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Research Article

Physicochemical quality characteristics of *nurungji* prepared from rice and *Raphanus sativus* powder

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Abstract This study investigated the physicochemical quality, antioxidant activity, instrumental sensory characteristics of *nurungi* prepared from rice and dried-radish root *bugak* powder (DRBP). DRBP was made from dried-radish root *bugak* (DRB) coated with 80% superfine glutinous and 20% non-glutinous rice powders. The *nurungji* food products were prepared using 80% non-glutinous rice and 20% glutinous rice, and DRBP, which was added at different levels of 2, 4, 6, 8, and 10%, respectively (NR-2, NR-4, NR-6, NR-8, and NR-10). The total polyphenol and flavonoid contents were increased from 21.34 to 27.87 mL, and 7.46 to 20.05 mgNE/mL respectively, as the amounts of DRBP increased. Color L*-value, pH, and hydration properties were decreased with the increased amounts of DRBP. The electronic tongue results showed that NR-6 sample had high umami scores and sourness compared to the control sample (NR-0). Furthermore, SEM images indicated different shapes between the control (NR-0) and other treatments. However, no differences among *nurungji* treated with DRBP. Therefore, the use of DRB coated with superfine glutinous and non-glutinous rice powders is a viable ingredient for *nurungji* preparation. This study shows that adding 6% DRBP produced *nurungji* with good- quality physicochemical and sensory characteristics.

Keywords *Raphanus sativus*, superfine rice powders, *bugak*, *nurungji*, physicochemical properties.

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1. Introduction

Nurungji is a traditional Korean food prepared from scorched rice. After boiling and serving the rice, a thin crust forms on the bottom of the cooking pot. When the bottom temperature of the pot exceeds 200℃, this crust develops a rich, flavorful taste that is enhanced by browning through the amino carboxyl reaction (Yang and Choi, 2016). *Nurungji* is eaten in its crisp state as a snack, infused in hot water to prepare scorched rice tea (*sungnyung*), or reboiled in water to produce scorched rice soup (Do et al., 2010). In recent years, rather than consuming rice as a stable food research and utilization as processed products that are favorable and beneficial to health. As the interest in adult diseases and health increases, there is a significant turning point in food consumption culture (Chae, 2014). According to Choi et al. (2017) consumers prefer food with low-fat, calorie, and high-fiber healthy foods. Therefore, developing food with such functionality has become an essential task in the food industry and research field to add various kinds of healthy food ingredients.

Several studies related to *nurungji* have been reported to improve physicochemical, antioxidant activities, and sensory properties. For example, total polyphenols, flavonoids and antioxidant activities were found to increase in grain *nurungji* with the increase of *Saccharina japonica* (kelp) concentration (Jeong and Choi, 2023). It was found that the optimal heating time for manufacturing *nurungji* is within 5 min to retain physicochemical properties but also to avoid the production of a high amount of acrylamide in the final product (Hwang et al., 2020). The preparation of *nurungji* with 8% purple sweet potato powder added after rice cooking was more favorable based on the content of total polyphenols, flavonoids, anthocyanin and antioxidant activities (Yong and Kang, 2022). Lee (2018) suggested that green whole grain is a good ingredient for increasing the consumer acceptability and functionality of *nurungji*. Radish (*Raphanus sativus*) is a root vegetable grown and consumed all over the world, and it has become part of the diet of human beings, although it is not widespread in other societies (Banihani, 2017). Radish is used in Unani, Greek-Arabic, and Indian folk medicine to treat a variety of ailments, including jaundice, gallstones, liver disorders, rectal prolapse, indigestion, and other gastrointestinal problems (Jeong et al., 2005). Radish contains carbohydrates, sugars, dietary fibres, protein, fat, and fluoride, it also contains several water-soluble vitamins (B_1, B_2, B_3, B_5, B_6, B_9, and C). Additionally, it contains minerals (calcium, iron, magnesium, manganese, zinc, potassium, and phosphorus) (Khattak, 2011). Radish was discovered to contain unique bioactive chemicals that have lately been identified as potentially beneficial to human health.

Lim et al. (2019) in their research found that the addition of 1% of radish powder to dairy products (milk, yoghurt, and kefir) showed good results in organoleptic properties compared to the control. Bae et al. (2012) reported sulfur-like ethylthiocyanate, butyl isothiocyanate, dimethyl-disulfide, and 4-methylthio-3-butylisothiocyanaate in white radish. White radish is mostly consumed as soup in Asia, it can be processed into pickling, drying and fermentation food products (Jung et al., 2022). Several research studies revealed that methylisogermabullone bioactive compounds isolated from radishes were found to stimulate small bowel mobility by activating the acetylcholinergic receptors, while 4-(methylthio)-3-butenyl isothiocyanate was found to induce apoptosis in human colon cancer cells, thereby reducing abnormal cell growth (Barillari et al., 2008). Furthermore, the spicy flavor of radish is due to some chemical substances like myrosinase, glucosinolate and isothiocyanate (Nakamura et al., 2008). Therefore, this study takes the health advantages of radish root and adds glutinous and non-glutinous rice at different concentrations of dried-radish root *bugak* powder (2, 4, 6, 10%) to develop *nurungji* and its effects on antioxidant activities, physicochemical and sensory properties.

In a previous study, Iradukunda and Kang (2023) found that coating apples with superfine glutinous and non-glutinous rice powders provide high-quality dry and air-fried *bugak* with nutritional properties, hence utilization of dried fruit or vegetables coated with superfine glutinous and non-glutinous rice powders not only protects for long shelf-life but also produces good quality characteristics of dried food products. In this study, white radish root which can be spoiled in a short time after harvesting was coated with superfine glutinous and non-glutinous rice, dried, and its powders were used as the ingredients up to 10% during *nurungji* making.

Superfine ground red rice has improved physicochemical and functional qualities, as well as higher enzymatic digestibility by α-amylase when particle size decreases (Chen et al., 2015). In addition, superfine grinding was found to increase specific surface area, water solubility index, swelling capacity, antioxidant activity, and solubility of functional substances like polysaccharides, echinacoside, acteoside and isoacteoside in C. *deserticola* (Hou et al., 2023). Zhu et al., (2012) reported a higher antidiabetic activity with reducing fasting blood glucose level and serum insulin level, a protective effect of pancreatic tissues including islet beta cells and reduced loss of islet cells of superfine grinding powder of bitter melon in diabetic rats. Yan et al. (2022), indicated that superfine grinding improves the effect of sensory properties by increasing the brightness, yellowness, and sweetness, decreasing sourness and bitness, also reported an increasing effect of total phenols content, flavonoids content, and the soluble dietary fibre of apple (*malus domestica*) pomace. Therefore superfine powders would provide wider application in food processing. Currently, research utilized superfine glutinous and non-glutinous rice powders as coating materials for radish root not only for purpose of extending shelf life but also improving physicochemical, sensory and functional properties of dried-radish root *bugak*. This study takes the health advantages of dried-radish root coated with superfine glutinous and non-glutinous rice powders and added in rice

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nurungji as ingredients at different concentrations (2, 4, 6, 10%) to develop *nurungji* food products and investigated its effects on physicochemical and sensory properties.

2. Materials and methods

2.1. Food ingredients and reagents

Radish roots were purchased from Gangneung-Wonju National University, Department of Plant Science in October (Gangneung, Korea), non-glutinous rice was purchased from the the Shillim Agriculture Cooperation Federation (Wonju, Korea), and glutinous rice was purchased from the Hoengseong Agricultural Cooperative processing plant (Hoengseong-gun, Korea). Superfine rice powders used as food coating materials were obtained using a superfine pulverizer (Fluid bed jet mill, Korea Powder System Co., Incheon, Korea) with average median diameters 10.1 and 10.68 for glutinous and non-glutinous rice, respectively. Chemical reagents, including ethyl alcohol, gallic acid, diethylene glycol, sodium carbonate, Folin-Ciocalteu agent, and 2,2-diphenyl-1-picrylhydrazyl were purchased from Sigma Aldrich Co. (St. Louis, MO, USA).

2.2. Samples preparation

2.2.1. Raw radish root and its characteristics

After the radish roots were washed and drained, the total soluble solids (TSS), potential of hydrogen (pH), and biometrical characteristics, including the diameter, weight, and length were measured on ten radish roots to obtain an average. Radish root was mechanically blended by blender (FM-909, Hanil Electric Co., Bucheon, Korea) to extract radish root juice for TSS and pH analysis. The length of raw radish root used was 16.80±1.05 cm, weight was 539.77±74.11 g, total soluble solids were 6±0.00 °Brix, pH was 5.75±0.01 and moisture content of 92.91±0.03%, The biometrical characteristic results were different from the one reported on spring and autumn by Kim et al. (2003), however moisture content, total soluble solids and pH were in range with their results from 92.57 to 94.71%, 4.30 to 7.30 and 5.74 to 6.11 °Brix, respectively.

2.2.2. Dried-radish root *bugak* and its powder preparation

Radish root powder was prepared according to Iradukunda and Kang (2023), radish roots were washed, cut into 2 mm pieces, and immersed in water for 3 min to avoid an enzymatic reaction, before superfine rice powders coated-treatment, the sliced radish root were dewatered at 24°C for 10 min. Then the sliced radish roots were coated with superfine 80% glutinous and 20% non-glutinous rice powders. Dried-radish root *bugak* (DRB) was prepared by applying heat treatment with hot water steam at over 100°C for 10 min, followed by drying at 50°C for 18 h using a hot air dryer (KED-132A, C&T Co., Ltd., Gwangju, Korea) to get, cooled, packaged in a polyethene packet and stored at 4°C for further processing. The prepared DRP bulk was ground into a powder using a grinder (FM-909, Hanil Electric Co.) and sifted using a 40-mesh sieve to obtaining a fine powder (DRBP).

2.2.3. Processing of *nurungji* with DRBP

Nurungji was prepared from 80% non-glutinous and 20% glutinous rice, to which 0%, 2%, 4%, 6%, 8%, and 10% DRBP was added. The DRBP was prepared using a modified version of the method described by Yong and Kang (2022). Rice was washed 3 times, and soaked in 300 mL of water at 24°C for 15 h, followed by dehydrating unit operation, 100 mL of water was added to the rice, 0, 2, 4, 6, 8, 10% DRBP. The mixture was cooked at 90±10°C for 19±2 min using an electric rice cooker (CRP-M1060SR, Kuku Electronics Co., Ltd., Yangsan, Korea), cooled and roasted at 200°C for 4 min using electrical *nurungji* maker (BE-7800, Bethel Electronic Co., Hwaseong, Korea) to get *nurungji.* The processed *nurungji* was cooled and stored at 4°C before further analysis. The formulations for *nurungji* preparation with different amounts of glutinous and non- glutinous rice and DRBP are shown in Table 1.

2.3. Physical properties analysis

2.3.1. Color measurement

The Hunter color value, L (whiteness/blackness), a (redness/greenness), and b (yellowness/ blueness) of *nurungji* added with DRBP was measured by colorimeter (CM-5, Konika Minolta Inc., Tokyo, Japan). 3 g of *nurungji* powdered sample was evenly spread on a petri dish (55×12 mm) for measurement (Yong and Kang, 2022). The L, a, and b values of the standard plate used for measurement were 93, -0.65, and 3.30. Each sample was measured ten times to obtain an average.

Table 1. **Formulation for *nurungji* prepared with different amounts of glutinous and non-glutinous rice and dried-radish root *bugak* powder**

Materials	NR-0	NR-2	NR-4	NR-6	NR-8	NR-10
NGR (g)	80	78	76	74	72	70
GR (g)	20	20	20	20	20	20
DRBP (g)	0	2	4	6	8	10
Water (g)	100	100	100	100	100	100
Total (g)	200	200	200	200	200	200

NGR, non-glutinous rice; GR, glutinous rice; DRBP, dried-radish root *bugak* powder coated with superfine glutinous and non-glutinous rice powder. NR-0; NR-2; NR-4; NR-6; NR-8; and NR-10 *nurungji* from rice with 0%, 2%, 4%, 6%, 8% and 10% dried-radish root *bugak* powder coated with superfine glutinous and non-glutinous rice powders, respectively.

2.3.2. pH and total soluble solids (TSS) determination

The pH of radish *nurungji* added with DRBP was measured using a pH meter (pH 210, Hanna, Woonsocker, RI, USA), 35 mL of distilled water was added to 5 g of *nurungji* powder, mixed, stirred well at 20℃ for 10 min, wait for 30 min at 20℃, and supernatant was separated by a centrifuge (Fleta 5, Hanil Scientific Inc., Gimpo, Korea) at 2,000 rpm for 20 min, the supernatant was filtrated by using (Whatman No. 2, UK) before checking the pH value, the experiment was done 3 times to get average. The filtrated solution was also used for TSS determination using a digital pocket refractometer (Atago, Ltd., Tokyo, Japan).

2.3.3. Texture characteristics measurement

The texture of *nurungji* added with DRBP was measured according to the method described by Lee (2018) with some modification after cutting *nurungji* samples into 2.5×2.5×2.5 cm, an analyzer (CR-100, Sun Scientific Co., Tokyo, Japan) was used under the conditions of distance 5 mm, plunger diameter 3 mm, trigger force 10.0 g and table speed of 60 mm/min, and all samples were repeated three times as average values.

2.3.4. Water hydration feature and water content determination

The hydration properties: swelling capacity (SC) was measured according to Gan et al. (2022), 1 g of *nurungji* samples were mixed with 20 mL of distilled water in a graduated cylinder, and after hydration in 24 hours, the additional volume of powder was recorded, while water absorption index (WAI) and water solubility index (WSI) were determined as reported by Lai et al. (2023), with little modification, 20 mL was added to 1 g of *nurungji* powder at 24℃, gently stirred for 10 min and incubated at 30℃ for 30 min, the mixture was separated by centrifuge at 2,000 rpm for 20 min. The sediment was taken for WAI analysis, and supernatant was poured into an aluminium dish and dried to constant weight at 105℃. Water content (WC) was measured in a weight-loss way according to AACC (2000), Samples were heated at 105℃ in a drying oven until the constant weight was achieved.

$$\text{SC (mL/g)} = \frac{\text{Addition volume of powder after hydration}}{\text{Weight of powder sample before hydration}}$$

$$\text{WAI (g/g)} = \frac{\text{Weight of sediment}}{\text{Dry weight of sample}}$$

$$\text{WSI (\%)} = \frac{\text{Weight of dry solid in supernatant}}{\text{Dry weight of sample}} \times 100$$

$$\text{WC (\%)} = \frac{W_1 - W_2}{W_1} \times 100$$

where W_1 was a total weight of sample before oven drying and W_2 was the weight of sample after oven drying.

2.3.5. Determination of rheological characteristics

Rheological measurements were carried out using a rheometer (AR 2000 ETC, TA Instrument Inc., New Castle, DE, USA), 15 mL of distilled water was added to 1 g of *nurungji* powder, stirred, left to 24℃ for 1 h and heated at 50℃ in a water bath (C-WBEMB, Changshin, Seoul, Korea).

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The samples were kept in refrigeration overnight. As described by Hitayezu et al. (2022) with some modification, 2 mL of sample paste was put on the lower plate of the rheometer measurement system with a 60 diameter/20 angle cone plate and held at 25℃ for 1 min. The flow behavior was examined at constant shear rates ranging from 0.1 to 100 S-1. The flow curve of the effects of shear rate on the shear stress and apparent viscosity was generated and analyzed using GraphPad Prism software (9.5.0, San Diego, CA, USA).

2.3.6. Scanning electron microscopy (SEM)

Surface morphology of the *nurungji* added with DRBP was evaluated as stated in report of Nisha et al. (2023). Prior to image analysis, samples were covered with double-sided sticky tape on the surface of the SEM stub, and they were sputter-coated in a vacuum with a gold machine (SCD005, Leica Microsystem GmbH A-170, Vienna, Austria). The samples were examined using a field- emission scanning electron microscope (JSM-750F, JEOL Ltd., Tokyo, Japan) under high vacuum, with a magnification of 100 and an accelerated voltage of 10 kV.

2.3.7. Electronic tongue analysis

To investigate taste features, An Astree II electronic tongue system (Alpha M.O.S, Toulouse, France) fitted with an auto-sampler and five sensors: PKS and CPS (complex taste detection) and (AHS, CTS, NMS, ANS, and SCS) corresponding to five basic tastes (sourness, saltiness, umami, sweetness, and bitterness respectively). Samples were made similar to the procedure reported by Choi et al. (2023) with little modification, Briefly 10 g of powder of *nurungji* added with DRBP was added to 100 mL of distilled water, stirred, left at 24℃ for 30 min and incubated to 60℃ for 10 min before centrifugation at 2,000 rpm for 10 min and extract was filtrated through Whatman No.1 filter paper (GE Healthcare, Little Chalfont, UK). After calibrating the E-tongue sensors and diagnostic system, all sample extracts were diluted to 10,000 ppm with double- distilled water before being analyzed in five replicates under analytical settings (0 s delay, 120 s acquisition, 1 s intervals, stirring rate of 1, and acquisition time of 1). For each sample analysis, the sensors were automatically washed with 25 mL of double-stilled water. The degree of taste was measured using principal components analysis (PCA) with statistical software incorporated in an Astree II electronic tongue.

2.3.8. Electronic nose analysis

Electronic nose characteristics were investigated using Heracles II E-Nose (Heracles Neo, Alpha MOS) to detect odor profile, the equipment consists of an auto-sampling, sample injector, detector, data recording, and analysis system. Three replicates of 3 g of *nurungji* added with dried-radish root *bugak* powder were used for each sample, as described by Jung et al. (2017). Analysis conditions were column (1) MXT-5 (2) MXT-1701, oven temperature from 50℃ (5 s) to 270℃ (30 s), injection temperature 200℃, injection volume 2,000 μL (headsspace), detector (FID), detector temperature 250℃, incubation time 3,000 s, incubation temperature 35℃, and agitation speed 500 rpm.

2.4. Antioxidant property analysis

2.4.1. Determination of total polyphenols (TPC) and flavonoids contents (TFC)

The *nurungji* added with DRBP was extracted according to the method described by Brahmi et al. (2022) with little adjustments. 20 mL of 95% ethyl alcohol was added to 10 g of *nurungji* powder, stirred, and left at 24℃ for 6 h. After centrifuging the mixture at 2,000 rpm for 20 min, the extract was retrieved and filtrated through Acrodisc (LC PVDF 0.45 μm), extract was stored at refrigeration before further analysis. TPC in the *nurungji* added with DRBP was analyzed following the Folin-Ciocalteu approach reported by Pinto et al. (2007), 0.25 mL of Folin-Ciocalteu reagent was added to 0.25 mL of sample extract, followed by addition of 2 mL of distilled water and the reaction was stirred with a vortex mixer and allowed to stand at 24℃ for 3 min before adding 0.25 mL of a 20% sodium bicarbonate solution, after the mixture was incubated at 37℃ for 30 min in a water bath, cooled, and the absorbance was evaluated at 750 nm using a spectrophotometer (Cary8454 UV-Vis, Agilent Technologies Inc., Santa Clara, CA, USA), and gallic acid was used as a reference. The TFC of *nurungji* added with DRBP was quantified as described by Kang et al. (2019) with some modifications. Diethylene glycol (0.2 mL) was added to 0.2 mL of sample extract and thoroughly stirred before adding 0.2 mL of 1 N NaOH. The mixture was vortexed and heated at 37℃ for 1 h before cooling and measuring absorbance at 420 nm with a spectrophotometer, and naringin was used to calculate the standard curve.

2.4.2. Determination of DPPH radical scavenging activity

The determination of DPPH clearance of *nurungji* with DRBP was investigated as reported by Blois (1958). 0.12 mL of 0.2 mM 1,1-diphenyl- 2-picrylhydrazyl (DPPH) was added to 0.4 mL of sample extract, vortex-mixed for 30 s, followed by dark incubation at 24°C for 10 min. Absorbance was detected at 525 nm through a Carry 8454 UV-Vis spectrophotometer and 0.05% ascorbic acid was used as positive control.

$$\text{DPPH radical scavenging activity (\%)} = \frac{\text{Absorbance of control} - \text{Absorbance of sample}}{\text{Absorbance of control}} \times 100$$

2.5. Statistical analysis

All data were repeated three times and expressed as the mean±standard deviation. Statistical analyses were performed using the IBM SPSS statistical program (26.0, IBM Corp., Armonk, NY, USA) to calculate the mean and standard deviation of each treatment group. A one-way analysis of variance and Duncan's multiple range test ($p<0.05$) were employed to compare treatment differences.

3. Results and discussion

3.1. Color

The color measurement result of *nurungji* produced from rice added with DRBP is indicated in Table 2 and external color structure is shown on Fig. 1. Whiteness (L) was found to be the highest in the control sample (NR-0) with 60.83±4.15. As the proportion of DRBP increased the whiteness decreased, however, there were no significant differences between NR-2 and NR-4 while NR-10 was found to be less in whiteness with 45.14±3.37. Redness (a) was high in NR-6 with (5.37± 0.46) but low in control sample (1.87±0.09), redness (a) of *nurungji* with DRBP increased with the increase in proportion of DRBP. Yellowness (b) value was found to be high in NR-4 and NR-6 samples with no significant difference while adding 2% of DRBP showed no significant difference in yellowness value compared to a control sample. The color change of *nurungji* samples is due to a non-enzymatic browning reaction caused by heating carbonyl groups of reducing sugars contained in rice and amino acid reacts to produce melanoidin, which is unique a savory flavor of *nurungji* (Hwang et al., 2020) and also color change might depend on DRBP, heating time and heating temperature (Hwang et al., 2018; Lee, 2018) The color measurement results were in range with those found in *nurungji* made from green whole grain (Lee, 2018).

Table 2. Color value of *nurungji* added with dried-radish root *bugak* powder coated with superfine glutinous and non-glutinous rice powders

Samples	Hunter color values		
	L[1)]	a	b
NR-0	60.83±4.15[2)]^{a}[3)]	1.87±0.09^{d}	13.02±0.81^{b}
NR-2	54.43±3.39^{b}	3.58±0.26^{c}	12.66±1.06^{b}
NR-4	54.14±1.81^{b}	4.46±0.33^{b}	14.23±1.14^{a}
NR-6	49.62±2.59^{c}	5.37±0.46^{a}	14.75±1.19^{a}
NR-8	47.78±3.14^{cd}	4.23±0.45^{b}	12.78±0.96^{b}
NR-10	45.14±3.37^{d}	3.75±0.38^{c}	11.46±0.87^{c}

[1)]L, lightness; a, redness/greenness; b, yellowness/blueness.
[2)]Values are mean±SD (n=3).
[3)]Values with different superscripts within a column are significantly different by Duncan's multiple ranges test ($p<0.05$).

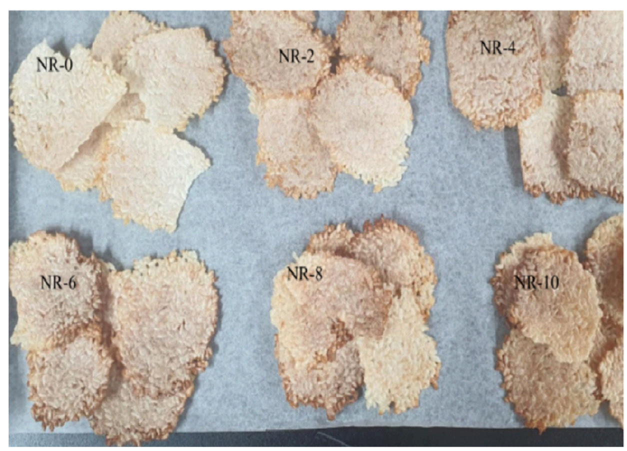

Fig. 1. External structure of *nurungji* added with dried-radish root *bugak* powder coated with superfine glutinous and non-glutinous rice powders. NR-0, NR-2, NR-4, NR-6, NR-8, and NR-10 (0%, 2%, 4%, 6%, 8%, and 10% of dried-radish root *bugak* powder coated with superfine glutinous and non-glutinous rice powders).

3.2. pH and total soluble solids (TSS)

The pH values and total soluble solid of *nurungji* with DRBP are shown in Table 3. pH values decreased with the increase of DRBP, however, no significant difference was

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Table 3. pH, total soluble solids, and hardness of *nurungji* added with dried-radish root *bugak* powder coated with superfine glutinous and non-glutinous rice powders

Samples	TSS (°Brix)[1)]	pH	Hardness (gf)
NR-0	1.80±0.17[2)d3)]	6.10±0.06[a]	4,047.33±659.16[a]
NR-2	1.93±0.05[c]	5.98±0.01[b]	4,300.66±671.93[a]
NR-4	2.23±0.05[b]	5.88±0.01[c]	4,331.73±290.15[a]
NR-6	2.30±0.00[ab]	5.77±0.00[d]	5,070±1094[a]
NR-8	2.40±0.00[a]	5.76±0.02[d]	5,640.66±571.67[a]
NR-10	2.40±0.00[a]	5.76±0.01[d]	5,957±1011.22[a]

[1)]TSS, total soluble solids; pH, potential of hydrogen.
[2)]Values are mean±SD (n=3).
[3)]Values with different superscripts within a column are significantly different by Duncan's multiple range test (p<0.05).

observed among samples with 6%, 8%, and 10% of DRBP (NR-6, NR-8, and NR-10). The pH values were significantly lower in all the treatment samples compared to control sample (NR-0) with pH of 6.10±0.06. Therefore, the addition of DRBP coated with glutinous and non-glutinous superfine powders in *nurungji* as ingredients may influence the shelf life, and can inhibit the growth of microorganisms. Ahn et al. (2019) in their finds found decreased effects of pH values in pork patties containing dry radish leaf and roots.

Total soluble solids were found to increase as the proportion of DRBP increased, a significant difference was observed in all treatment samples compared to control sample (NR-0) with 1.80±0.17 °Brix, NR-6, NR-8, and NR-10 (addition of 6%, 8%, and 10% of DRBP indicated no significant difference. Hence our results showed that supplementation of *nurungji* with DRBP up to 6% or above may increase total soluble solids (TSS) value of *nurungji* food products.

3.3. Texture

As results indicated in Table 3, the hardness of *nurungji* added with DRBP increased with the increase of DRBP, however, no significant difference was found between control samples and other treated samples with DRBP. The sample (NR-10) with 10% DRBP was harder compared to other sample treatments with 5,957±1,011.22 gf, but not statistically significantly different from other *nurungji* with DRBP. It is thought that the hardness increased as dietary fiber increased. There may be some or no similar research on *nurungji* added with DRBP, but Yong and Kang (2022) reported the increasing effect of hardness of *nurungji* prepared with purple sweet potato and also the hardness of *yanggaeng* prepared with different levels of watermelon radish flesh powder was found to increase as an increase of watermelon radish flesh powder (Lee et al., 2021). Therefore, our results suggest that preparation of *nurungji* with DRBP up to 10% may provide *nurungji* products with good texture characteristics comparable to control *nurungji* samples (NR-0).

3.4. Water hydration features (SC, WAI, WSI) and water content (WC)

Water hydration properties and water content of *nurungji* supplemented with DRBP results are shown in Table 4. The swelling capacity (SC) was found to be high (10.33±0.57 mL/g) in control samples (NR-0) with significantly different (p<0.05) compare to other samples treatments. The more DRBP are added to *nurungji,* the swelling capacity decreases however there were no significant differences between sample treatments NR-2 and NR-4 (2, and 4% of DRBP). The decrease in swelling capacity with increasing DRBP is likely due to the higher fiber content, which swells less than rice in water. Water absorption index (WAI) results indicated that no significant difference between the control sample (NR-0) with other sample treatments (NR-2, NR-4, and NR-6) however WAI value was high in *nurungji* (10.16±2.03 g/g) with 10% of DRBP (NR-10) with no difference to *nurungji* with 8% (NR-8) of DRBP. The increased water absorption index at higher powder concentrations suggests that the fibers in radish roots can retain more water within their structure. Hence preparation of *nurungji* added with DRBP may have an increased effect on WAI. Apart from this, the water solubility index (WSI) showed a significant decreasing difference between the control sample (NR-0) and other samples treatments, it was ranging from 8.06±0.18% to 5.30±0.20%, thus the utilization of DRBP during *nurungji* preparation decreases the WSI value. The reduction in the water solubility index is consistent with the presence of more insoluble fibers, which reduce the overall solubility of the *nurungji* matrix. Water content (WC) results, indicated a low value of WC (2.11±0.21) in control sample (NR-0) while NR-10 (*nurungji* with 10% of DRBP) was found to be high in water content (9.23±0.00%). It was found that the moisture content results for all sample treatments were in range with the moisture content found in 5 different commercial *nurungji* products (Yang and Choi, 2016). Our research suggested that preparation

Table 4. Hydration properties and water content of *nurungji* added with dried-radish root *bugak* powder coated with superfine glutinous and non-glutinous powders

Samples	SC (mL/g)$^{1)}$	WAI (g/g)	WSI (%)	WC (%)
NR-0	10.33±0.57$^{2)a3)}$	7.11±0.50^{c}	8.06±0.18^{a}	2.11±0.21^{d}
NR-2	8.00±0.62^{b}	7.81±0.95^{c}	7.11±0.09^{b}	2.87±0.22^{c}
NR-4	7.66±0.57^{bc}	8.24±0.45^{bc}	6.57±0.03^{c}	3.24±0.29^{c}
NR-6	6.83±0.57^{c}	7.13±0.54^{c}	6.14±0.03^{d}	4.48±0.26^{b}
NR-8	6.33±0.28^{d}	9.73±1.02^{b}	5.25±0.12^{e}	8.82±0.31^{a}
NR-10	4.83±0.57^{e}	10.16±2.03^{a}	5.30±0.20^{e}	9.23±0.00^{a}

$^{1)}$SC, swelling capacity; WAI, water absorption index; WSI, water solubility index; WC, water content.
$^{2)}$Values are mean±SD (n=3).
$^{3)}$Values with different superscripts within a column are significantly different by Duncan's multiple range test ($p<0.05$).

of *nurungji* with DRBP may increase the water content value of *nurungji* food products however addition of DRBP above 6% may produce *nurungji* food products with water content above the recommended water content of *nurungji* food products of 6% according to KS (T036). Higher water content in treated samples suggests that adding radish root powders increases the overall moisture retention, which could positively or negatively impact shelf life and texture, depending on the products's storage conditions and intended use.

3.5. Rheological characteristics

The rheological characteristics of food materials affect their processing, appearance, texture, taste, and shelf life (Tang et al., 2022). As indicated on Fig. 2A. Steady shear properties of control sample (NR-0) showed highly shear-thinning fluids with high yield stress compared to sample with powders of dried-radish root *bugak* coated with superfine glutinous and non-glutinous rice powder however NR-8 and NR-10 showed no significance. This might be caused by the addition of DRBP with high fiber content, particle aggregation, and starch dispersions (Chang et al., 2008; Cho, 2010). The magnitude of apparent viscosity indicated on Fig. 2B was higher than those of control samples however the addition of DRBP coated with glutinous and non-glutinous superfine rice powders showed no significant difference in viscosity between all samples- treatments. Park

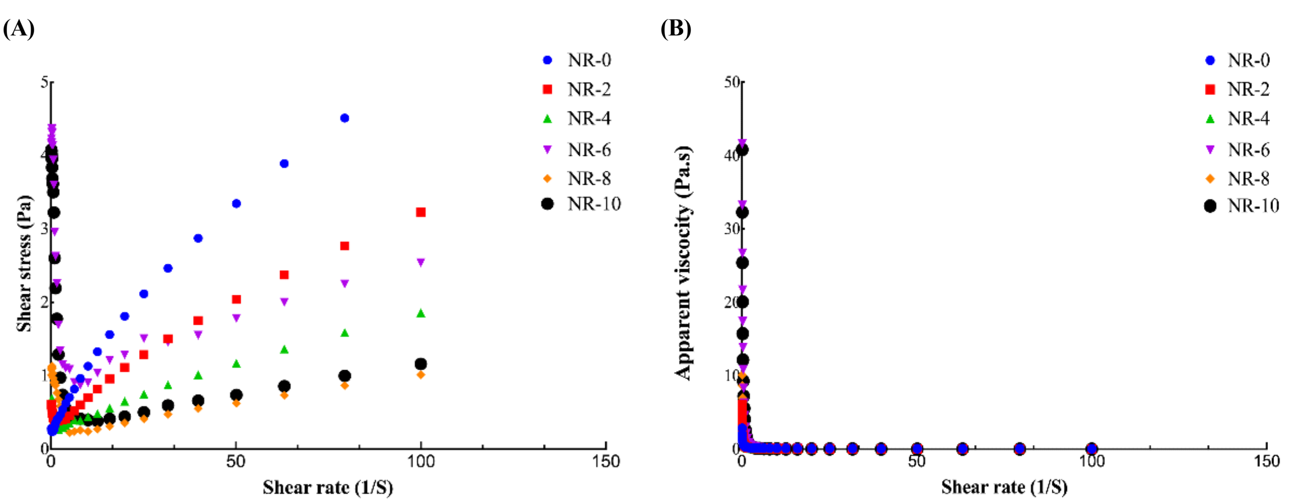

Fig. 2. Rheological properties of *nurungji* samples powder; effect of shear rate on shear stress of *nurungji* samples (A) and effect of shear rate on apparent viscosity of *nurungji* samples (B). NR-0, rice *nurungji* without addition of dried-radish root *bugak* powder coated with superfine glutinous and non-glutinous rice powders; NR-2, NR-4, NR-6, NR-8, and NR-10, rice radish *nurungji* with 2, 4, 6, 8, and 10% of dried-radish root *bugak* powder coated with superfine glutinous and non-glutinous rice powders.

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and Cho (2004) found that protein content and particle size distribution are factors that might affect viscosity of flour, hence it is believed that the addition of DRBP coated with glutinous and non-glutinous superfine rice powders reduced gluten content of *nurungji*, decreased starch content, and increased particle size, which might affect the viscosity characteristics.

3.6. Scanning electron microscopy (SEM)

Scanning electron microscopy examination showed a difference in microstructures of the different *nurungji* formulations with different levels of DRBP coated with superfine glutinous and non-glutinous powders (Fig. 3) however control sample (NR-0) and NR-2 (2% of DRBP) exhibited no difference, homogeneous structure with little air bubbles of similar size. It was observed that the addition of DRBP coated with glutinous and non-glutinous superfine rice powders affects the structure of prepared *nurungji* compared to control sample treatments. As the increasing of the level of DRBP increases the structure of produced *nurungji* becomes more compact, thicker cell walls and non-homogeneous cell structure.

3.7. Electronic tongue and nose

The human sense of taste includes five primary tastes: sweet, sour, bitter, salty, and umami. Used trained or untrained human sensory panels to evaluate the flavor of various food products. However, operating and training a sensory panel is time-consuming and costly. Sensory panels may generate bias if panelists are not well-trained. Hence, many researchers used e-tongue, a quick, accurate, and cost-effective alternative to the human tongue (Tan and Xu, 2020). E-tongue of five sample treatments of *nurungji* added with DRBP coated with superfine glutinous and non-glutinous rice powders were analyzed and compared with control sample (NR-0) as indicated on (Fig. 4A). The control sample (NR-0) had high scores in saltiness, sweetness, and bitterness compared to sample treatments added with DRBP while umami and sourness were found to be high in NR-6 (*nurungji* treated with 6% of DRBP). Therefore, adding DRBP to *nurungji* has an increasing effect on umami and sourness but decreases effects on saltiness, sweetness, and bitterness. This might be due to coating radish root with superfine glutinous and non-glutinous rice powder and heat treatment (steaming operation) applied to dried-radish root *bugak* during manufacturing. These pre-treatment operations (coating and steaming) and roasting (Cho et al., 2020) might reduce radish's pungent flavor. To identify the differences or similarities between control and treatment samples with DRBP principal component analysis (PCA) was used (Fig. 4B), the addition of DRBP affected taste among control and sample treatments however no significant difference between NR-8 and NR-10 (*nurungji* with 8 and 10% DRBP respectively). Electronic nose (odor characteristics) was analyzed by PCA as shown on Fig. 4C, PCA results indicated that no significant difference in odor characteristics between control sample (NR-0) and *nurungji* with 2%, and 4% of DRBP (NR-2 and NR-4) however different from other samples. The sample treatments with 8%, and 10% of DRBP also were similar in odor features while treatment sample with 6% of DRBP (NR-6) exhibited unsimilarity odor characteristics with all sample treatments. There are available studies related to sensory odor tastes of *nurungji* added with DRBP but Chen et al. (2017) reported that the radish odor is particularly described as pungent and might be attributed to the concentration of isothiocyanates and thiocyanates which may affect the sensory taste of *nurungji* samples added with DRBP.

3.8. Antioxidant property

Table 5 shows the total polyphenol and flavonoid contents of *nurungji* to which DRBP were added. The total polyphenol content was 21.34±1.78 mg GAE/mL in the control sample, without significant differences with NR-2, NR-4, and NR-6 sample treatments but significantly different ($p<0.05$) with NR-8, and NR-10. The polyphenol contents were found to be high in NR-10 (*nurungji* with 10% of DRBP) however with NR-8 sample no significant differences were observed. Therefore, the total polyphenol content increased significantly as the amount of DRBP added increased. The total flavonoids content was low in control sample (7.46±1.02 mg GAE/mL) compared to other sample treatments, the TFC increased in proportion to the amount of DRBP added, however, NR-6 sample (*nurungji* with 6% of DRBP) was high in TFC (21.75±2.04 mg GAE/mL). The TPC and TFC results were found to be in range with the research reported in 5 different commercial *nurungji* products by Yang and Choi (2016) and Hwang et al. (2020) but

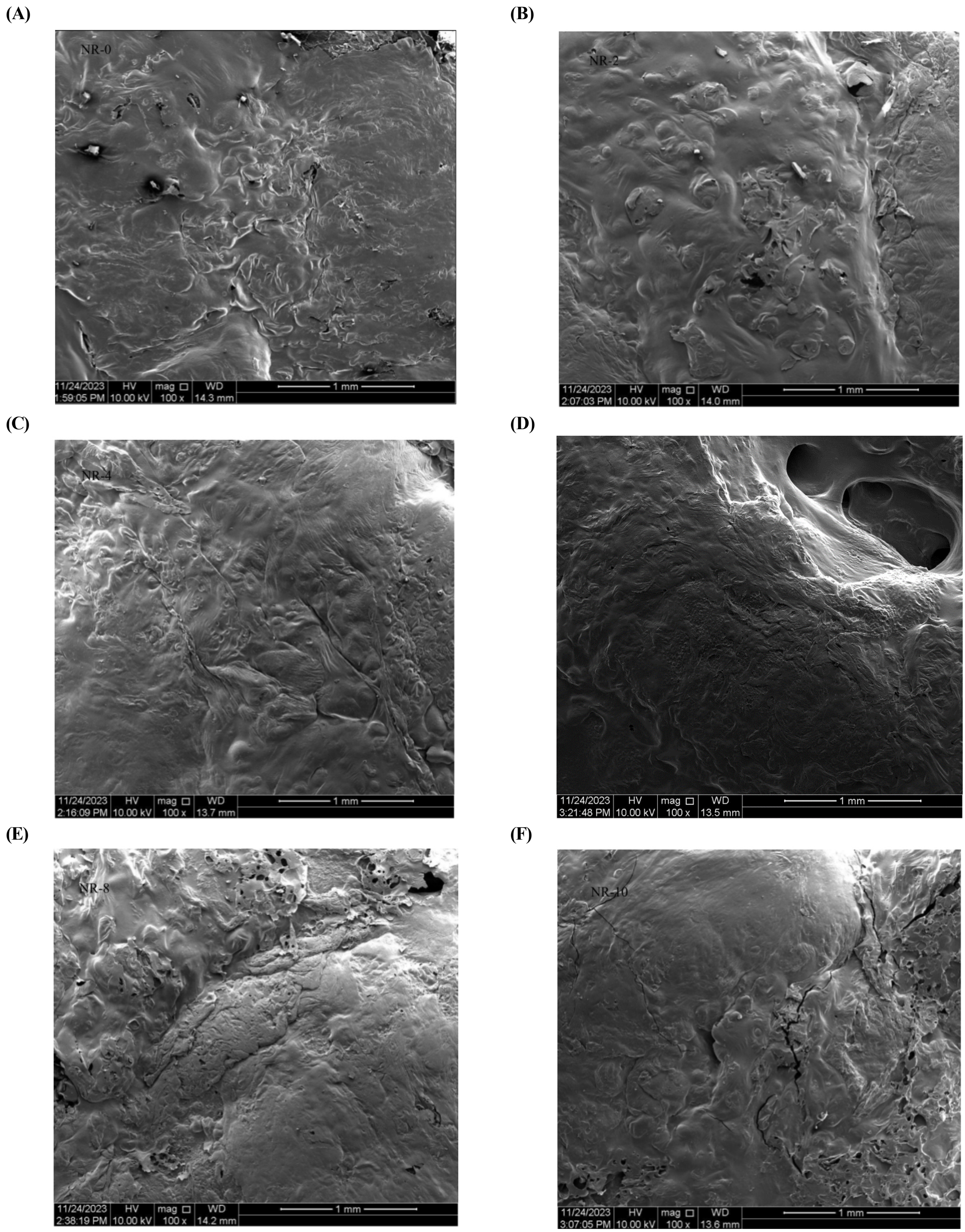

Fig. 3. Scanning electron micrographs of *nurungji* added with different levels of dried-radish root *bugak* powder coated with superfine glutinous and non-glutinous rice powders at magnification 100×. A, NR-0; B, NR-2; C, NR-4; D, NR-6; E, NR-8; F, NR-10.

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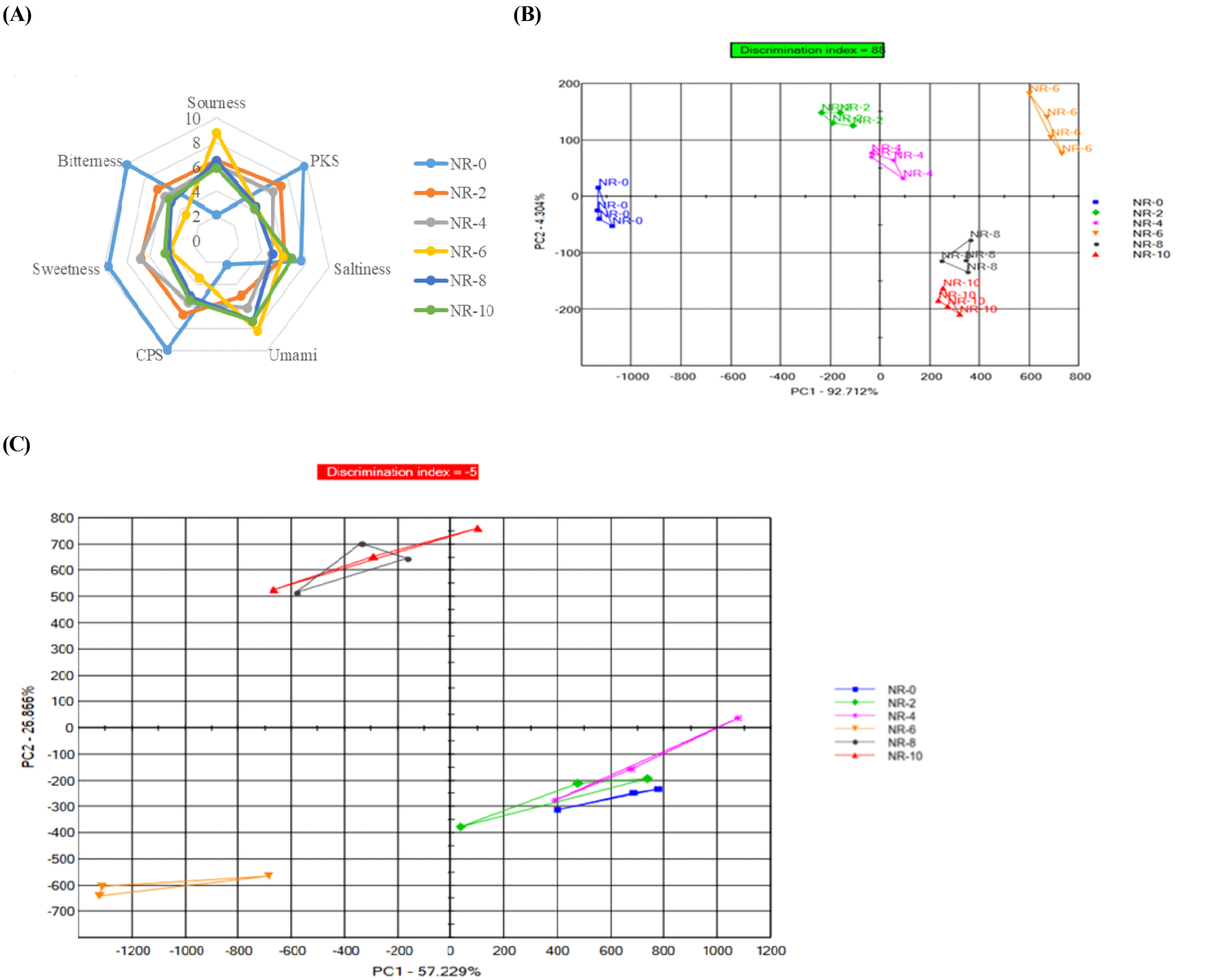

Fig. 4. Electronic tongue and electronic nose patterns of the *nurungji* added with dried-radish root *bugak* powder coated with superfine glutinous and non-glutinous rice powders. PKS and CPS are two universal sensors of the device (Shen et al., 2022), (A), Radar plot for the electronic tongue; (B), PCA (principal component analysis) plot based on electronic tongue data; (C), PCA plot based on electronic nose signals.

different from other *nurungji* food products added with different food materials (Lee, 2018; Yong and Kang, 2022). Besides, Table 5 shows the results of measuring the DPPH radical scavenging activity and indicated that the DPPH assay was lowest in control sample (NR-0) with 8.68±1.88 compared to other sample treatments. The more we increased the amounts of DRBP also DPPH assay increased however, there were no statistically significant differences in DPPH scavenging activity of *nurungji* treated with DRBP coated with superfine glutinous and non-glutinous rice powders samples. The *nurungji* treated with 4% (NR-4%) exhibited a high value of DPPH assay of 16.29±7.60 compared to other samples. our results are found to be in range with DPPH radical scavenging activity reported in 5 different commercial *nurungji* products by Yang and Choi (2016). There may few or no available research about *nurungji* fortified with white radish powders but our findings revealed that additional of DRBP coated with superfine glutinous and non-glutinous rice to *nurungji* preparation may improve the antioxidant activity (DPPH scavenging activity) compared to control *nurungji* sample products.

Table 5. Contents of total polyphenol and flavonoid, and antioxidant activities of *nurungji* added with dried-radish root *bugak* powder coated with superfine glutinous and non-glutinous powders

Samples	Total polyphenol (mg GAE/mL)[1)]	Total flavonoid (mg NE/mL)	DPPH (%)
NR-0	21.34±1.78[2)b3)]	7.46±1.02[c]	8.68±1.88[c]
NR-2	21.00±2.59[b]	12.57±3.06[bc]	12.67±1.66[bc]
NR-4	23.06±0.59[b]	9.50±1.77[c]	16.29±7.60[b]
NR-6	21.69±2.97[b]	21.75±2.04[a]	13.03±2.17[bc]
NR-8	25.47±3.56[a]	15.29±0.58[b]	13.40±0.62[bc]
NR-10	27.87±2.14[a]	20.05±5.23[ab]	14.48±1.25[bc]
Vitamin C (0.1%)			58.69±2.17[a]

1)GAE, gallic acid equivalent; NE, naringin equivalent; DPPH, 2,2-diphenyl-1-picryl-hydrazyl radical.
2)Values are mean±SD (n=3).
3)Values with different superscripts within a column are significantly different by Duncan's multiple range test.

4. Conclusions

In this study, DRBP was added to rice *nurungji* preparation in different ratios, and their physicochemical quality characteristics and sensory properties (E-tongue and E-nose) were analyzed. Total polyphenol and flavonoid contents, hardness, total soluble solids (°Brix), pH, WAI, water content, and b hunter color value (yellowness) increased significantly with higher amounts of DRBP added in rice *nurungji* processing, but swelling capacity, WSI and L hunter color (whiteness) value decreased with the increasing proportional of DRBP added. The E-tongue showed a significant difference between control sample (NR-0) and other sample treatments with high scores in saltiness, sweetness, and bitterness in control sample but low scores for umami and sourness. E-nose indicated no difference between control sample (NR-0) and NR-2 and NR-4 however significant differences were found from other sample treatments. SEM images exhibited compact, thicker cell walls and non- homogenous cell structures as the amount of DRBP was added. Therefore, considering the physical-chemical quality, SEM images, and E-tongue results found, it would be desirable to prepare *nurungji* with up to 6% of DRBP. More study is needed to develop *nurungji* food items with white radish root juice and dried uncoated radish root powders, as well as to compare their physicochemical and nutritional quality attributes to existing *nurungji* food products. Additionally, further research is needed to use DRBP as an ingredient in the development of various food products.

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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, Kang YH. 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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