



Research Article

# Characteristics of dried apple *bugak* (Korean traditional dried food) using superfine powders as coating materials

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**Abstract** Dried apple *bugak*, a traditional Korean dried food, was made using superfine powders of glutinous rice (GR), non-glutinous rice (NGR), and *Wasabia koreana* Nakai leaf (WKNL) as coating materials. This study aimed to determine the effect of coating sliced apples with superfine GR powders substitute with superfine NGR and WKNL powders at different ratios. Apple slices coated with superfine GR, NGR and WKNL powders were air-fried and compared with dried and air-fried apple *bugak* coated with superfine GR powders. The results showed that coating apple slices with superfine GR powders with the addition of superfine NGR and WKNL powders significantly increased oil absorption capacity and antioxidant activity but reduced viscosity, water absorption capacity, total polyphenol, total flavonoids contents, and improved color and structural improvements. Among all the samples, 80:20:5-treated (GR:NGR:WKNL) dried and air-fried *bugak* showed enhanced quality characteristics. Thus, the results suggested that coating apple slices by the substituting GR superfine rice powders with 10 or 20% of NGR and 3 or 5% of WKNL superfine powders produces good quality dried and air-fried *bugak* with nutritious characteristics.

**Keywords** apple, superfine glutinous rice powder, non-glutinous rice powder and *Wasabia koreana* Nakai leaf powder, *bugak*, physical and chemical properties



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## 1. Introduction

Among Korean traditional foods, the *bugak* can be classified as dried or fried ones (KFRI, 2020). Dried *bugak* is made by coating raw food with glutinous rice powder and is not as popular as fried *bugak*, but the raw chip market has been expanding. These chips contain various nutritional ingredients depending on the type of raw material (i.e., the food ingredient) used. Fruits and vegetables are healthy food materials that can be used as raw food and in future foods. Apples play a significant role in fundamental research concerning the production of

upcycled foods (Zhang et al., 2019). Apples that are difficult to distribute due to poor taste and low grade need to be used for pressed juice and manufacturing products in the form of dried chips, a convenient food. Among apples, *Hongro* is harvest earlier than *Fuji* and is used less as a processed product than as raw fruit. The peels of *Hongro* apples are rich in phenolic antioxidants and non-starch polysaccharides, including pectin, which are cell wall components (Choi and Chung, 2019). Apple chips deteriorate in quality during storage, therefore, it is necessary to resolve this by preventing moisture absorption rate and loss of nutrients and improving sensory quality characteristics during storage.

Among milling technologies, superfine grinding to produce micrometer and nanometer powders has attracted attention (Xiao et al., 2022). Unlike conventional grinding, superfine grinding has a particle size of 19.08  $\mu\text{m}$ , which affects pasting and thermal properties. As particles become smaller, the gelatinization temperature and various viscosity values, including peak viscosity, decrease (Zhang et al., 2021). Thus, during steam treatment of the coating powder, it can be gelatinized in a short time. Superfine grinding can improve functional features such as water-holding capacity and oil-holding capacity (Zhao et al., 2018; Zhang, 2020). Superfine ground powder of water dropwort (*Oenanthe javanica*) is an excellent ingredient for drinks and as particle size decreases, soluble polysaccharide content and total dissolution increases significantly. Also, the smaller the particles, the higher the water-holding capacity and the lower the oil-binding capacity (He et al., 2019). Superfine grinding is also thought to increase dispersion properties of cell wall components to reduce sedimentation when making drinks and increase stability to prevent

layer separation (Kang, 2020). Thus, this method can be applied to the manufacture of batters using residues and coating material after extraction.

This study used superfine ground powders such as non-glutinous rice (NGR) and *Wasabia koreana* Nakai leaf (WKNL) powder and coating materials prepared by modifying the *bugak* manufacturing method of the traditional food. They were prepared by varying the the relative proportion of food-coating materials. In particular, the traditional method of using 100% glutinous rice (GR) powder is replaced with up to 20% NGR powder, and the quality characteristics of dried and air-fried apple *bugak* prepared by using WKNL powder with 3% and 5% of the total rice powder were investigated.

## 2. Materials and methods

### 2.1. Food ingredients and reagents

*Hongro* apples were purchased from orchards (Imgye, Gangwon-do, Korea) in August. The superfine powder was used for experiments after finally grinding of GR, NGR, and WKNL using a superfine pulverizer (Fluid bed jet mill, Korea Powder System Co., Ltd., Incheon, Korea). For chemical composition analysis, Folin-Ciocalteu agent, sodium carbonate, diethylene glycol, 2,2'-diphenyl-1-picryl-hydrazyl (DPPH), and gallic acid were purchased from Sigma Aldrich (St. Louis, MO, USA).

### 2.2. Sample preparation

#### 2.2.1. Superfine rice flour and WKNL powder preparation

GR, NGR, and WKNL were first ground to a coarse texture using a cutter mill, to a fine powder using a blade mill and an air-classified mill (ACM-185, Korea Powder System Co., Ltd., Incheon, Korea), and superfine powder using an air jet mill (Fluid bed jet mill, Korean Powder System Co., Ltd.,

Incheon, Korea). The average median diameter ( $D_{50}$ ) of the prepared superfine powder was 10.01, 10.68, and 7.14  $\mu\text{m}$  in GR, NGR, and WKNL powder, respectively.

### 2.2.2. Bugak preparation and its powders

Apples were cut into 2 mm pieces, blanched at 100°C for 2 min, immersed in cool water, coated with superfine powder, heat treated with hot water-steam above 100°C for 10 min, and dried at 55°C for 15 h to produce dried apple *bugak*. Air fried *bugak* was manufactured by heat-treating the dried *bugak* at 160°C for 2 min with an air fryer (MEA-T10LW, Guangdong Tredy Electrical Co., Ltd., Guangzhou, China). The ratios of the coating powder used to manufacture the *bugak* were 100%, 90% and 80% of superfine GR powder, 0%, 10% and 20% of superfine NGR powder, 0%, 3%, and 5% of superfine WKNL powder (i.e., the treatments were 100:0:0 (control), 100:0:3, 100:0:5, 90:10:0, 90:10:3, 90:10:5, 80:20:0, 80:20:3, and 80:20:5% GR:NGR:WKNL). The prepared *bugak* (Fig. 1) was ground to a powder (FM-909, Hanil electric., Bucheon, Korea) and passed through a 40 mesh size. This (hereafter referred to as *bugak*

powder or samples) was used for all analyses.

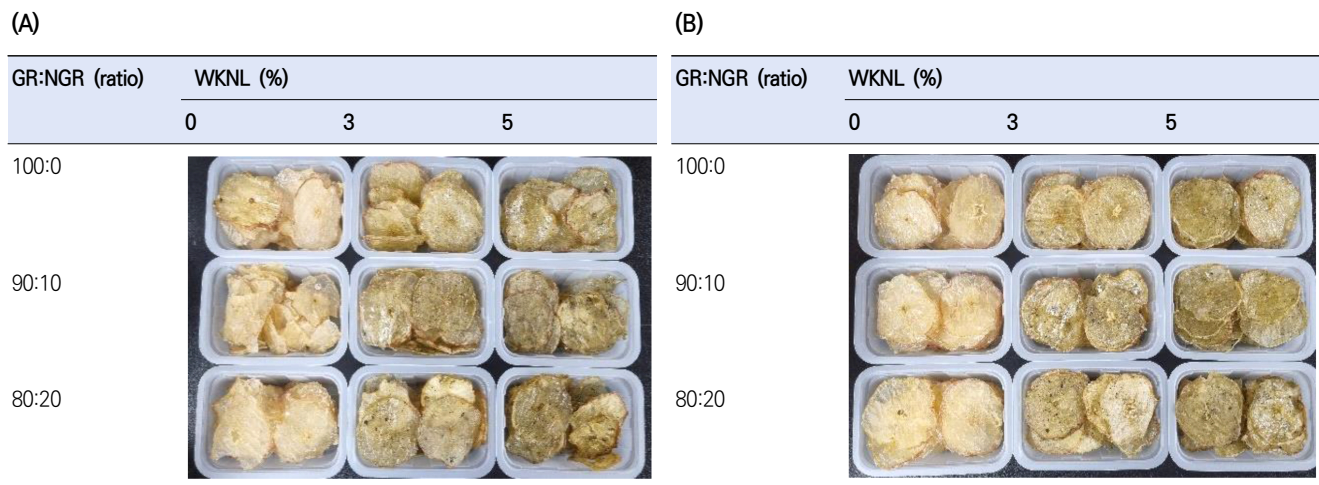
## 2.3. Bugak characterization

### 2.3.1. Measurement of color value of *bugak*

A color difference meter (CM-5, Konika Minolta Inc., Tokyo, Japan) was used to measure Hunter L (lightness), a (red/greenness) and b (yellowness). Each sample was measured ten times to obtain an average value. The L, a, and b values of the standard white plate used at the time were 92.97, -0.67, and 3.31, respectively.

### 2.3.2. Microstructure observation of *bugak*

Scanning electron microscope (SWM; SM-IT500LA, JEOL Ltd., Tokyo, Japan) was used to examine the surface morphology of the apple *bugak* with a few modifications to the method described by Aradwad et al. (2022). Prior to the images analysis, samples of both *bugak* were placed on the surface of a two adhesive tapes and attached to aluminum stubs using double-coated carbon taps prior to images analysis (SCD005, Leica Microsystem GmbH A-170, Vienna, Austria). The samples were observed under high vacuum with a magnification of 500 $\times$  and



**Fig. 1.** Exterior appearance of dried (A) and air-fried *bugak* (B). A and B are dried and air-fried apple *bugak* coated with superfine rice powders in the different ratio, 100%, 90%, 80% of glutinous rice (GR) and 0%, 10%, 20% of non-glutinous rice (NGR) with different concentrations of *Wasabia koreana* Nakai leaf powder (WKNL) 0%, 3% and 5%.

accelerated voltage of 15 kV and 20 kV under high vacuum mode.

## 2.4. Characterization of *bugak* powder

### 2.4.1. Determination of water absorption and oil absorption capacity

Water absorption capacity (WAC) and oil absorption capacity (OAC) were analysed using the modified approach of Wang et al. (2022). The water absorption capacity was determined by mixing 1.0 g of *bugak* powder with 25 mL of distilled water in a centrifuge tube, waiting for 30 min for the mixture to be completely mixed, and centrifuged at 2,500 rpm for 10 min. After centrifugation, the supernatant was removed, and WAC was calculated using the following equation:

$$\text{WAC (OAC) \%} = \frac{[(\text{Weight of sediment} - \text{Weight of sample}) / \text{Weight of sample}] \times 100$$

The oil absorption capacity was determined in the same way by using soybean oil (CJ, Corp., Incheon, Korea) instead of distilled water.

### 2.4.2. Determination of total polyphenols and flavonoids

A hot water extract was prepared by adding 1 g of *bugak* powder to 100 mL of distilled water at 95°C in water bath (C-WBE-B, Changshin Science, Seoul, Korea) for 1 h. The extract mixture was cooled, filtered (Whatman No. 2), and used for further analysis. The total polyphenol content in the extract was analysed by adding 0.25 mL of the Folin-Ciocalteu reagent and 2 mL of distilled water to 0.25 mL of the sample, waiting for 3 min, and then adding 0.25 mL of 20% Na<sub>2</sub>CO<sub>3</sub>. The solution was left to react at 37°C for 30 min in a water bath, after which absorbance was determined at 750 nm using

a spectrophotometer (Cary 8454 UV-Vis, Agilent Technologies Inc., Santa Clara, CA, USA). Gallic acid was used as the standard and polyphenol concentration was estimated using the calibration curve. The total flavonoid content (TFC) was determined by adding 10 mL of diethylene glycol and 1 mL of 1 N NaOH to 1 mL of the hot water extract and allowing it to react at 37°C for 1 h in a water bath, and after which absorbance was measured at 420 nm using a spectrophotometer. Naringin was used as a standard for flavonoid calculation.

### 2.4.3. Determination of antioxidant activity

The antioxidant activity of hot water *bugak* powder extract was tested based on its 1,1-diphenyl-2-picryl-hydrazyl (DPPH) and 2,2'-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid (ABTS) radical scavenging activity. Blois' (1958) method was used, in which 0.8 mL of 0.2 mM 1,1-diphenyl-2-picryl-hydrazyl (DPPH) was added to 0.2 mL of the extract, mixed thoroughly, and left to stand at room temperature for 10 min. A spectrophotometer (Cary 8454 UV-Vis, Agilent Technologies Inc., Santa Clara, CA, USA) was used to detect absorbance at 525 nm. The ABTS radical scavenging activity was determined using Kim and Lee's (2016) technique. 7.4 mM ABTS diammonium salt and 2.6 mM K<sub>2</sub>S<sub>2</sub>O<sub>8</sub> were mixed and kept in the dark for 24 h to produce radicals. The absorbance of a solution of ABTS diluted with phosphate-buffered saline (pH 7.4) was determined at 732 nm using a spectrophotometer before 2 mL of this solution was added to 0.2 mL of the extract in a test tube and allowed to react in the dark for 10 min. Then absorbance was measured again. ABTS radical scavenging activity was determined as the difference in absorbance before (0.7±0.03) and after sample addition by calculating the percentage (%).

#### 2.4.4. Measurement of rheological characteristics

The rheological properties of apple *bugak* coated were investigated using the method adopted by Showkat et al. (2022) with certain sample preparation adjustments. Briefly, 1 g of *bugak* powder was mixed with 20 mL of distilled water, stirred and left at room temperature for 1 h before heating in a water bath (C-WBE-B, Changshin, Seoul, Korea) at 50°C. Then samples refrigerated overnight prior to further analysis. A rheometer (AR 2000 ETC, TA Instruments Inc., New Castle, DE, USA) was used to assess the rheological properties of the samples. To do this, 4 mL of sample paste was placed on the lower plate of the rheometer measuring system with a 40 mm diameter/2° angle cone plate for 1 min and 0.5 mm gap set at a constant temperature of 25°C. The flow behavior was studied at a constant shear rate from 0.1 to 100 S<sup>-1</sup> and the dynamic oscillatory frequency sweep (0.1-100 rad/s) test at 1% strain. The influence of shear rate on shear stress and apparent viscosity of the sample was expressed as shear stress - shear rate and apparent viscosity - shear rate flow curves.

#### 2.5. Statistical analysis

All data were interpreted in triplicate and are reported as the mean ± standard deviation (SD). The rheological data were analyzed using GraphPad Prism Software (9.5.0, San Diego, CA, USA) and IBM SPSS Statistics (26.0, IBM Corp., Armonk, NY, USA) was used for statistical analysis of the data, and one-way analysis of variance and Duncan's test ( $p < 0.05$ ) were used to determine whether there were significant differences between the treatments.

## 3. Results and discussion

### 3.1. Color

Color is an important quality factor for the

consumer acceptability of food products. In fact, color and appearance are the initial quality indicators for consumers (Murid et al., 2022). The color parameters of the apple *bugak* were presented in a Table 1. Lightness and yellowness of the dried and air-fried *bugak* decreased with an increase in the proportion of superfine NGR and WKNL powder. However, the air-fried apple *bugak* 80:20:0-treated (% GR:NGR:WKNL) apple *bugak* was lighter ( $65.81 \pm 3.51$ ) than the dried one from the same treatment. In fact, the dried samples were closer in lightness to the air-fried control (100:0:0) samples. In general, the air-frying process had a stronger yellowing and lightening effect than the drying process across all treatments. The air-fried 80:20:5-treated *bugak* was the most yellow ( $18.07 \pm 1.53$ ) of all samples. The hot-air drying had a significant effect on apple slices ( $p < 0.05$ ) in Hunter L (lightness), which was greatly enhanced following the drying operation, although the differences between the drying temperatures were not significant. In addition, the Hunter b (yellowness) value increased considerably after drying (Beigi, 2015). The Hunter a value (redness/greenness) varied from  $-0.18 \pm 5.92$  to  $-2.27 \pm 0.38$ , the higher the proportion of NGR and WKNL powder the more green the samples (or more negative the a values were). Green product colors are preferred. Kian-Pour et al. (2022) revealed that a coating-blanching pre-treatment with starch solutions considerably improved the drying properties, color and texture of celery root chips. Similarly, drying or heat-treating dried red apples resulted in a decrease in Hunter L and an increase in Hunter a and b values (Kidoń and Grabowska, 2021). Our findings demonstrate that coating sliced apples with superfine GR, NGR and WKNL powder at various ratios may considerably improve the color and texture of dried and air-fried apple *bugak*.

**Table 1.** Color difference values of powders from apple *bugak* coated with superfine rice and *Wasabia koreana* Nakai leaf powder

<i>Bugak</i>	GR <sup>1</sup> :NGR ratio (%)	<i>Wasabia koreana</i> leaf powder (%)	L <sup>3</sup>	a	b
Dried	100:0	0	65.09±5.40 <sup>fg2)</sup>	-0.90±0.37 <sup>ab</sup>	15.27±1.86 <sup>bcd</sup>
		3	58.04±5.88 <sup>gh</sup>	-0.18±5.92 <sup>b</sup>	12.52±4.31 <sup>a</sup>
		5	48.04±8.17 <sup>d</sup>	-1.62±0.72 <sup>ab</sup>	14.43±1.71 <sup>abcd</sup>
	90:10	0	63.15±4.10 <sup>a</sup>	-1.19±0.33 <sup>ab</sup>	14.05±3.09 <sup>abcd</sup>
		3	49.27±5.41 <sup>f</sup>	-1.37±1.12 <sup>ab</sup>	13.79±1.42 <sup>abcd</sup>
		5	47.29±14.13 <sup>fg</sup>	-2.27±0.38 <sup>a</sup>	14.22±2.27 <sup>abcd</sup>
	80:20	0	59.13±3.54 <sup>b</sup>	-1.16±0.42 <sup>ab</sup>	13.22±2.73 <sup>ab</sup>
		3	50.43±4.64 <sup>e</sup>	-1.81±0.45 <sup>a</sup>	13.31±1.95 <sup>abc</sup>
		5	45.09±8.09 <sup>e</sup>	-1.83±0.50 <sup>a</sup>	13.77±1.96 <sup>abcd</sup>
Air-fried	100:0	0	61.67±5.71 <sup>bc</sup>	-0.98±0.19 <sup>ab</sup>	13.85±2.69 <sup>abcd</sup>
		3	58.42±5.24 <sup>a</sup>	-1.73±0.70 <sup>ab</sup>	15.90±1.69 <sup>d</sup>
		5	51.53±6.47 <sup>a</sup>	-1.91±0.62 <sup>a</sup>	15.76±1.24 <sup>d</sup>
	90:10	0	63.45±3.85 <sup>bc</sup>	-1.31±0.50 <sup>ab</sup>	13.64±1.53 <sup>abcd</sup>
		3	58.83±4.64 <sup>a</sup>	-2.20±0.22 <sup>a</sup>	14.83±2.19 <sup>abcd</sup>
		5	51.07±7.25 <sup>a</sup>	-2.11±0.44 <sup>a</sup>	15.70±1.87 <sup>d</sup>
	80:20	0	65.81±3.51 <sup>c</sup>	-1.46±0.29 <sup>ab</sup>	15.09±1.78 <sup>bcd</sup>
		3	56.02±5.53 <sup>fg</sup>	-2.07±0.43 <sup>a</sup>	15.62±2.05 <sup>cd</sup>
		5	55.24±8.10 <sup>fg</sup>	-1.95±0.48 <sup>a</sup>	18.07±1.53 <sup>e</sup>

<sup>1</sup>)GR, glutinous rice; NGR, non-glutinous rice.

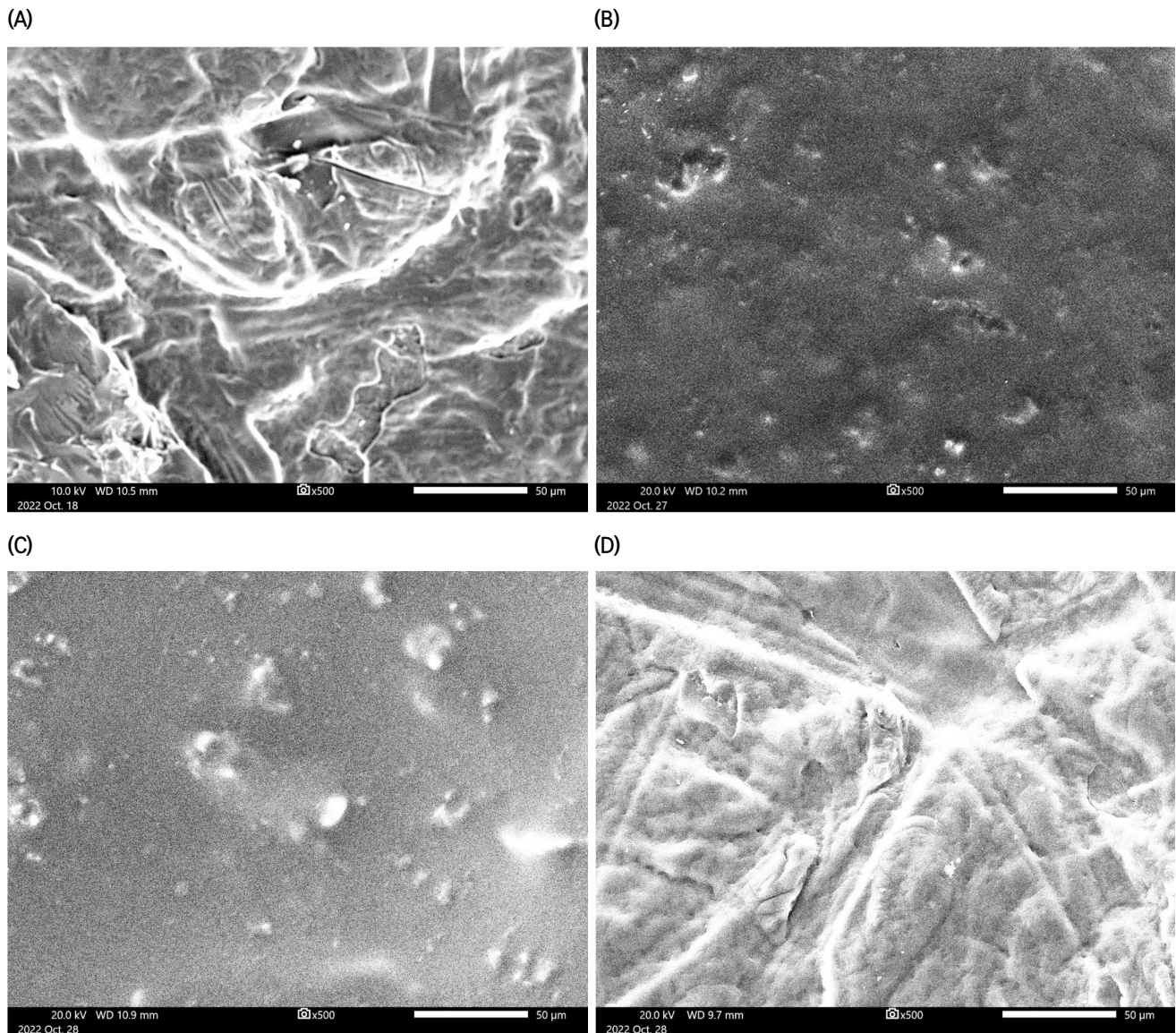
<sup>2</sup>)Different superscripts in a column indicate significant difference at p<0.05 by Duncan’s multiple range test. Values are means±SD (n=3).

<sup>3</sup>)L, lightness; a, redness/greenness; b, yellowness.

### 3.2. Scanning electron microscopy (SEM)

Fig. 2. shows SEM images. The microstructure of dried 100:0:0-treated (A) and 80:20:5-treated (B) apple *bugak* revealed a honeycomb-like structure, indicating that the superfine rice powder coating might protect the cellular structure of the apple. However (80:20:5) treatment produced less of a honeycomb structure with fewer pores than the control treatment. A previous study indicated that the porosity and microstructure could be affected by different drying methods, and in dried apple slices, it is related to changes in external pressure, water migration, microstructure and shrinkages as a result of pressure, moisture loss and heating (Zhu

et al., 2022). Fig. 2(C), (D) show SEM images of the air-fried samples of 100:0:0-treated (C) and 80:20:5-treated (D) apple *bugak*. Unlike the microstructure of the dried apple *bugak* small cracks appeared in the cellular structure without destruction of the surface layer structure of the control sample. However, the 80:20:5-treated sample had a honeycomb structure with a protective surface layer, which may be a result of the coating with the combination of GR, NGR, and WKNL superfine powder. In addition, SEM revealed a finer structure in the air-fried apple *bugak* than in the dried apple *bugak*. Thus, the gelatinization and structural alterations in starches and proteins of air-fried *bugak* samples were more



**Fig. 2.** Microstructure of dried (A and B) and air-fried (C and D) apple *bugak* at a magnification of 500x. (A and C) microstructure of 100:0:0 formula superfine rice powder (glutinous and non-glutinous), *Wasabia koreana* Nakai leaf powder and (B and D) showed 80:20:5 formulation.

extensive than those in dried apple *bugak* samples. The same result was obtained for chips of cassava/ rice under baking and frying (Ahza et al., 2015).

### 3.3. Water and oil absorption capacities

The ability of a food to retain water when an external force is applied is referred to as WHC. This study assessed the water absorption capacity of the

apple *bugak*, which is representative of its water-holding capacity. The hydration properties of the dried and air-fried apple *bugak* are presented in Table 2. Both the dried and air-fried samples had significantly lower WAC than the control samples ( $p < 0.05$ ). Among the air-fried samples, the control had the highest WAC ( $758.67 \pm 45.36\%$ ), whereas the 80:20:5 samples had the lowest ( $578.67 \pm 15.37\%$ ).

**Table 2.** The water absorption ratio and oil absorption ratio of powders from apple *bugak* coated with superfine rice and *Wasabia koreana* Nakai leaf powder

<i>Bugak</i>	GR <sup>1</sup> :NGR ratio (%)	<i>Wasabia koreana</i> leaf powder (%)	Water absorption ratio (%)	Oil absorption ratio (%)
Dried	100:0	0	758.67±45.36 <sup>i2)</sup>	146.00±7.00 <sup>ef</sup>
		3	690.33±13.01 <sup>gh</sup>	151.67±12.10 <sup>ef</sup>
		5	714.00±24.33 <sup>h</sup>	138.33±4.04 <sup>bcd</sup>
	90:10	0	720.00±8.89 <sup>h</sup>	126.67±11.72 <sup>abcd</sup>
		3	643.00±14.00 <sup>def</sup>	143.33±12.06 <sup>cdef</sup>
		5	668.00±9.85 <sup>efg</sup>	137.33±10.01 <sup>abcde</sup>
	80:20	0	651.33±4.73 <sup>def</sup>	144.00±11.27 <sup>cdef</sup>
		3	625.67±13.01 <sup>bcd</sup>	145.00±4.00 <sup>def</sup>
		5	595.67±9.29 <sup>ab</sup>	138.67±12.10 <sup>bcd</sup>
Air-fried	100:0	0	770.67±0.58 <sup>i</sup>	160.33±9.29 <sup>f</sup>
		3	673.33±32.01 <sup>fg</sup>	138.33±17.10 <sup>bcd</sup>
		5	695.00±1.00 <sup>gh</sup>	125.33±12.58 <sup>abc</sup>
	90:10	0	712.67±9.07 <sup>h</sup>	123.67±4.04 <sup>ab</sup>
		3	633.00±16.52 <sup>cde</sup>	118.67±2.31 <sup>a</sup>
		5	677.33±2.52 <sup>fg</sup>	133.00±10.15 <sup>abcde</sup>
	80:20	0	633.33±37.69 <sup>cde</sup>	125.33±13.32 <sup>abc</sup>
		3	600.67±8.62 <sup>abc</sup>	144.67±3.51 <sup>def</sup>
		5	578.67±15.37 <sup>a</sup>	119.67±2.89 <sup>ab</sup>

<sup>1</sup>)GR, glutinous rice; NGR, non-glutinous rice.

<sup>2</sup>)Different superscripts in a column indicate significant difference at p<0.05 by Duncan's multiple range test. Values are means±SD (n=3).

Therefore, the WAC decreased as the proportion of NGR superfine powder increased in the coating. On the other hand, as indicated in Table 2, oil absorption increased with increasing proportions of superfine NGR powder in the coating, and the samples showed significant differences (p<0.05) in both dried and air-fried apple *bugak*. In the air-fried apple *bugak*, oil absorption capacity was highest in the control samples (160.33±9.29%) and lowest in the 90:10:3-treated samples (118.67±2.31%). The oil absorption capacity might also be affected by the air-frying process; the air-fried samples differed significantly from the dried in this regard. We know of no other studies similar to this

one. However, Jung et al. (2013) found that *bugak* made with fermented glutinous rice batter and unroasted sesame oil has a higher oil absorption capacity than that made with wheat flour batter and soybean oil.

### 3.4. Total polyphenol and total flavonoid contents

The TPC and TFC of dried and air-fried *bugak* samples were significantly enhanced by the addition of WKNL and NGR superfine powders. As shown in Table 3, the addition of superfine WKNL leaf powder (3, 5%) increased the TPC and TFC of the dried *bugak* samples, However, among the air-fried *bugak*, TPC and TFC decreased in the 100:0:5-



**Table 3.** Contents of total polyphenol and total flavonoid of powders from apple *bugak* coated with superfine rice and *Wasabia koreana* Nakai leaf powder

<i>Bugak</i>	GR <sup>1</sup> :NGR ratio (%)	<i>Wasabia koreana</i> leaf powder (%)	Total polyphenol (mg/100 g powder)	Total flavonoid (mg/100 g powder)
Dried	100:0	0	231.34±2.09 <sup>cd<sup>e</sup>2)</sup>	53.51±1.85 <sup>ab</sup>
		3	236.37±0.33 <sup>def</sup>	142.08±30.36 <sup>de</sup>
		5	243.90±4.43 <sup>fg</sup>	287.13±50.93 <sup>g</sup>
	90:10	0	225.94±3.86 <sup>bcd</sup>	54.66±8.32 <sup>ab</sup>
		3	238.30±2.90 <sup>ef</sup>	134.39±26.15 <sup>cd<sup>e</sup></sup>
		5	223.81±0.58 <sup>bc</sup>	241.02±43.26 <sup>f</sup>
	80:20	0	218.41±2.98 <sup>ab</sup>	106.53±28.86 <sup>cd</sup>
		3	232.12±5.26 <sup>cd<sup>e</sup></sup>	124.79±10.39 <sup>cd<sup>e</sup></sup>
		5	230.18±3.62 <sup>cd<sup>e</sup></sup>	92.12±35.22 <sup>bc</sup>
Air-fried	100:0	0	232.72±4.66 <sup>cd<sup>ef</sup></sup>	102.69±19.19 <sup>cd</sup>
		3	288.51±17.97 <sup>i</sup>	110.37±20.17 <sup>cd</sup>
		5	237.91±3.94 <sup>ef</sup>	33.62±3.16 <sup>a</sup>
	90:10	0	211.65±5.22 <sup>a</sup>	11.43±4.40 <sup>g</sup>
		3	252.78±9.90 <sup>gh</sup>	208.36±20.18 <sup>f</sup>
		5	230.52±8.36 <sup>cd<sup>e</sup></sup>	166.06±5.96 <sup>e</sup>
	80:20	0	255.10±2.32 <sup>h</sup>	50.83±24.02 <sup>ab</sup>
		3	252.59±0.89 <sup>gh</sup>	104.61±7.62 <sup>cd</sup>
		5	267.65±5.57 <sup>i</sup>	150.72±38.77 <sup>de</sup>

<sup>1</sup>)GR, glutinous rice; NGR, non-glutinous rice.

<sup>2</sup>)Different superscripts in a column indicate significant difference at  $p < 0.05$  by Duncan's multiple range test. Values are mean±SD (n=3).

treated samples relative to control. However, the substitution of superfine NGR rice decreased the amount of TPC and TFC. The sample 100:0:0, 100:0:5 and 80:20:5-treated samples showed significantly different in TPC and TFC values in all with 231.34±2.09, 243.90±4.43, 230.18±3.62, and 53.51±1.85, 287.13±50.93, and 92.12±35.22, respectively. The lowest TPC and TFC were found in air-fried apple *bugak* (90:10:0) with 211.65±5.22 and 11.43±4.40, respectively, whereas the highest TPC value was found in fried apple *bugak* sample (100:0:3) with 288.51±17.97 and the highest value of TFC was indicated in dried apple *bugak* (90:10:5) with 241.02±43.26. When more superfine WNK powder

was added, the TPC and TFC increased, excluding the air-fried *bugak* sample, which showed decreased TPC and TFC values. A previous study found that the amount of WKNL powder increased in pork patties and resulted in an increase in total flavonoid and phenolic content compared to the control (Kim, 2022). Additionally, according to Ertekin and Seydim (2018), drying increases the phenol content of apple slices. This effect is more pronounced at higher drying temperatures. Hot air caused bound phenolics to escape from the tissue. Thus fortifying *bugak* with superfine WNK powder can be used as food strategy to enhance TPC and TFC; however, the addition of superfine NGR and air-frying

treatment may decrease the TPC and TFC in *bugak* chips.

### 3.5. Antioxidant activity

The DPPH assay is frequently used to measure the potential of bioactive compounds to scavenge free radicals, whereas the ABTS assay can be used as an index to indicate the antioxidant activity of identified samples (Zhao et al., 2015). Table 4 shows the results of the DPPH and ABTS assays used to measure the antioxidant activities in dried and air-fried apple *bugak*. The antioxidant activity

increased significantly with the addition of superfine NGR and WKNL powders. Antioxidant activity was highest in the 80:20:5-treated dried apple sample ( $17.01 \pm 0.45\%$ ) and lowest in the air-fried 100:0:0-treated apple samples ( $3.08 \pm 4.03\%$ ). In addition, results from the ABTS assay indicated that antioxidant capacity increased with the addition of NGR and WKNL superfine powder in both dried and air-fried apple *bugak*, but there were no significant differences ( $p < 0.05$ ) between the 100:0:0, 100:0:3, 100:0:5, 90:10:5, and 80:20:3 treatments among the dried *bugak* samples. The ABTS value ranged from

**Table 4.** Antioxidant activity of powders from apple *bugak* coated with superfine rice and *Wasabia koreana* Nakai leaf powder

<i>Bugak</i>	GR <sup>1</sup> :NGR ratio (%)	<i>Wasabia koreana</i> leaf powder (%)	DPPH <sup>3</sup> (%)	ABTS (%)
Dried	100:0	0	8.69±1.39 <sup>b2)</sup>	21.99±0.56 <sup>b</sup>
		3	14.28±2.72 <sup>def</sup>	20.61±0.57 <sup>b</sup>
		5	14.48±1.30 <sup>def</sup>	21.91±1.26 <sup>b</sup>
	90:10	0	11.74±1.59 <sup>bode</sup>	14.31±3.79 <sup>a</sup>
		3	16.71±1.20 <sup>f</sup>	24.19±1.65 <sup>bc</sup>
		5	15.20±1.27 <sup>ef</sup>	21.99±2.29 <sup>b</sup>
	80:20	0	11.05±0.85 <sup>bcd</sup>	14.52±1.17 <sup>a</sup>
		3	14.53±0.85 <sup>def</sup>	21.26±4.55 <sup>b</sup>
		5	17.01±0.45 <sup>f</sup>	24.48±8.51 <sup>bcd</sup>
Air-fried	100:0	0	3.08±4.03 <sup>a</sup>	26.47±2.85 <sup>bode</sup>
		3	14.10±1.03 <sup>def</sup>	28.88±3.09 <sup>cde</sup>
		5	8.73±3.69 <sup>b</sup>	30.38±1.04 <sup>cde</sup>
	90:10	0	8.59±0.95 <sup>b</sup>	26.46±6.56 <sup>bode</sup>
		3	8.97±2.21 <sup>bc</sup>	31.10±1.35 <sup>e</sup>
		5	12.31±1.40 <sup>cde</sup>	30.39±2.24 <sup>cde</sup>
	80:20	0	12.63±0.70 <sup>de</sup>	32.24±1.13 <sup>e</sup>
		3	12.42±0.32 <sup>cde</sup>	30.61±1.63 <sup>de</sup>
		5	14.40±1.85 <sup>def</sup>	30.39±2.05 <sup>cde</sup>
0.1% Vitamin C			50.97±2.83 <sup>g</sup>	28.70±1.54 <sup>cde</sup>

<sup>1</sup>)GR, glutinous rice; NGR, non-glutinous rice.

<sup>2</sup>)Different superscripts in a column indicate significant difference at  $p < 0.05$  by Duncan's multiple range test. Values are means±SD (n=3).

<sup>3</sup>)DPPH, 1,1-diphenyl-2-picryl-hydrazyl (DPPH) radical scavenging activity; ABTS, 2,2'-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid (ABTS) radical scavenging activity.

14.31±3.79% to 32.24±1.13% across all treatments and was found to be higher in air-fried than dried apple *bugak*.

### 3.6. Rheological characteristics

The deformation and flow characteristics of a substance under stirring, transport, and external force are referred to as its rheological properties. The shear stress versus shear rate for powder paste from dried apple *bugak* coated with superfine rice (GR and NGR) and WKNL powder at different

concentrations was determined from 0 to 100 S<sup>-1</sup> at 25°C and is shown in Fig. 3. The control sample (100:0:0) showed that the value of flow behaviour was high compared to the sample with superfine NGR and WKNL powder at 3 and 5%. However sample (*bugak* 100:0:5) showed less flow behaviour as the amount of superfine WKNL powder increase besides from that, the samples with high amount of WKNL powder (*bugak* 80:20:5) indicated a high flow behaviour as the quantity of superfine NGR and WKNL powder increased. This might be caused

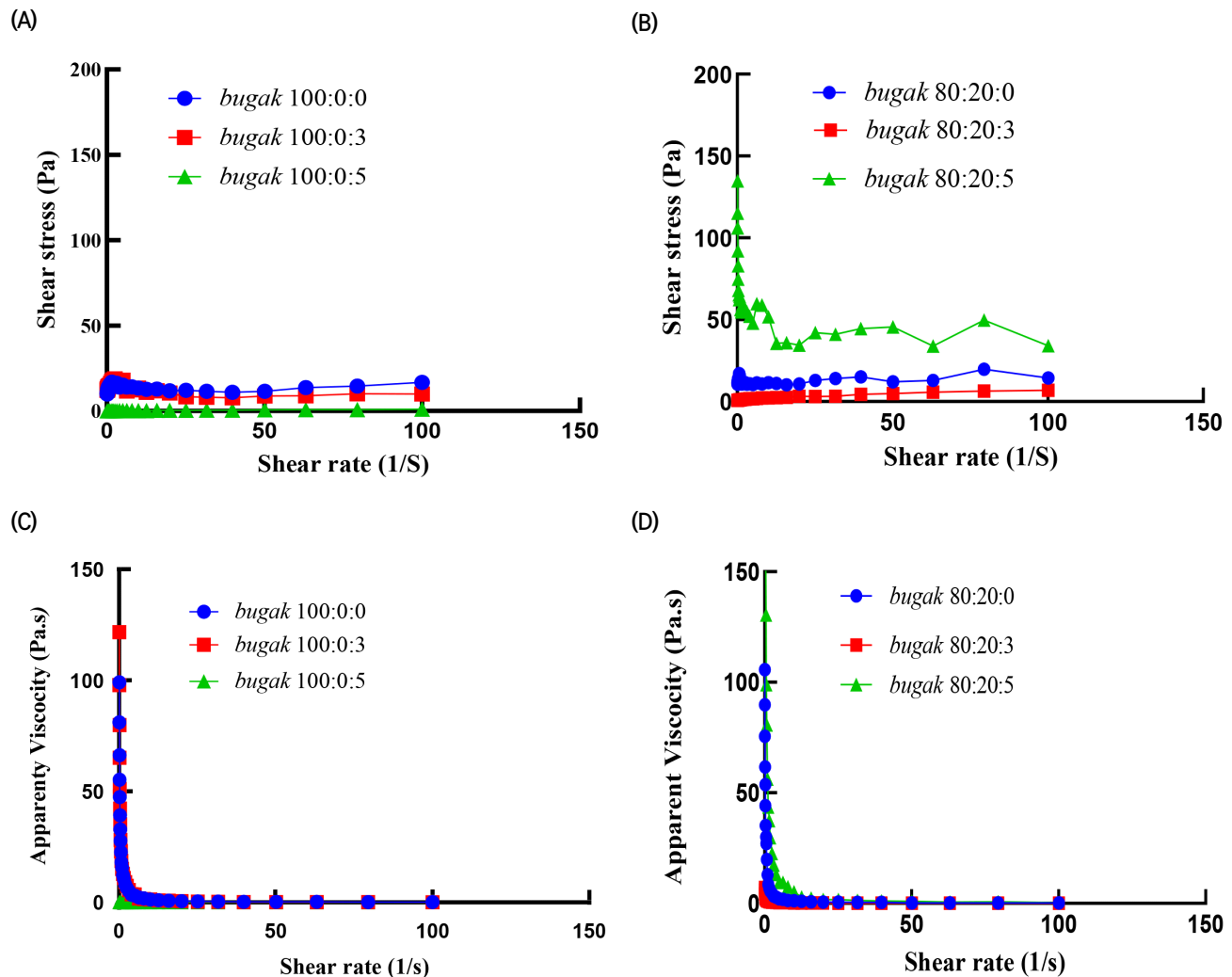


Fig. 3. Rheological properties of dried apple *bugak* powder: shear stress–shear rate (A, B) and apparent viscosity–shear rate (C, D). A–D are samples from dried apple *bugak* powder coated with superfine rice powder in the proportion of 80:20 (glutinous rice and non-glutinous) with different concentrations of *Wasabia koreana* Nakai leaf powder 0%, 3% and 5%.

by the 20% substitution of NGR superfine powders. Yoo (2006) reported that glutinous rice flour dispersions had much lower yield stress values than NGR flour dispersions and the lower value of rheological parameters may be explained by the amylose content, which significantly impacts the flow characteristics of starch. In this study, the viscosity was decreased for all *bugak* samples, Bhandari et al. (2002) reported decreased viscosity in corn starch/amaranth paste due to high breakage of the intra-and intermolecular associate bonding system in the starch network micelles at high shear rates. Guo et al. (2022) reported that the texture

parameters of superfine corn bread improved with decreasing particle size. Based on these studies, we concluded that coating apple with GR substituted with NG and WKNL superfine powder reduced dried apple *bugak* viscosity, thereby enhancing its shear-thinning behaviour. In contrast, Fig. 4 showed the rheological properties of the air-fried apple *bugak*. The flow behaviour of the paste was significantly higher for the treatment, including 5% superfine WKNL powder, than in the other treatments. The only exception was 100:0:5 treatment, which had a lower flow behavior. Even if the incorporation of NGR and WKNL superfine powder resulted in a

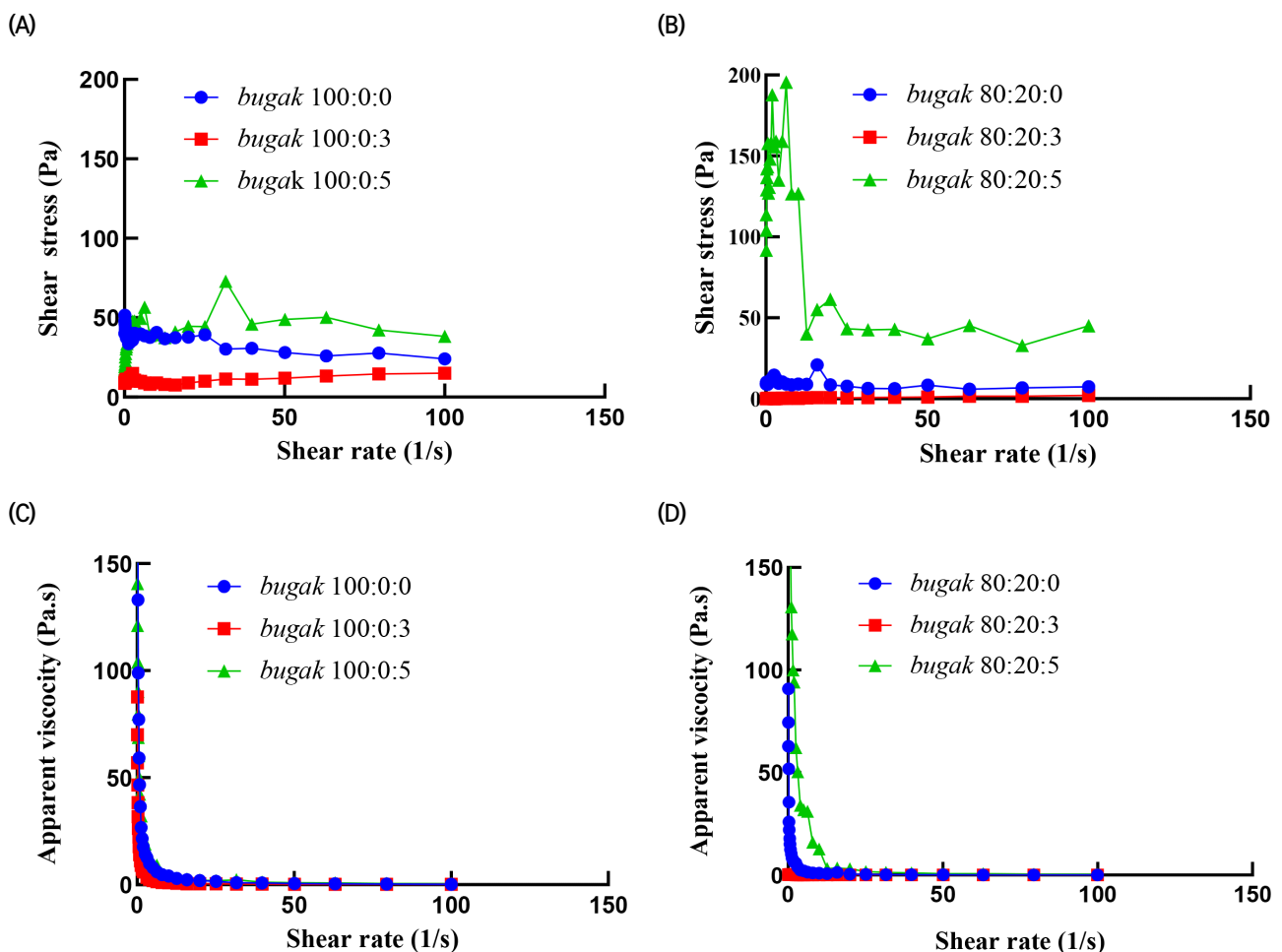


Fig. 4. Rheological properties of air-fried apple *bugak*: shear stress–shear rate (A, B) and apparent viscosity–shear rate (C, D). A–D are samples from air fried apple *bugak* coated with superfine rice in the proportion of 80:20 (glutinous rice and non-glutinous) with different concentrations of *Wasabia koreana* Nakai leaf powder 0%, 3% and 5%.

significant increase in the flow behaviour of the paste, viscosity did not differ significantly between the treatments. Furthermore, in general, viscosity decreased with the increase in shear rate. However, in 80:20:5 treatment, the viscosity was initially high relative to other treatments but decreased as the shear rate increased. Qiu et al. (2019) found that the viscosity of wasabi paste was decreased with increasing shear rate. Based on these findings, we concluded that the addition of superfine NGR and WKNL powder substitutes, which have high amount amylose content, can decrease amylopectin content of the GR powder responsible for the sticky rice quality. This might affect the decrease in viscosity in response to an increase in shear rate but may also increase shear stress and hence reduce the stickiness properties of dried and air-fried apple *bugak*.

## 4. Conclusions

We found that dried and air-fried apple *bugak* produced by substituting superfine GR with NGR and WKNL powders showed good nutritional and functional qualities compared to the traditional *bugak* product produced using GR powders. These findings indicated that supplementing GR and WKNL with superfine GR powder significantly enhanced the physiochemical properties of dried and air-fried apple *bugak*. In addition, superfine NGR and WKNL powder formulations improved the hydration, color, rheology, and structural properties of the dried apple *bugak*. These characteristics play a vital role in consumers acceptability. The results obtained could be very valuable for industries that want to take advantage of superfine NGR and WKNL powders as coating materials which can serve as alternatives or supplements to GR powders in the processing of *bugak* products. Further

research is needed to develop *bugak* products coated with GR, NGR and WKNL superfine powders combined with other ingredients to make chips with better nutritional value, taste, and consumers acceptability. Dried or air-fried apple *bugak* powders to be used as ingredients in ready-to-eat food products. Future research is needed to determine the shelf life and microbiological stability of fruit or vegetable *bugak* coated with superfine GR, NGR and WKNL powders.

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### Conflict of interests

The authors declare no potential conflicts of interest.

### Author contributions

Conceptualization: Iradukunda D, Kang YH. Methodology: Iradukunda D. Formal analysis: Iradukunda D. Validation: Iradukunda D, Kang YH. Writing - original draft: Iradukunda D. Writing - review & editing: Iradukunda D, Kang YH.

### Ethics approval

This article does not require IRB/IACUC approval because there are no human and animal participants.

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## References

Ahza AB, Fidiana TI, Suryatman S. Physical, sensorial

- and chemical characteristics of simulated chips of cassava (*Manihot esculenta* Crantz): Rice (*Oryza sativa* L.) mix. *Procedia Food Sci*, 3, 82-95 (2015)
- Aradwad PP, Thirumani Venkatesh AK, Mani I. Infrared drying of apple (*Malus domestica*) slices: Effect on drying and color kinetics, texture, rehydration, and microstructure. *J Food Process Eng*, 46, e14218 (2022)
- Beigi M. Hot air drying of apple slices: Dehydration characteristics and quality assessment. *Heat Mass Transf*, 52, 1435-1442 (2015)
- Bhandari PN, Singhal R, Kale D. Effect of succinylation on the rheological profile of starch pastes. *Carbohydr Polym*, 47, 365-371 (2002)
- Choi JH, Chung SK. Antioxidant and antimicrobial activities of polyphenols isolated from unripe apples (*Malus pumila* cv. Hongro). *Korean J Food Preserv*, 26, 690-696 (2019)
- Dubois M, Gilles KA, Hamilton JK, Rebers PA, Smith F. Colorimetric method for determination of sugars and related substances. *Anal Chem*, 28, 350-356 (1956)
- Ertekin Filiz B, Seydim AC. Kinetic changes of antioxidant parameters, ascorbic acid loss, and hydroxymethyl furfural formation during apple chips production. *J Food Biochem*, 42, e12676 (2018)
- Guo X, Dai T, Chen, M, Deng L, Chen J, Liu C. Steam bread made by superfine purple corn flour: Texture characteristics and *in vitro* starch digestibility. *LWT-Food Sci Technol*, 169, 113967 (2022)
- He S, Tang M, Sun H, Ye Y, Cao X, Wang J. Potential of water dropwort (*Oenanthe javanica* DC.) powder as an ingredient in beverage: Functional, thermal, dissolution and dispersion properties after superfine grinding. *Powder Technol*, 353, 516-525 (2019)
- Jung L, Song Y, Chung L, Choe E. Characteristics on lipid and pigments of lotus root, dried laver, and perilla leaf bugak (Korean fried cuisine) made by Korean traditional recipe. *Korean J Food Cook Sci*, 29, 805-814 (2013)
- Kang YH. *Wasabia koreana* Nakai leaf powder, concentrate, concentrated dry powder, and its preparation method. Korea Patent No. 10-2189252 (2020)
- KFRI. Korean Traditional Food-Standard No T075 (*bugak*). Available from: <https://www.kfri.re.kr>. Accessed Nov. 11, 2020.
- Kian-Pour N, Akdeniz E, Toker OS. Influence of coating-blanching in starch solutions, on the drying kinetics, transport properties, quality parameters, and microstructure of celery root chips. *LWT-Food Sci Technol*, 160, 113262 (2022)
- Kidon M, Grabowska J. Bioactive compounds, antioxidant activity, and sensory qualities of red-fleshed apples dried by different methods. *LWT-Food Sci Technol*, 136, 11302 (2021)
- Kim JH, Lee SH. Antioxidative and microbial activities of *Oenothera biennis* extracted by different methods. *Korean J Food Preserv*, 23, 233-238 (2016)
- Kim M. Antioxidant activity and quality characteristics of pork patties with added *Wasabia koreana* Nakai leaf powder. *Korean J Community Living Sci*, 33, 429-439 (2022)
- Murid M, Khan MKI, Butt MS, Maan AA, Sablani SS. Evaluation of electrostatic powder coating method to prolong the shelf life of cheese slices. *J Food Sci*, 87, 1742-1753 (2022)
- Qiu L, Zhang M, Bhandari B, Fang Z, Liu Y. Size reduction of raw material powder: The key factor to affect the properties of wasabi (*Eutrema yunnanense*) paste. *Adv Powder Technol*, 30, 1544-1550 (2019)
- Showkat QA, Majid D, Rather JA, Naqash S, Dar BN, Makroo HA. Drying of lotus rhizome slices: Influence of drying conditions on Fourier transform infrared spectroscopy, rheology, functional, and physicochemical characteristics of lotus rhizome powder. *J Food Process Eng*, 45, e13954 (2022)
- Wang RM, Xie QT, Wang SY, Chen P, He TS, Zhang

- B. The structural, functional and digestive characteristics of acorn starch after combined debranching and heat-moisture treatment and their relationships. *Int J Food Sci Technol*, 57, 7622-7633 (2022)
- Xiao Y, Zhang J, Zhang L. Effect of superfine grinding on physicochemical properties and endogenous enzyme induced flavonoid transformations Tartary buckwheat bran. *LWT-Food Sci Technol*, 162, 113420 (2022)
- Yoo B. Steady and dynamic shear rheology of glutinous rice flour dispersions. *Int J Food Sci Technol*, 41, 601-608 (2006)
- Zhang H, Chen L, Yang T, Liu Q, Chen X, Zhang Y, Shu G, Li J. Production of superfine green tea powder from processing wastes: Characterization of chemical composition and exploration of antimicrobial potential against *Ralstonia solanacearum*. *LWT-Food Sci Technol*, 104, 142-147 (2019)
- Zhang J, Dong Y, Nisar T, Fang Z, Wang ZC, Guo Y. Effect of superfine-grinding on the physicochemical and antioxidant properties of *Lycium ruthenicum* Murray powders. *Powder Technol*, 372, 68-75 (2020)
- Zhang T, Xiao S, Ding Z, Song Y. Effects of superfine grinding on physicochemical properties and morphological structure of coix seed powders. *J Cereal Sci*, 102, 103361 (2021)
- Zhao G, Zhang R, Dong L, Huang F, Tang X, Wei Z, Zhang M. Particle size of insoluble dietary fiber from rice bran affects its phenolic profile, bioaccessibility and functional properties. *LWT-Food Sci Technol*, 87, 450-456 (2018)
- Zhao X, Zhu H, Zhang G, Tang W. Effect of superfine grinding on the physicochemical properties and antioxidant activity of red grape pomace powders. *Powder Technol*, 286, 838-844 (2015)
- Zhu J, Liu Y, Zhu C, Wei M. Effects of different drying methods on the physical properties and sensory characteristics of apple chip snacks. *LWT-Food Sci Technol*, 154, 112829 (2022)