

# Effect of black carrot (*Daucus carota* L.) flour on quality properties and retarding retrogradation by shelf-life of *Sulgidduck* (rice cake)

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**Summary.** Black carrot (*Daucus carota* L.) contains anthocyanins, which are natural pigments that confer a bright red color. It has gained attention as a functional food that reduces the risk of diseases such as diabetes and heart disease and also demonstrates antioxidant activity. The goal of the present study was to identify the optimal proportion of black carrot flour for use in *Sulgidduck* (rice cake) in order to achieve high quality and retard retrogradation or tendency to become stale. *Sulgidduck* was prepared by replacing 0%, 0.5%, 1%, 2%, 3%, and 4% of the rice flour with black carrot flour; these preparations were designated as the control (without BC flour), BC0.5, BC1, BC2, BC3, and BC4.

**Key words:** anthocyanins, black carrot, quality properties, retarding retrogradation, shelf-life, *Sulgidduck* (rice cake)

## Introduction

Black carrot (*Daucus carota* L.) is cultivated in Turkey, Egypt, Afghanistan, Pakistan, and India (1). Particularly, in Turkey, black carrot (BC) is used to make 'Kanji' and 'Shalgam', which are traditional fermented drinks, BC juice, or concentrate (1). Recently, consumer interest in food safety and healthy functional foods containing natural pigments has increased (2). BC has attracted attention for its high anthocyanin content (1750 mg/kg) (3). Anthocyanins are natural pigments with a bright red color that reduce the risk of heart disease, atherosclerosis, diabetes, and neurological degenerative disease (4). Anthocyanins in BC are more resistant to pH changes in food than anthocyanins from other plants (4). Studies have evaluated the effects of temperature, solid content, and pH on the stability of BC anthocyanins (4), including the effects of processing on the antioxidant composition and color (5), and the effects of BC concentrate on a traditional Turkish dry-fermented sausage (6).

*Dduck* (rice cake) is a traditional Korean food for a long period time, particularly after advancements in the field of agriculture (7). Rice cake is manufactured using rice, glutinous rice, or grains soaked in water, then steamed or boiled or fried (7). According to the method of manufacture, *Dduck* has been classified into steamed, fried, and boiled *Dduck* (7). Among these, *Sulgidduck* (rice cake) is the most basic form, a loaf of steamed rice flour in one layer (7). *Sulgidduck* recipe is very simple and can be used as a substitute for breakfast or snack. It is possible to maintain the quality of these cakes for weeks if they are kept frozen (8).

Recently, *Sulgidduck* has been developed by adding a number of different health functional foods. Prior studies on *Sulgidduck* examined the quality characteristics of *Sulgidduck* when *Corni fructus* powder is added (7), and supplemented with *Citrus* peel powder (9), the effect of adding minor ingredients (10), and the quality characteristics of *Curcuma longa* L powder *Sulgidduck* (11).

In this study, BC *Sulgidduck* containing a high concentration of anthocyanins was analyzed to determine its quality properties and retardation of retrogradation by shelf-life.

## Materials and Methods

### Materials

The ingredients were used in the formula of *Sulgidduck* (rice cake) included BC (Gujwa, Jeju, Korea) which was freeze-dried and ground to fine flour that was passed through 40 mesh sieve. 500 g of rice (Icheon, Korea) was washed with water three times and soaked in water for 12 h, and then the water was removed for 20 min using a sieve. Next, 1% salt and 10% water were added to the rice and then it was powdered using a roll-mill (Dongwon System Co., Ltd., Seongnam, Korea) twice and passed through 20 mesh sieve. Sugar and salt (CJ Cheiljedang Co., Ltd., Incheon, Korea) were purchased from local market.

### Preparation of *Sulgidduck*

Preparation of *Sulgidduck* was described by Lee YN et al., and Kim YS (12, 13). First, 1% salt, 10% sugar, and 10% water were added to the rice flour according to the progress. BC flour (0%, 0.5%, 1%, 2%, 3%, and 4%) were added and the *Sulgidduck* samples were designated as the control (without BC flour), BC0.5 (0.5% BC flour), BC1 (1% BC flour), BC2 (2% BC flour), BC3 (3% BC flour), and BC4 (4% BC flour). Mixed materials were placed in a steamer (25 x 25 x 10 cm) and steamed for 20 min and then left without heat for 10 min. The *Sulgidduck* was analyzed after cooling for 30 min at room temperature. The formula of *Sulgidduck* is presented in Table 1.

### Moisture content and water holding capacity

The moisture content of the *Sulgidduck* was measured using a Moisture analyzer (MB35, OHAUS, Zurich, Switzerland). Water holding capacity was determined using the equation shown below. A total of 20 mL of distilled water was added to 1 g of sample, mixed, and centrifuged for 10 min at 3000 rpm (Universal 32R, Hettich, Tuttlingen, Germany). The experiments were carried out in triplicate.

**Table 1.** Formulas for *Sulgidduck* prepared with different amounts of black carrot flour

Samples	Ingredients (g)				
	Rice flour	Black carrot flour	Water	Sugar	Salt
Control	500	0	50	50	5
BC0.5	497.5	2.5	50	50	5
BC1	495	5	50	50	5
BC2	490	10	50	50	5
BC3	485	15	50	50	5
BC4	480	20	50	50	5

*Control:* Without added black carrot flour. *BC0.5:* Addition of 0.5 g of black carrot flour/100 g of rice flour. *BC1:* Addition of 1 g of black carrot flour/100 g of rice flour. *BC2:* Addition of 2 g of black carrot flour/100 g of rice flour. *BC3:* Addition of 3 g of black carrot flour/100 g of rice flour. *BC4:* Addition of 4 g of black carrot flour/100 g of rice flour.

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

### Determination of pH

For pH determination, 10 g *Sulgidduck* was mixed with 90 mL distilled water and shaken in a homogenizer (Ingenieurburo CATM. Zipperer, Staufen, Germany) for 1 min. The experiments were carried out in triplicate and a pH meter was used (SP-701, Suntext, New Taipei City, Taiwan).

### Color determination

The color of *Sulgidduck* was measured using a color measurement spectrophotometer (CR-400, Minolta, Tokyo, Japan) set for Hunter's value. The *L* (lightness), *a* (redness), and *b* (yellowness) colors obtained from the midsection of the sample and  $\Delta E$  (total color difference) were calculated using the following equation. The average results of the *L*, *a*, *b*, and  $\Delta E$  values were calculated from triplicate measurements.

$$\Delta E = (L_{\text{sample}} - L_{\text{standard}})^2 + (a_{\text{sample}} - a_{\text{standard}})^2 + (b_{\text{sample}} - b_{\text{standard}})^2$$

### Texture profile analysis

After cooling for 1 h, the texture profile of *Sulgidduck* (30 x 30 x 20 mm) was measured using a Rheometer (Compac-100II, Sun Scientific Co., Ltd., Tokyo,

Japan). The texture profile was determined with the two-bite compression test using a cylindrical probe (No. 1, D: 20 mm). The texture parameters included were hardness, springiness, cohesiveness, and chewiness. The texture parameters of each *Sulgidduck* were averaged in triplicate.

#### *Determination of retrogradation rate*

Retrogradation rate of BC *Sulgidduck* by shelf-life was measured as described by Rojas JA et al., (14) using Rheometer (Compac-100II, Sun Scientific Co., Ltd., Tokyo, Japan). The Avrami exponent ( $n$ ) and time constant ( $1/k$ ) were determined using the Avrami equation.

$$e^{-kt^n} = \frac{E_t - E_0}{E_1 - E_0}, \quad \log[-\ln \frac{E_t - E_0}{E_1 - E_0}] = \log k + n \log t$$

$E_t$ : the maximum hardness,  $E_t$ : hardness after  $t$  h,  $E_0$ : the initial hardness,  $k$ : time constant ( $\text{time}^{-1}$ ),  $n$ : Avrami exponent

#### *Determination of total phenol content*

Total phenol in the *Sulgidduck* was determined using the Folin-Ciocalteu method (15). First, 0.9 N Folin-Ciocalteu reagent (96703-8130, Junsei Chemical Co., Ltd, Tokyo, Japan) was added to a 0.8 mL diluted sample containing 0.15 mL sodium carbonate solution (1.93211.0500, Merk, Darmstadt, Germany). After incubation for 2 h at room temperature, the total phenol in *Sulgidduck* was measured using an Infinite 200 PRO multimode reader (804003459, Tecan, Mannheim, Switzerland) at 750 nm.

#### *DPPH free-radical scavenging activity*

DPPH free-radical scavenging activity was determined as described by Qwele K et al., (16) with some modifications. For this purpose, 0.0078 g 1,1-diphenyl-2-picrylhydrazyl (DPPH) (Sigma Aldrich, Darmstadt, Germany) was reacted in 10 mL ethanol (Merk, Darmstadt, Germany). Next, 0.1 mL sample and the mixture of DPPH and ethanol were incubated for 30 min in the dark at room temperature. The absorbance of the samples was measured using an Infinite 200 PRO multimode reader (804003459, Tecan, Mannheim, Switzerland) at 520 nm. Ethanol was used as a

control. The inhibition percentage ( $\text{IC}_{50}$ ) was calculated using the following equation.

$$\text{DPPH inhibition (\%)} = [1 - (\frac{\text{O.D of sample}}{\text{O.D of control}})] \times 100$$

#### *Sensory evaluation*

For this study, a panel of 30 individuals participated in the 7-point test to determine the degree of overall acceptability for *Sulgidduck* (1 = extremely dislike, 4 = neither like nor dislike, 7 = extremely like). Subjects received six samples (10 x 10 x 10 mm) on white plates (20 cm diameter) at room temperature and were asked to rate the degree to which they liked the *Sulgidduck*. The panels evaluated the samples for color, flavor, moistness, sweetness, chewiness, and overall acceptability.

#### *Statistical analysis*

All data are shown as the means of triplicate experiments and their standard deviations. Data analysis was carried out using one-way ANOVA. Duncan's multiple range test was also used to identify significant differences between the means at the  $P < 0.05$  significance level using SPSS 12.0 (SPSS Inc, Chicago, Quarry Bay, Hongkong) statistical software.

## **Results and Discussion**

#### *Moisture content and water holding capacity*

The moisture content of BC *Sulgidduck* is shown in Table 2. The control and BC0.5 showed the lowest values, 27.27% and 27.25%, respectively. As BC flour content increased, the moisture content also significantly increased ( $P < 0.05$ ), with BC4 showing the highest values of 36.42%. These results are consistent with those of Korean steamed rice cake containing different amounts of red onion (17), Hasuo (*Polygoni Multiflori Radix*) (18), and astringent persimmon powder (19). However, studies on *Sulgidduck* with sweet potato (20), acai berry (21), and corni fructus (7) powder revealed conflicting results. Water holding capacity generally increased from the control (109.74%) to BC1 (149.95%), but it decreased in BC2 and BC3 to 115.33% and 118.47%, respectively. BC4 showed the highest water holding capacity at 237.11%.

### pH properties

As shown in Table 2, the pH of BC *Sulgidduck* generally significantly decreased with the increasing amounts of BC flour that was used ( $P < 0.05$ ). BC4 showed the lowest pH value, 5.91. This result is similar to that of *Sulgidduck* made with black chokeberry (22), for which the control, 1%, 3%, 5%, and 7% samples had pH values of 6.04, 5.64, 4.57, 4.12, and 3.98, respectively. *Sulgidduck* made with acai berry (21) and, saltwort (8) also showed the highest pH values in the control and pH decreased as the amount of added ingredient increased.

### Color properties

For color properties, *L*-value (lightness) appeared to significantly decrease with increasing BC flour (Table 3); the control was 74.32 and BC4 was 30.44 ( $P < 0.05$ ). *a*-value (redness) for the control was -1.12 and the samples with added BC were 6.61–10.32. *b*-value (yellowness) was decreased in BC samples (from -4.39 to -1.39) compared to the control (4.75).  $\Delta E$  (total color difference) was significantly affected by the content of

BC flour; the control showed the lowest value of 22.75, while BC4 was the highest at 66.92 ( $P < 0.05$ ). These results agree with those for purple onion *Sulgidduck* (17) and cornus *Sulgidduck* (7). And acai berry *Sulgidduck* (21) and purple sweet potato *Sulgidduck* (20) showed that *L* and *b*-value were decreased and *a*-value was increased with increasing BC content. These results were considered that affect of colorant of anthocyanins.

### Textural properties

The textural properties of BC *Sulgidduck* were the lowest in control (474.53 g/cm<sup>2</sup>), while BC3 was the highest (831.77 g/cm<sup>2</sup>) in hardness (Fig. 2). This is similar to the results of Hwang SJ (17) showed that the control had the lowest value of 425.14 kg and increased in which they showed hardness was increased as BC levels increase. The results of Lee MH et al., Nam SJ & Park GS, and Choi YS (11, 18, 21) were consistent with our results. When the additive is used as a powder, moisture content was removed and the solid content such as dietary fiber was increased. In contrast, for the addition

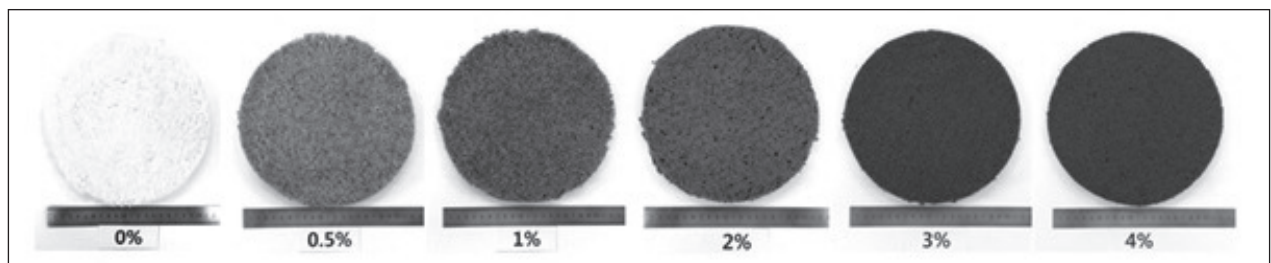
**Table 2.** Moisture content, water holding capacity, and pH of *Sulgidduck* made with different amounts of black carrot flour

Samples	Moisture content (%)	Water holding capacity (%)	pH
Control	27.27 ± 0.751 <sup>c</sup>	109.74 ± 27.65 <sup>b</sup>	6.37 ± 0.02 <sup>a</sup>
BC0.5	27.25 ± 0.22 <sup>c</sup>	138.31 ± 1.03 <sup>b</sup>	6.29 ± 0.02 <sup>b</sup>
BC1	29.38 ± 1.52 <sup>bc</sup>	149.95 ± 23.42 <sup>b</sup>	6.27 ± 0.03 <sup>b</sup>
BC2	29.43 ± 0.46 <sup>bc</sup>	115.33 ± 30.35 <sup>b</sup>	6.19 ± 0.02 <sup>c</sup>
BC3	30.40 ± 0.97 <sup>b</sup>	118.47 ± 3.70 <sup>b</sup>	6.15 ± 0.03 <sup>c</sup>
BC4	36.42 ± 2.91 <sup>a</sup>	237.11 ± 46.23 <sup>a</sup>	5.91 ± 0.04 <sup>d</sup>

<sup>1)</sup> Values are mean ± SD of 3 replicates.

<sup>a-d</sup> Different superscripts within the same column are significantly different by Duncan's multiple range test ( $P < 0.05$ ).

Control: Without added black carrot flour. BC0.5: Addition of 0.5 g of black carrot flour/100 g of rice flour. BC1: Addition of 1 g of black carrot flour/100 g of rice flour. BC2: Addition of 2 g of black carrot flour/100 g of rice flour. BC3: Addition of 3 g of black carrot flour/100 g of rice flour. BC4: Addition of 4 g of black carrot flour/100 g of rice flour.



**Figure 1.** Photographs of *Sulgidduck* containing different amounts of black carrot flour.

**Table 3.** Color values of *Sulgidduck* made with different amounts of black carrot flour

Samples	Hunter's color value			
	L	a	b	E
Control	74.32 ± 1.02 <sup>1a</sup>	-1.12 ± 0.05 <sup>c</sup>	4.75 ± 0.10 <sup>a</sup>	22.75 ± 1.25 <sup>c</sup>
BC0.5	50.12 ± 1.57 <sup>b</sup>	8.42 ± 0.24 <sup>c</sup>	-4.39 ± 0.12 <sup>d</sup>	47.84 ± 1.62 <sup>d</sup>
BC1	40.92 ± 1.27 <sup>c</sup>	10.32 ± 0.16 <sup>a</sup>	-4.48 ± 0.06 <sup>d</sup>	57.18 ± 1.45 <sup>c</sup>
BC2	40.33 ± 1.00 <sup>c</sup>	9.25 ± 0.29 <sup>b</sup>	-2.98 ± 0.29 <sup>c</sup>	57.43 ± 1.13 <sup>c</sup>
BC3	32.50 ± 0.62 <sup>d</sup>	6.61 ± 0.35 <sup>d</sup>	-1.37 ± 0.16 <sup>b</sup>	64.74 ± 0.53 <sup>b</sup>
BC4	30.44 ± 0.53 <sup>c</sup>	7.89 ± 0.58 <sup>c</sup>	-1.39 ± 0.14 <sup>b</sup>	66.92 ± 0.25

<sup>a1)</sup> Values are Mean ± SD of 3 replicates.

<sup>a-c</sup> Different superscripts within the same column are significantly different as determined by Duncan's multiple range test ( $P < 0.05$ ).

Control: Without added black carrot flour. BC0.5: Addition of 0.5 g of black carrot flour/100 g of rice flour. BC1: Addition of 1 g of black carrot flour/100 g of rice flour. BC2: Addition of 2 g of black carrot flour/100 g of rice flour. BC3: Addition of 3 g of black carrot flour/100 g of rice flour. BC4: Addition of 4 g of black carrot flour/100 g of rice flour.

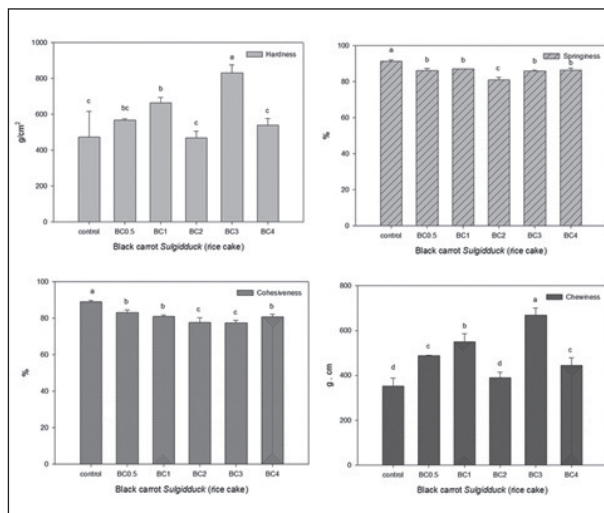
of purple sweet potato (20) and chestnut (23), hardness decreased with increasing additives. Samples containing BC flour showed significantly lower values than the control for springiness and cohesiveness ( $P < 0.05$ ). This was similar to the results of Hwang SJ and Nam SJ & Park GS (17, 18) for springiness and cohesiveness. Chewiness increased from 389.65 to 668.20 g·cm compared to the control (352.76 g·cm).

#### Retarding retrogradation by shelf-life using Avrami equation

The retarding of retrogradation of BC *Sulgidduck* was analyzed using the Avrami equation at 20°C af-

ter 0, 24, 36, and 48 h to determine hardness (Table 4). The values of the Avrami exponent ( $n$ ) represent the crystallization state of *Sulgidduck* and were 0.17, 0.06, 0.11, and 0.45 for the control, BC0.5, BC1, and BC2, respectively. BC3 and BC4 showed values of 3.80 and 2.73, respectively. Thus, BC0.5 and BC1 had the strongest effects on retrogradation compared to the control; if more than 2% BC flour was used, there was no retrogradation on inhibitory effect. Studies of rice cake on retrogradation of (24) showed that the Avrami exponent ( $n$ ) in the control was 1.71, it was 2.55 in 3% trehalose added sample, and it was 1.50 in 9% trehalose added sample. The effect of retarding retrogradation was dependent on the additive level. Chung HC showed similar results; the control value was 1.15, 30% sourdough was 1.20, and 50% sourdough was 1.04 (25).

A time constant ( $1/k$ ) was used as the reciprocal of the rate constant ( $k$ ), and the effect of retrogradation was based on a high value of the time constant ( $1/k$ ) compared to the control (24). The time constant ( $1/k$ ) indicates the rate of retrogradation and was 125.00 in the control and 333.33 in BC0.5 (the highest value); BC4 showed the lowest value of 4.95. This indicates that the level of additives has an important effect on retarding retrogradation. Kim SS & Chung HY showed that retarding retrogradation depends on the amounts of trehalose and modified starch added; the time constant ( $1/k$ ) of the control was 82.64 and sam-



**Figure 2.** Photographs of *Sulgidduck* containing different amounts of black carrot flour.



ples with added trehalose and modified starch ranged from 104.17 to 400.00 (24). Chung HC showed that as the level of sourdough increased, a reduced retrogradation of rate increased (25). Therefore, BC0.5 (333.33) showed the highest time constant ( $1/k$ ) compared to the control (125.00) and the greatest inhibitory effect for retarding retrogradation. The addition of 0.5%–1% BC flour is recommended to maximize the retrogradation of inhibitory effect.

#### Total phenol content

Total phenol content of BC *Sulgidduck* significantly increased with the level of black carrot flour ( $P<0.05$ ) (Table 5); the control was 0.04 g GAE/mg and BC4 was 0.25 g GAE/mg. BC and purple sweet potato have anthocyanin, but also contain phenolic compounds (26). With increasing amounts of BC flour, total phenolic content increased. Similar studies showed that the amount of total phenolic compounds in sausages increased as purple sweet potato powder increases (27). BC sausage showed the lowest phenolic compound levels in the control of 785.00 mg GAE/kg; the sample containing 5% black carrot concentrate contained 1201.48 mg GAE/kg (6).

#### DPPH free-radical scavenging activity

DPPH radical scavenging activity was represented as the  $IC_{50}$  value, which is the concentration that

removes 50% of the free radicals (Table 5).  $IC_{50}$  of BC *Sulgidduck* significantly decreased, with values of 1001.81 g/mL (control), 362.44 g/mL (BC0.5), 276.76 g/mL (BC1), 113.53 g/mL (BC2), 64.05 g/mL (BC3), and 35.76 g/mL (BC4) ( $P<0.05$ ). Thus, as the content of BC flour increases, DPPH radical scavenging activity increases. These results are consistent with those of Ekici L et al., who showed that the DPPH radical scavenging activity of BC concentrate increased from 42.26% to 56.21% according to the level of addition (0.5%–2.0%) (6). This is also similar to the results of Lee N et al., as the pigment and powder of purple sweet potato increased (0%–4%), radical scavenging activity increased from 17.41% to 62.00% (27).

#### Sensory properties

For sensory properties using the 7-point test, the control showed the highest scores (5.55) for color and BC0.5 and BC4 had high scores for flavor (4.75) (Table 6). Moistness was low in the control (4.20) and BC0.5 (4.25), but BC1, BC2, BC3, and BC4 did not significantly differ ( $P<0.05$ ). For sweetness, BC4 showed the highest scores as 5.20. Chewiness was not significantly different except for the control (4.35) ( $P<0.05$ ). Overall acceptability showed the highest score in BC4 at 5.05. This is similar to *Sulgidduck* to which vitamin leaves were added, with high scores compared to control in flavor, taste, and texture (28).

**Table 4.** Avrami exponent ( $n$ ), rate constant ( $k$ ), and time constant ( $1/k$ ) of *Sulgidduck* with different amounts of black carrot flour

Samples	Avrami equation analysis		
	Avrami exponent ( $n$ ) <sup>1)</sup>	Rate constant ( $k$ ) <sup>2)</sup>	Time constant (h) ( $1/k$ )
Control	0.17 <sup>3)</sup>	$0.80 \times 10^{-2}$	125.00
BC0.5	0.06	$0.30 \times 10^{-2}$	333.33
BC1	0.11	$0.80 \times 10^{-2}$	125.00
BC2	0.45	$4.00 \times 10^{-2}$	25.00
BC3	3.80	$19.8 \times 10^{-2}$	5.05
BC4	2.73	$20.2 \times 10^{-2}$	4.95

<sup>1)</sup>Values obtained from slope of plot  $\log\{-\ln(E_t-E_\infty)/(E_0-E_\infty)\}$  vs  $\log t$ .

<sup>2)</sup>Values obtained from slope of plot  $\ln(E_t-E_\infty)$  vs time.

<sup>3)</sup>Values are mean  $\pm$  SD of triplicate experiments.

Control: Without added black carrot flour. BC0.5: Addition of 0.5 g of black carrot flour/100 g of rice flour. BC1: Addition of 1 g of black carrot flour/100 g of rice flour. BC2: Addition of 2 g of black carrot flour/100 g of rice flour. BC3: Addition of 3 g of black carrot flour/100 g of rice flour. BC4: Addition of 4 g of black carrot flour/100 g of rice flour.

**Table 5.** Antioxidant activity of *Sulgidduck* made with different amounts of black carrot flour

Samples	Total phenolic content (g GAE /mg)	DPPH IC <sub>50</sub> (g/mL)
Control	0.04 ± 0.01 <sup>1)f</sup>	1001.81 ± 234.70 <sup>a</sup>
BC0.5	0.05 ± 0.01 <sup>c</sup>	362.44 ± 19.95 <sup>b</sup>
BC1	0.09 ± 0.01 <sup>d</sup>	276.76 ± 29.57 <sup>bc</sup>
BC2	0.15 ± 0.01 <sup>c</sup>	113.53 ± 18.78 <sup>cd</sup>
BC3	0.21 ± 0.01 <sup>b</sup>	64.09 ± 14.10 <sup>d</sup>
BC4	0.25 ± 0.00 <sup>a</sup>	35.76 ± 12.40 <sup>d1)</sup>

Values are Mean ± SD of triplicate experiments.

<sup>a-f</sup>Different superscripts within the same column are significantly different by Duncan's multiple range test ( $P < 0.05$ ).

Control: Without added black carrot flour. BC0.5: Addition of 0.5 g of black carrot flour/100 g of rice flour. BC1: Addition of 1 g of black carrot flour/100 g of rice flour. BC2: Addition of 2 g of black carrot flour/100 g of rice flour. BC3: Addition of 3 g of black carrot flour/100 g of rice flour. BC4: Addition of 4 g of black carrot flour/100 g of rice flour.

## Conclusion

In this study, we evaluated the quality properties and ability to retard retrogradation with *Sulgidduck* (rice cake), a traditional Korean steamed rice cake, with added BC flour (0%, 0.5%, 1%, 2%, 3%, and 4%). The moisture content and water holding capacity of BC *Sulgidduck* increased according as BC increased. pH significantly

decreased as BC increased ( $P < 0.05$ ). The  $L$ -value was significantly decreased as BC increased ( $P < 0.05$ ), while the  $a$ -value increased increasing BC addition; the  $b$ -value was low in the samples containing BC flour compared to the control. BC *Sulgidduck* showed increased hardness with increasing BC content. The retarding retrogradation analysis using the Avrami equation for 0, 24, 36, and 48 h showed that BC0.5 and BC1 had effects compared to the control. BC0.5 and BC1 showed low values for the Avrami exponent ( $n$ ) and high values for the time constant ( $1/k$ ). Thus, 0.5%–1% of BC flour retards the retrogradation of *Sulgidduck* compared to the control. For total phenol content and DPPH radical scavenging activities, BC *Sulgidduck* showed a significantly higher antioxidant capacity with increasing BC ( $P < 0.05$ ). In sensory evaluation, BC4 showed high scores for flavor, moistness, sweetness, and chewiness, but not for color.

Based on our results, black carrot is a good source for the production of *Sulgidduck* and improves the quality properties and retards retrogradation effects. A level of 4% BC flour is considered the most optimal for improving quality properties and antioxidant activities and 0.5%–1% BC flour is more suitable for retarding retrogradation.

## Acknowledgement

This research was supported by Korea University Grant (K1711241), and grateful acknowledgements

**Table 6.** Sensory properties of *Sulgidduck* made with different amounts of black carrot flour

Samples	Sensory characteristics					
	Color	Flavor	Moistness	Sweetness	Chewiness	Overall acceptability
Control	5.55 ± 1.10 <sup>1)a</sup>	4.40 ± 1.14 <sup>a</sup>	4.20 ± 1.06 <sup>b</sup>	4.50 ± 1.36 <sup>ab</sup>	4.35 ± 0.99 <sup>b</sup>	4.45 ± 1.19 <sup>a</sup>
BC0.5	4.50 ± 1.40 <sup>b</sup>	4.75 ± 0.97 <sup>a</sup>	4.25 ± 1.16 <sup>b</sup>	5.00 ± 0.97 <sup>ab</sup>	4.90 ± 1.12 <sup>ab</sup>	4.90 ± 1.25 <sup>a</sup>
BC1	4.70 ± 1.26 <sup>ab</sup>	4.70 ± 1.42 <sup>a</sup>	5.10 ± 1.07 <sup>a</sup>	4.30 ± 1.42 <sup>b</sup>	5.20 ± 1.24 <sup>a</sup>	4.60 ± 1.43 <sup>a</sup>
BC2	5.05 ± 1.15 <sup>ab</sup>	4.65 ± 1.42 <sup>a</sup>	5.00 ± 1.26 <sup>ab</sup>	4.90 ± 1.02 <sup>ab</sup>	4.85 ± 1.31 <sup>ab</sup>	5.00 ± 1.52 <sup>a</sup>
BC3	4.45 ± 1.61 <sup>b</sup>	4.60 ± 1.10 <sup>a</sup>	4.50 ± 1.36 <sup>ab</sup>	4.80 ± 1.47 <sup>ab</sup>	4.55 ± 1.23 <sup>ab</sup>	4.50 ± 1.40 <sup>a</sup>
BC4	4.55 ± 1.61 <sup>b</sup>	4.75 ± 1.33 <sup>a</sup>	4.85 ± 1.18 <sup>ab</sup>	5.20 ± 1.06 <sup>a</sup>	4.80 ± 1.11 <sup>ab</sup>	5.05 ± 1.39 <sup>a1)</sup>

Values are Mean ± SD of triplicate experiments.

<sup>a-b</sup>Different superscripts within the same column are significantly different by Duncan's multiple range test ( $P < 0.05$ ).

Control: Without added black carrot flour. BC0.5: Addition of 0.5 g of black carrot flour/100 g of rice flour. BC1: Addition of 1 g of black carrot flour/100 g of rice flour. BC2: Addition of 2 g of black carrot flour/100 g of rice flour. BC3: Addition of 3 g of black carrot flour/100 g of rice flour. BC4: Addition of 4 g of black carrot flour/100 g of rice flour.

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