

²⁾Different letters in a row denote values that were significantly different ($p < 0.05$).

³⁾ $p = 0.701$, $p = 0.899$, and $p = 0.187$ for springiness, cohesiveness, and gumminess, respectively.

Table 6. Chromaticity of *sulgitteok* prepared with various concentrations of lyophilized sedum powder

	CO ¹⁾	SS-1	SS-2	SS-3
Lightness (L^*)	88.96 ± 1.66 ^{a2)}	76.93 ± 0.59 ^b	75.76 ± 0.48 ^b	63.97 ± 1.46 ^c
Greenness ($-a^*$)	-0.32 ± 0.29 ^a	-2.78 ± 1.01 ^b	-4.78 ± 1.32 ^c	-5.65 ± 1.19 ^c
Yellowness (b^*)	16.25 ± 1.08 ^a	14.13 ± 2.43 ^a	6.65 ± 1.76 ^b	5.98 ± 1.38 ^b
Chroma (C^*)	16.26 ± 1.33 ^a	14.44 ± 1.09 ^a	8.19 ± 1.86 ^b	8.24 ± 2.36 ^b
Hue angle (h°)	91.19 ± 1.12 ^a	101.38 ± 4.98 ^b	125.39 ± 2.15 ^c	134.24 ± 4.59 ^d

¹⁾Groups are the same as in Table 1.

²⁾Different letters in a row denote values that were significantly different ($p < 0.05$).

Color saturation (C^*) and tone (h°) were calculated from the color values (Table 6). A hue angle of 90° means 'yellow', 150° means 'green', and 180° means 'greenish blue (cyan)'. Despite significant differences between the control and SS-1, the hue angle of SS-1 remained 'yellow', but SS-2 and SS-3 exhibited a 'green' color tone (20). Thus, the addition of 5% SP to *sulgitteok* could not change the color tone (h°) of the rice cake to green.

The chroma (C^*) of SS-2 and SS-3 was significantly lower than that of both the control and SS-1. Chroma describes the vividness or dullness of a color. In spite of no upper limit in chroma, the chroma scale for normal reflecting materials may extend as high as 20, and green colored specimens found in nature, in the range of approximately 8 have vivid color (21,22). Thus, SS-2 and SS-3 were vivid, green-colored *sulgitteok*.

TPCs and radical scavenging capacity

Compared to the control, the TPCs of the SP-treated groups were significantly elevated accompanied by an increase in the radical scavenging ability (Table 7). Polyphenol compounds are universally present in plants. Phenolic compounds are regarded as the major phytochemicals responsible for the antioxidant activity in plants (23). A difference in the antioxidant abilities of rice and *S. sarmentosum*, indicates that sedum has a more potent antioxidant capacity (higher TPC) than rice (11,24). Therefore, replacement of rice by SP could be an efficient way to improve the antioxidant value of rice cakes.

Sensory evaluation

The sensory characteristics of *sulgitteok* prepared with SP were evaluated by a 12-member panel (Fig. 2). The

moistness, flavor, and softness (elasticity) of the SP-treated groups were not significantly different from the control ($p=0.198$ for moistness, $p=0.978$ for flavor, and $p=0.227$ for softness). The control and SS-3 received a significantly higher sensory score than SS-1 and SS-2 in the color category because SS-3 had a vivid, green appearance. Thus, a sufficient amount of a colored subsidiary ingredient should be added to rice cakes to give color, thereby improving the sensory quality of the product. No significant difference was detected between the control and SS-2 in the taste category. SS-1 received a lower sensory score than the both control and SS-2 in taste. The SS-3 received the lowest sensory score because it presented too strong of a sedum taste (slightly bitter). Significant differences in the overall acceptability

Fig. 2. Descriptive sensory analysis of *sulgitteok* prepared with various concentrations of lyophilized sedum powder. Groups are the same as in Table 1. M: moistness ($p=0.198$), C: color ($p=0.032$), F: flavor ($p=0.978$), T: taste ($p=0.019$), S: softness and/or elasticity ($p=0.227$), O: overall acceptability ($p=0.014$).

Table 7. Total polyphenol content and radical scavenging capacity of *sulgitteok* prepared with various concentrations of lyophilized sedum powder

	CO ¹⁾	SS-1	SS-2	SS-3	BHT
TPC ³⁾	12.39 ± 2.23 ^{a2)}	46.52 ± 5.15 ^b	80.65 ± 3.48 ^c	148.89 ± 9.35 ^d	—
DPPH ⁴⁾	518.34 ± 9.54 ^a	493.39 ± 9.42 ^a	468.46 ± 6.51 ^b	418.16 ± 9.67 ^d	15.78 ± 0.19 ^e

¹⁾Groups are the same as in Table 1.

²⁾Different letters in a row denote values that were significantly different ($p < 0.05$).

³⁾Total polyphenol contents (mg/100 g *sulgitteok*, dry weight).

⁴⁾Radical scavenging capacity (IC₅₀, µg/mL).

were detected among the tested samples in the following order: SS-2>control>SS-1>SS-3. In order to investigate which sensory factors contributed to the overall acceptability, a simple linear regression analysis was performed. A strong, positive correlation was detected between taste and overall acceptability ($R^2=0.99$, $p>0.01$), and between color and overall acceptability ($R^2=0.72$, $p>0.05$). However, moistness, softness (elasticity), and flavor did not contribute to an increase of overall acceptability. Therefore, 10% SP was considered a desirable concentration in order to improve the sensory quality.

CONCLUSION

The present study was performed to increase the availability of and to improve the nutraceutical value of rice cakes by the addition of an antioxidant subsidiary ingredient, sedum. Based on the results of this study, the nutritional value and antioxidant capacity of *sulgitteok* were significantly increased in proportion to increasing SP supplementation. In addition, samples with 10% of added SP had a vivid, green appearance, and attracted the panel's interests and/or preferences in sensory evaluation. Taking into consideration the decrease in PR and ER, and the increase in hardness in the samples with 20% added SP (SS-3), the substitution of 10% rice powder with the SP in rice cakes could be an efficient method to improve the antioxidant and nutritional values as well as the sensory quality of *sulgitteok*.

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