Original article

Addition of firik improves the antioxidant and quality characteristics of steamed rice cake (*Sulgidduk*)

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Summary. Firik (or Frekeh) is a green wheat with high antioxidant activity and dietary fibers. Our aim was to analyze the antioxidant activities, quality characteristics, retarding retrogradation effect and sensory properties of *Sulgidduk* then to suggest the optimum proportion of firik in *Sulgidduk*. Five different samples were prepared with different amounts of firik powder (0%, 5%, 10%, 15%, and 20%). Firik has higher water holding capacity than rice: 401.50% and 221.74% respectively. The swelling power was varied with the temperature. Antioxidant activities of *Sulgidduk* significantly increased (p<0.05). The L-value and a-value significantly decreased, whereas b-value and ΔE increased with the increase in the amount of firik powder (p<0.05). Hardness, cohesiveness, springiness, chewiness, and gumminess decreased but not in a gradual manner (p<0.05). Retrogradation retardation revealed the strongest effect for the group treated with 5-10% firik powder that showed the lowest Avrami exponent. The group treated with 5% powder had the highest score in sensory evaluation test. These results suggest that the addition of 5% firik powder is suitable for improving the consumer acceptability and functionality of *Sulgidduk*.

Key words: antioxidant activity, firik, quality, retarding retrogradation, sensory evaluation

Introduction

Firik, cultivated in Cyprus, Middle East, Greece, Turkey, and North Africa, is known as a traditional functional food (1). After it is harvested during the immature stage, it is burned and dried in the sunlight (1). Firik which belongs to wheat family is usually produced in the Middle East and firik is a traditional cuisine in Anatolia, which is used as a substitute for rice or bulgur in pilav. (2). Firik generally comprises 77% of carbohydrates, 12.7% of proteins, and 16.5% of dietary fibers as nutritional components. Furthermore, firik has a low fat content and blood sugar index and is a rich source of vitamin A, B1, B2, C, and E, zeaxanthin, lutein, and minerals such as phosphorus, magnesium, zinc, iron, and calcium (1). Dietary fibers and fructo-oligosaccharides present in firik impart health-promoting characteristics, while the antioxidant activities of the phenolic compounds contribute to antimicrobial, anticancer, antitumor, and anti-inflammatory effects (3). These polymers decrease as the wheat ripen (4). During wheat ripening, the levels of soluble fiber decrease and those of insoluble fibers increase (3). In comparison with mature wheat, firik is rich in water-soluble cellulose that binds to high amount of water, thereby imparting water-binding ability, swelling power, viscosity, and gel formation characteristics; all these properties are favorable for the application of firik in food (3).

Prior studies about firik have investigated the physical, chemical change by maturation time of wheat, (4), and water-uptake properties as per the maturation process, processing method (3), physical characteristics (5), chemical components (1), and functional ingredients (6). As a wheat cultivar, firik is preferred over common wheat owing to the cost of production (4). However, no study has evaluated the fiber content, antioxidant activities, and various biological components of firik for its application in food industry.

Steamed rice cake (*Sulgidduk*), a traditional rice cake in Korea, is still used by many people as a meal substitute (7). Rice cake is made by mixing various materials such as rice powder, potato powder, or starch as main ingredients and fruits and vegetables as other ingredients (8). Rice cakes are classified into steamed, boiled, fried, or kneaded rice cakes according to method of cooking (8). *Sulgidduk* is the most typical steamed rice cake prepared with a simple recipe using only rice; hence, it lacks nutrients and easily undergoes retrogradation, posing difficulties in commercial applications (8). Thus, there is an unmet need to retard the process of retrogradation and improve the nutritional value using health-promoting ingredients. Prior research about retrogradation retardation in *Sulgidduk* has been conducted with the supplementation of wheat powder (9), rice bran (10), oligosaccharides (11), and apple pomace dietary powder (12).

In this study, we analyzed the antioxidant activities, quality characteristics, retrogradation retardation of *Sulgidduk* supplemented with firik.

Materials and methods

Materials

Each ingredient was prepared by pulverization of rice powder (500 g) through a 40-mesh sieve. Before pulverization, rice (Uiseong, Korea) and firik (Health and Food Co., Ltd, Seoul, Korea) were washed five times and soaked in water for 24 h then drying for 1 h at room temperature (25°C). The grains were treated with 1% salt (CJ Cheiljedang Co., Ltd) and 10% water (distilled water) and subjected to grinding using a roll mill (DK 101, Donggwang Co., Ltd, Daegu, Korea). The powder was prepared with pass through a 20-mesh sieve. Sugar (CJ Cheiljedang Co., Ltd, Incheon, Korea) and salt were purchased from a local market.

Preparation of Sulgidduk

The steaming temperature was set to 100°C and the samples were steamed in a steamer (25 ´ 25 ´ 10 cm) for 20 min then cooling at room temperature (25°C) for 10 min. Samples were prepared with different amounts of firik and designated as F0 (without firik powder), F5 (5% firik powder), F10 (10% firik powder), F15 (15% firik powder), and F20 (20% firik powder). *Sulgidduk* formula was determined based on the studies on the retardation of retrogradation by the addition of wheat powder (9) and effects of black carrot powder on *Sulgidduk* (7). The formula of the *Sulgidduk* shown in Table 1. To prepare *Sulgidduk*, each powder was mixed and sugar and water were added to the mixture.

Physical analysis of firik

Water-holding capacity and swelling power

The water-holding capacity of firik was measured by the modified method of Song et al (7). Before measuring the water-holding capacity, firik was freeze-dried for 48 h and determined by dissolving 1 g of the sample in 20 mL of distilled water at room temperature 25°C in a 45-mL test tube then vortexing for 1 h. Three replicates were prepared for each sample. Mixed materials were centrifuged for 20 min at 4,000 rpm (Universal 32R, Hettich, Tuttlingen, Germany) and the water-holding capacity was calculated using the following formula:Water-holding capacity (%) = (Precipitate (g) – Sample (g))/Sample (g)

Swelling power was measured by the method of Schoch et al (13) with some modifications. A total of 0.5 g of sample was mixed in 25 mL of water in a centrifuge tube, and the sample was heated at 60, 70, 80, and 90°C for using a water bath for 20 min. The supernatant was poured into a container that had been preheated and weighed. Swelling power was estimated

Table 1. Formulation of *Sulgidduk* with different amounts of firik powder

Ingredients	Firik powder content (%)				
	Control[1)]	F5	F10	F15	F20
Rice powder	500	475	450	425	400
Firik powder	0	25	50	75	100
Water	50	50	50	50	50
Sugar	50	50	50	50	50
Salt	5	5	5	5	5

[1)] Control: without firik powder, F5: 5% firik powder, F10: 10% firik powder, F15 :15% firik powder, F20: 20% firik powder.

using the below equation:

Swelling power (%) = Weight of sediment (g)/ weight of sample (g) ´ 100

Antioxidant activities of firik

Preparation of sample

Before sample extraction, each sample was freeze-dried for 96 h and then pulverized using a high speed grinder. A total of 1 g of powder was extracted for 3 h with 15 mL of distilled water. Centrifugation was performed for 10 min at 3,000 rpm (Universal 32R, Hettich, Tuttlingen, Germany) and the samples were filtered through the Whatman No. 1 filter paper.

Total phenol content

The total polyphenol content was analyzed using the method of Folin-Denis with slight modification, as suggested by Akay et al (14). A solution containing 0.9 M Folin-Ciocalteu reagent (Junsei Chemistry, Tokyo, Japan) and 20% (w/v) sodium carbonate solution (Merck kGaA, Darmstadt, Germany) was prepared and 10 μL of samples were vortexed with 790 μL of distilled water for 1 min. A total of 50 μL of 0.9 N Folin-Ciocalteu reagent (Junsei Chemistry, Tokyo, Japan) was added to 150 μL of 20% sodium carbonate solution (Merck kGaA, Darmstadt, Germany) and the reaction mixture was incubated for 30 min at room temperature in the dark. The absorbance of each sample was measured at 750 nm wavelength using a microplate reader (Infinite 200 PRO, Tecan, Mannedorf, Switzerland). Gallic acid (Merck kGaA, Darmstadt, Germany) was used as a standard and the absorbance of each sample was converted to gallic acid equivalent (GAE).

Flavonoid content

The flavonoid content was measured as previously described (15) with slight modifications. A total of 1 mL of sample was vortexed with 150 μL of 5% sodium nitrite (Junsei Chemistry, Tokyo, Japan) for 6 min in the dark (25°C), followed by the addition of 300 μL of 10% aluminum chloride (Junsei Chemistry, Tokyo, Japan) and incubation in the dark (25°C) for 5 min. The solution was reacted by adding 1 mL of 1 N sodium hydroxide solution (Daejung Chemicals & Metals, Gyeonggi, Korea), Each sample was measured at 520 nm. Absorbance calibration curves were prepared using quercetin (Sigma-Aldrich Co., Ltd, Mo, USA) as a standard, and the total flavonoid content of each sample was converted to quercetin equivalent (QE).

Ferric-reducing antioxidant power (FRAP)

Ferric-reducing antioxidant power was measured method by "authors names of (16)" with some modifications. The reagents used included 0.2 M phosphate buffer (pH 6.6), 1% potassium ferricyanide (Merck kGaA), 10% trichloroacetic acid (Sigma-Aldrich Co., Ltd, Mo, USA), and 0.1% ferric chloride ($FeCl_3$) (Junsei Chemistry, Tokyo, Japan). A total of 250 μL of sample and 250 μL of 0.2 M phosphate buffer and 1% potassium ferricyanide were allowed to react for 30 min at 50°C and the mixture was treated with 250 μL of 10% trichloroacetic acid. A total of 0.5 mL of this mixture was treated with 0.5 mL of distilled water and 0.1% $FeCl_3$. The absorbance of each solution was measured at 700 nm.

Quality characteristics of Sulgidduk

Moisture content

The moisture content of each sample was measured using a moisture analyzer (MB35, OHAUS, Zurich, Switzerland). A total of 5 g of sample was obtained from the central part of each sample.

pH

To determine the pH value of each sample, 10 g of sample was mixed with 90 mL of distilled water in a 250-mL beaker and homogenized (Unidrive 1000D, CAT M. Zipperer GmbH, Staufen, Germany) for 1 min. The pH of the solution was measured after 15 min.

Color

To measure the color of samples, the surface of each sample was evaluated using a colorimeter (CR-400, Konica Minolta, Osaka, Japan) according to Hunter's color value system. The parameters *L* (brightness), *a* (redness), and *b* (yellowness) were measured. The value of ΔE (total color difference) was calculated using the following equation:

ΔE=√((L_sample-L_standard)2+(a_sample-a_standard)^2+(b_sample-b_standard)2) where ΔL, Δa, and Δb are the differences in L, a, and b values between calibration white board (L: 96.62, a: −0.04, b: 1.63) and sample, respectively.

Texture analysis

After cooling for 10 min, the samples were cut at a uniform size (2 × 2 × 2 cm). Textural properties (hardness, chewiness, gumminess, springiness, and cohesiveness) of samples were measured using a rheometer (Sun rheometer Compac-100 II, Sun Scientific Co., Ltd, Tokyo, Japan). The texture profile was set with the two-bite compression test using the following operation conditions: No. 1 Φ20 mm prove; maximum weight, 2 kg; distance, 33%; table speed, 120 mm/min; 2 bites.

Retrogradation analysis from isothermal crystallization kinetics

Retrogradation rate of each sample was measured with the previously described method (17) using a rheometer (Sun rheometer Compac-100 II, Sun Scientific Co. Ltd, Tokyo, Japan). To measure the hardness, samples preserved at 20°C for 0, 3, 6, 9, 12, 24, and 48 h were analyzed by the Avrami equation as follows: $\theta = (E_L-E_t)/(E_L-E_0) = e^{-kt^n}$

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

To obtain the values of hardness and time, each sample was measured at a given time. The equation is shown below. Avrami exponent (n) was calculated using the slope of the plot represented by the equation given below. The rate constant (k) was determined by the y-intercept value. Time constant ($1/k$) is the reciprocal of the rate constant (k).

$$\log[-\ln(E_L-E_t)/(E_L-E_0)] = \log k + n \log t$$

Sensory evaluation

A panel of 50 individuals (20-30 years of age, except those with celiac disease) participated in this test and analyzed the appearance, flavor, texture, sweetness, and overall acceptability of samples using the 9-point scale method (strong dislike = 1 and strong like = 9). The panels received five samples (2 × 2 × 2 cm) on a white plate.

Statistical analysis

All data were expressed as the mean ± standard deviation of triplicate experiments. All data obtained from measurements were evaluated by one-way analysis of variance (ANOVA) using SPSS ver. 23.0 (SPSS InC., Chicago, IL, USA). Significance between the means of measured experimental values was analyzed by Duncan's multiple range test (p<0.05).

Result and discussion

Water-holding capacity and swelling power

The water-holding capacity was measured at 25°C, while the swelling were measured at 60, 70, 80, and 90°C. The results are presented in Table 2. The water-holding capacity and swelling power were affected by amylose, amylopectin structure of starch, proteins, soluble fibers, and insoluble fibers (18-20). The higher the content of long chain amylopectin molecule is, the swelling power increased. Firik had higher water-holding capacity than rice, suggesting that rice

Table 2. Water-holding capacity and swelling power of firik and rice

Properties	Temperature (°C)	Firik	Rice
Water-holding capacity (%)	25	401.50 ± 5.61	221.74 ± 4.24
Swelling power (%)	60	6.83 ± 0.58^{d}	0.68 ± 0.16^{c}
	70	7.58 ± 0.09^{c}	2.43 ± 0.43^{b}
	80	10.51 ± 0.3^{b}	2.45 ± 0.21^{b}
	90	18.73 ± 0.42^{a}[1)]	4.2 ± 0.31^{a}

[1)]Values are expressed as mean ± standard deviation

[a-d]Different superscripts indicate significant differences between values in the same row according to Duncan's range test (p<0.05)

has more compact structure and firik has more fiber content. The higher the water-binding capacity is, the longer is the moisture retention in the food; hence, the moisture content would be high for a longer time and affect retrogradation (7). In addition, firik had higher swelling power than rice that increased at higher heating temperature during gelatinization. This observation correlated with the results of water-holding capacity analysis. The swelling power increased for both firik and rice with an increase in the temperature. The better water-holding capacity of firik may be attributed to its thin and loose seed coat as compared to the compact seed coat of rice so that addition of firik makes structure of *Sulgidduk* loose than control.

Antioxidant activities

Polyphenols comprise various molecules with many phenol structure and several subgroups of phenolic compounds (21). The polyphenols are components of yellow, green, red orange and purple pigments found in plant and they interact with the lipids, proteins, and carbohydrates that decrease lipid absorption and oxidation, and then create an antioxidative environment that prevent the effects of various reactive oxygen species (22-23). Antioxidant compounds act as anticancer and antimicrobial agents and reduce the risk of cardiovascular and gastrointestinal disorders (24). Firik has many health benefit compounds such as dietary fibers, fructose-rich polymers and fructo-oligosaccharides and phenolics, which may act as antioxidants (6). The total phenolic content of firik varied according to the maturation degrees and stages (16). During the process of ripening, the content of total phenolics as well as the antioxidant activity were low (6). Total phenolic and flavonoid contents of samples are shown in Table 3 and these values slightly increased with the increase in the amount of firik. The results of FRAP analysis were in line with those of total phenol and flavonoid content analyses. Although the difference was small, the control group showed the lowest value of 0.08 mg/mL, while the F20 group showed the highest value of 0.12 mg/mL for FRAP. A similar result was also confirmed in rice cake containing Asparagus powder (24) or Moringa oleifera leaf extract (8). Rice and firik had a polyphenol content of 2.80 and 11.53 μg GAE/mg, respectively, and a flavonoid content of 87.45 and 105.38 g QE/mg, respectively. The value of FRAP was 0.11 mg/mL for rice and 0.21 mg/mL for firik. This discrepancy is likely due to differences in the antioxidant compound content of each grain.

Moisture content and pH values

The moisture content and pH values of *Sulgidduk* are shown in Table 4. F20 group showed the lowest value (38.20%), while the control and F5 groups had the highest values (41.36%); however, no significant difference was observed between different groups except F20 group. Similar results were also observed with rice cake treated with Aronia powder (25) and cabbage powder (26). The moisture content affects the texture and retrogradation of food (7). Lower moisture content correlated with higher hardness values and quick retrogradation (7). The pH value of the sample increased with an increase in the amount of firik powder. The pH of samples ranged from 4.38 to 5.48, but no significant difference was observed. The pH affects the texture alkaline pH may result in larger pores and lower hardness

Table 3. Antioxidant activities of *Sulgidduk* with different amounts of firik powder

Samples	Firik powder content (%)					F-value (p value)
	Control[2)]	F5	F10	F15	F20	
Total phenolic content (g GAE/mg)	1.32 ± 0.10[b,1)]	1.32 ± 0.10[b]	1.71 ± 0.46[a,b]	1.99 ± 0.39[a,b]	2.41 ± 0.72[a]	3.531[*] (0.048)
Flavonoid content (g QE/mg)	0.25 ± 0.11[b]	0.32 ± 0.19[b]	0.92 ± 0.22[a]	1.10 ± 0.25[a]	1.28 ± 0.23[a]	15.313[***] (0.000)
Ferric-reducing antioxidant power assay (mg/mL)	0.08 ± 0.01[d]	0.09 ± 0.01[c]	0.10 ± 0.00[b]	0.11 ± 0.00[b]	0.12 ± 0.00[a]	21.059[***] (0.000)

[1)] *Values are expressed as mean ± standard deviation*

[a-d] *Different superscripts indicate significant differences between values in the same row according to Duncan's range test (p<0.05)*

[*] *p < 0.05,* [***] *p < 0.001*

[2)] *Control: without firik powder, F5: 5% firik powder, F10: 10% firik powder, F15 :15% firik powder, F20: 20% firik powder.*

Table 4. Moisture content and pH values of *Sulgidduk* with different amounts of firik powder

Properties	Firik powder content (%)					F-value (*p* value)
	Control[2)]	F5	F10	F15	F20	
Moisture (%)	41.36 ± 0.10[a1)]	41.36 ± 0.11[a]	40.52 ± 0.19[b]	40.34 ± 0.13[b]	38.20 ± 0.02[c]	339.709[***] (0.000)
pH	4.38 ± 0.12[c]	5.18 ± 0.04[b]	5.37 ± 0.12[a]	5.43 ± 0.07[a]	5.48 ± 0.01[a]	91.590[***] (0.000)

[1)] *Values are expressed as mean ± standard deviation*
[2)] *Control: without firik powder, F5: 5% firik powder, F10: 10% firik powder, F15 :15% firik powder, F20: 20% firik powder.*
[a-c] *Different superscripts indicate significant differences between values in the same row according to Duncan's range test ($p<0.05$)*
[***] *$p < 0.001$*

values (7). On the other hand, acidic pH may result in smaller pores and compact texture, causing an increase in hardness (7). We observed that firik (pH 7.48) had higher pH than rice (pH 5.36) and considered that the pH of firik contribute to pH of *Sulgidduk.*

Color properties

The *L*-values (brightness) slightly decreased with the amount of firik powder increased (Table 5 and Fig. 1) ($p<0.05$). The color values were as follows: Rice (*L*: 96.37, *a*: −1.18, *b*: 4.67) and firik (*L*: 76.60, *a*: 3.73, *b*: 20.63). The control group had a value of 81.82, while the F20 group had a value of 79.39 ($p<0.05$). The *a*-values (redness) for the control was −1.39; the addition of firik resulted in a decrease in the *a*-values. The *b*-values (yellowness) increased for firik-treated samples (from 4.79 to 14.47) as compared with the control sample (4.79). ΔE- value was significantly affected by firik; the control group showed the lowest value of 0.07, while F20 group had the highest value of 10.04 ($p<0.05$). These results are in accordance with those reported in *Chlorella* powder (27) added or *Asparagus* powder added *Sulgidduk* (24). In these studies in which powder containing chlorophyll or carotenoid was added, similar results were observed, showing that *L* and *a* values decreased and *b* value increased as the content of powder increased. The difference in the ingredients and the content of chlorophyll and carotenoid may affect the results.

Table 5. Color values of *Sulgidduk* with different amounts of firik powder

Color value	Freekeh powder content (%)					F-value (*p*-value)
	Control[2)]	F5	F10	F15	F20	
L^*	81.82±0.10[a1)]	81.23±0.52[b]	80.47±0.37[c]	79.57±0.36[d]	79.39±0.41[d]	45.997[***] (0.000)
a^*	-1.39±0.11[a]	-2.29±0.11[b]	-2.35±0.13[bc]	-2.44±0.27[cd]	-2.49±0.52[d]	253.194[***] (0.000)
b^*	4.79±0.15[d]	11.02±0.23[c]	13.83±0.77[b]	14.31±0.77[ab]	14.47±0.13[a]	629.047[***] (0.000)
ΔE	0.07±0.59[d]	6.32±0.03[c]	9.20±0.72[b]	9.84±0.04[a]	10.04±0.19[a]	718.964[***] (0.000)

[1)] *Values are expressed as mean ± standard deviation*
[2)] *Control: without firik powder, F5: 5% firik powder, F10: 10% firik powder, F15 :15% firik powder, F20: 20% firik powder.*
[a-d] *Different superscripts indicate significant differences between values in the same row according to Duncan's range test ($p<0.05$)*
[***] *$p < 0.001$*

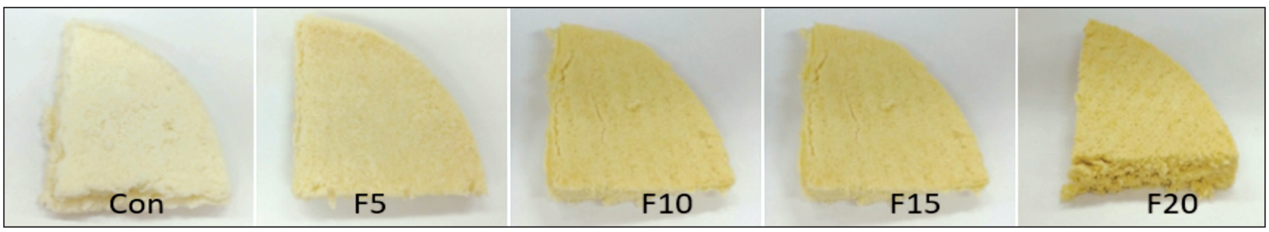

Figure1. Photographs of *Sulgidduk* containing different amounts of firik powder.

Textural properties

Hardness, cohesiveness, springiness, chewiness, and gumminess were compared between samples (Table 6). The control group showed the highest value of hardness (3.43 N), while the values reported for the samples containing firik powder were lower than the value of the control group. However, F5 group showed the lowest value (2.16 N) among the firik-treated samples, while the highest value was reported for F20 group (3.07 N). Cohesiveness is related to the degree of stickiness of rice cake and is a characteristic attributed to the restoring force against binding force or deformation required to maintain the shape or form of food (28). Cohesiveness decreased with an increase in the amount of firik (p<0.05). Thus higher the amount of firik is, it makes easily brittle the product. Springiness is a property that helps the product gain its original shape upon removal of force (28). Springiness value was the lowest for F15 and F20 (7.43 and 7.60 mm, respectively) groups. Gumminess is a collective texture that is related to hardness and cohesiveness. F5 (1.68 N) group had the lowest value for gumminess, as observed with the hardness results. Chewiness value which is the energy required to chew was lower for samples supplemented with firik than the control samples, and F5, F10, F15, and F20 groups had lower values (30). The texture of rice cake depends on the quantity and size of starch, ratio of amylose to amylopectin, gelatinization or retrogradation degree of starch, and fiber content of sub-ingredients (31). Firik has 16.5% dietary fiber that imparts good prebiotic effects and other health-promoting benefits (32-33). The report published by USDA (2017) revealed that rice and firik had a fiber content of 2.4 and 15.6 g/100 g, respectively. It is suggested that the hardness and chewiness decreased with the presence of these dietary fibers, which may interfere with the binding of amylose or amylopectin and water absorption capacity (29). This result was similar to the sesame leaf powder (30) containing high dietary fiber. It was reported that addition of sesame powder reduces the hardness and chewiness of rice cake. The opposite results were observed with the addition of pumpkin leaf powder, wherein hardness, springiness, and chewiness increased as the amount of pumpkin leaf powder increased (31). These results reported that addition of sub-ingredients which have lower moisture content than the main ingredient give more hard texture to the rice cake by competing with the main ingredient. Then the main ingredient loses their moisture to sub ingredient (31). The major factors affecting the texture were addition of the firik powder to *Sulgidduk* widens the intermolecular gap thereby resulting in the decrease in the hardness.

Evaluation of retrogradation by Avrami equation

Starch undergoes gelatinization upon cooking or processing and starch retrogradation during cooling or storage affects the texture, digestibility, shelf-life, and consumer preference of starch-containing food (32).

Table 6. Textural properties of *Sulgidduk* with different amounts of firik powder

Properties	Freekeh powder content (%)					F-value
	Control[2)]	F5	F10	F15	F20	(p-value)
Hardness (N)	3.43±0.35[a1)]	2.16±0.31[c]	2.44±0.06[c]	2.85±0.08[b]	3.07±0.12[ab]	15.722[***] (0.000)
Cohesiveness (%)	0.80±0.31[a]	0.78±0.02[a]	0.71±0.02[b]	0.66±0.03[bc]	0.61±0.02[c]	21.193[***] (0.000)
Springness (mm)	8.69±0.33[a]	8.81±0.34[a]	8.59±0.05[a]	7.43±0.46[b]	7.60±0.44[b]	10.345[***] (0.001)
Chewiness (N*mm)	23.64±1.09[a]	14.76±1.95[b]	14.87±0.69[b]	14.03±1.12[b]	14.27±0.97[b]	33.093[***] (0.000)
Gumminess (N)	2.72±0.10[a]	1.68±0.24[b]	1.73±0.08[b]	1.89±0.07[b]	1.88±0.05[b]	33.383[***] (0.000)

[1)] *Values are expressed as mean ± standard deviation*

[2)] *Control: without firik powder, F5: 5% firik powder, F10: 10% firik powder, F15 :15% firik powder, F20: 20% firik powder.*

[a-c] *Different superscripts indicate significant differences between values in the same row according to Duncan's range test (p<0.05)*

[***] *p < 0.001*

Upon crystallization, starchy food exhibits an increase in rigidity and firmness and the polymer and solvent phases undergo separation, a process called as syneresis that produces undesirable effects on starch-based products (19). To retard the process of retrogradation of starch, food company usually control the temperature, moisture content, pH, and starch type and add saccharides that inhibit the decrease in the moisture content or emulsifying agents that reduce the stiffening speed. The retardation in the retrogradation of *Sulgidduk* supplemented with firik was analyzed using the Avrami equation at 20°C for 0, 3, 6, 9, 12, 24, 36, and 48 h. The values of Avrami exponent (*n*) represent the crystallization state of *Sulgidduk* and were 0.98, 0.73, 0.93, 0.98, and 0.96 for the control, F5, F10, F15, and F20 groups, respectively. Lower Avrami exponent (*n*) and rate constant values and higher time constant value corresponded to stronger retrogradation retardation effects (34). Thus, F5, F10, and F20 had stronger retrogradation retardation effects than the control group, with F5 group showing the strongest effects as shown in Table 7. Retardation of retrogradation was dependent on the amount of additives. A previous study (7) showed similar results, wherein the retardation of retrogradation was different based on the ratio of additives added to the rice cake. The value was 0.17 for the control group and 0.06, 3.80, and 2.73 for 0.5%, 3%, and 4% groups. These results show that 5% firik had better retardation of retrogradation effects than the other groups. Time constant (1/k) was used as the reciprocal of rate constant (k) and indicated the rate of retrogradation; the value was 19.67 (lowest value) for the control group and 28.69, 42.13 (the highest value), 27.20, and 23.95 for F5, F10, F15, and F20 groups, respectively. Thus, the addition of 5% or 10% of firik powder maximized the retardation of retrogradation in *Sulgidduk*. We used Avrami equation to analyze retrogradation retardation and observed results similar with those reported by previous studies using wheat (11) and chia seed (29), wherein low values of Avrami exponent and rate constant and high values of time constant were observed for the groups supplemented with wheat or chia seed. Kim & Chung (11) found that the addition of 10% and 20% wheat may retard retrogradation. We found that the addition of 5% and 10% firik may retard retrogradation to a level similar to that observed with the addition of less than 5% wheat.

Sensory evaluation

The results of the sensory evaluation test of *Sulgidduk* containing firik powder were shown in Table 8. The control group had the highest score (7.34) for appearance, while F5 group showed the highest score for flavor, texture, sweetness, and overall acceptability. No significant difference was observed in the flavor among different samples. F5 (6.00) and F10 (6.62) groups had higher values than the control (6.10) group (p<0.05), while F15 (5.78) and F20 (5.58) groups had lower values than the control group. The scores of overall acceptability were higher for F5 (7.14) and F10 (6.58) groups than for the control group (6.42). F15 (5.60) and F20 (5.50) groups had lower scores than the control group but had same scores for flavor, texture, sweetness, and overall acceptability.

Table 7. Avrami exponent (n), rate constant (k), and time constant (T) of *Sulgidduk* with different amounts of firik powder

Avrami equation analysis	Freekeh powder content (%)				
	Control[3)]	F5	F10	F15	F20
Avrami exponent(n)[1)]	0.9838	0.7264	0.9324	0.9763	0.9577
Rate constant (k)[2)]	5.01×10^{-2}	3.49×10^{-2}	2.37×10^{-2}	3.68×10^{-2}	4.17×10^{-2}
Time constant (h) (1/k)	19.67	28.69	42.13	27.20	23.95

[1)] *Values obtained from the slope of plot*
[2)] *Values obtained from the slope of plot ln(E_L-E_t) vs time*
[3)] *Control: without firik powder, F5: 5% firik powder, F10: 10% firik powder, F15 :15% firik powder, F20: 20% firik powder.*

Table 8. Sensory preference scores for *Sulgidduk* with different amounts of firik powder

Sensory preference	Freekeh powder content (%)					F-value (p-value)
	Control[2)]	F5	F10	F15	F20	
Appearance	7.34±1.32[a1)]	6.64±1.26[b]	5.98±1.17[c]	5.58±1.20[d]	5.10±1.40[d]	24.028[***] (0.000)
Flavor	6.00±1.23[b]	6.62±1.18[a]	6.10±1.36[a]	5.78±1.40[b]	5.58±1.47[b]	4.350[***] (0.002)
Texture (Chewiness)	5.92±1.69[c]	7.22±1.13[a]	6.54±1.55[b]	5.6±1.43[cd]	5.30±1.25[d]	14.593[***] (0.000)
Sweetness	6.12±1.42[b]	6.82±1.26[a]	6.52±1.61[ab]	5.40±1.32[d]	5.60±1.50[cd]	8.804[***] (0.000)
Overall preference	6.42±1.46[b]	7.14±1.26[a]	6.58±1.39[b]	5.60±1.32[c]	5.50±1.30[c]	13.182[***] (0.000)

[1)] *Values are expressed as mean ± SD of triplicate observations*
[a-d]*Different superscripts indicate significant differences between values in the same row according to Duncan's range test (p<0.05)*
[***]*p < 0.001*
[2)] *Control: without firik powder, F5: 5% firik powder, F10: 10% firik powder, F15 :15% firik powder, F20: 20% firik powder.*

Conclusion

The purpose of this study was to apply firik to the Korean traditional food, *Sulgidduk*, and examine the antioxidant activities, quality characteristics, retarding retrogradation effect and sensory evaluation. The water holding capacity of each grain was higher for firik at 401.50% and rice showed lower value at 221.74%. The swelling power was varied with the temperature. The results of antioxidant activity showed a significant increase with addition of firik and the color values of *Sulgidduk* (*L* and *a*) decreased with the addition of firik but the *b* value increased as the amount of added firik increased. The hardness and gumminess decreased but not gradually whereas the cohesiveness, springiness and chewiness decreased with the increasing level of firik. F5 received the highest score in the results of Avrami and sensory evaluation. Collectively, these results suggest that the most optimal level of firik to improve the quality characteristics and retard the retrogradation effect was found to be 5% for the production of *Sulgidduk*. This study will allow the value of Sulgidduk increased for improving the quality properties and consumer preference.

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