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Production and Quality Characteristics of Gluten-Free Noodles Made with Pregelatinized Rice Flour

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Abstract

This study aimed to establish the optimal conditions for producing gluten-free noodles by varying the amount of pregelatinized rice flour added to the regular rice flour and investigating their quality characteristics. With an increase in the amount of added pregelatinized rice flour, the brightness of the noodles decreased, and the color became more yellow both before and after cooking. Adding pregelatinized rice flour to the noodles also increased hardness, elasticity, chewiness, stickiness, and adhesiveness. The textures of the two groups of samples (PR-10 and PR-15) were similar to that of the control, indicating comparable structural characteristics. Furthermore, the absence of gluten made it inherently challenging to form gluten-free noodles. Still, adding pregelatinized rice flour improved the processability of the dough, leading to better noodle formation. An optimal addition of 15% pregelatinized rice flour was deemed suitable for optimal noodle formation in gluten-free noodles. This study established blending conditions using pregelatinized rice flour to improve the poor processability of gluten-free noodles. The findings are expected to be valuable for the industry's future development of gluten-free processed food.

Keywords: gluten-free, rice flour, pregelatinized rice flour, noodle

Introduction

Although rice is one of the three major cereal crops, its consumption is continuously decreasing in contrast to the consumption of wheat because of westernized dietary habits (Um & Yoo, 2013). Wheat flour is the main ingredient in most western foods, but it contains gluten (Nam et al., 2015). Despite its beneficial tensile strength and viscoelasticity, gluten is known to cause celiac disease (Joung et al., 2017). Celiac disease is an allergic reaction to gluten caused by gliadin, which is a component of wheat flour. The symptoms include diarrhea, vomiting, abdominal pain, and distension (Nam et al., 2015). As a substitute material for gluten-free food, ingredients such as rice, corn, sorghum, buckwheat, millet, sweet potatoes, and potatoes are used. Among them, rice has the properties of being easily digested and absorbed, and it is also hypoallergenic, mild, and colorless, with a high yield (Wu et al., 2019). Rice, on the other hand, does not contain gluten, making it a good alternative to wheat flour. In western countries, rice has been added as a gluten-free ingredient in various processed foods (Lee et al., 1995) from cookies (Yildiz & Gocmen, 2021) to bread (Kang et al., 2014) and pasta (Jung & Yoon, 2016). Among cereal-based flours, rice flour is also a suitable food for patients with celiac disease. Based on characteristics that include a low probability of allergic reactions, low fat content, low sodium content, high digestibility, and white color, rice flour is a desirable ingredient for gluten-free products (Park & Eun, 2021). In particular, noodles have been consumed as a meal replacer in South Korea, where the consumer preference for noodles is steadily increasing (Song et al., 2017). The sales of noodles in 2022 showed a 12.3% increase compared to the previous year (KOSIS, 2022). However, because rice lacks gluten, the formation of noodle dough is difficult, and cooked noodles have inadequate tensile strength and viscoelasticity (Seo et al., 2011). Thus, studies have investigated ways to improve their inadequate texture through the addition of a dough conditioner (vital wheat gluten, bean powder, gums, etc.) (Park & Eun, 2021).

Hydroxypropyl methyl cellulose (HPMC) is a globally accepted cellulose derivative with good stability and excellent water solubility. The hydroxyl group (-OH) in HPMC mediates hydrogen bonding to allow HPMC to serve as an alternative to gluten as a thickener and binder (Burdock, 2007). Studies have investigated the use of cellulose derivatives with such benefits to develop food additives to replace the gluten in muffins (Kim

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& Kang, 2012), noodles (Cho et al., 2011), and bread (Sivramakrishnan et al., 2004). Han et al. (1988) reported that α-rice flour can be produced via the gelatinization of rice flour, which characteristically raises the viscosity. Thus, this study aimed to establish the optimal conditions for producing rolled noodles by varying the added amount of pregelatinized rice flour (PR) to ordinary rice flour, and determine the quality characteristics of the produced noodles.

Materials and Methods

Materials

The rice flour used in this study was the commercially available Nonghyup Gangwondo Rice Flour (Injekirin Nonghyup Co., Ltd., Gangwon-do, Korea). Noodles were produced by adding PR (Yoosung Food Co., Ltd., Gwangju-si, Gyeonggi-do, Korea) to ordinary rice flour at ratios of 0% (control), 10% (PR-10), 15% (PR-15), 20% (PR-20), and 25% (PR-25). Additionally, raw bean powder (Hamyang-Nonghyup Co., Ltd., Hamyang-gun, Korea), salt (Hanju Co., Ulsan, Korea), and HPMC (Cheminex Co., Ltd, CN10T, AnyAddy®, Korea) were added to the noodles. The optimal conditions for flour dough formation were determined by setting the formulas through preliminary experiments.

Preparation of noodles with rice flour

To produce noodles with rice flour, blended rice flour was prepared through the addition of 10, 15, 20, or 25% PR, along with the raw bean powder, HPMC, and salt, which was dissolved in the mixing water prior to use (Table 1). The HPMC was added at a ratio of 1% based on the amount of rice flour to assist with dough conditioning. At room temperature, the blended flour and mixing water were added to a dough mixer (KMM020, Kenwood Ltd., Hertfordshire, UK) and mixed for 3 min. The prepared dough was rolled in a noodle maker (HSN-2, Hunwoo, Seoul, Korea) in a five-step rolling process using rolling steps of 7.5, 5.0, 4.0, 3.3, and 2.7 mm. The noodles were cut to produce a 3 mm width and 2.4 mm thickness. In the case of the non-PR rice flour (control), the noodle dough did not form. The characteristics of the noodles with the PR-blended rice flour and 100% wheat flour (wheat) were compared. Because of the high water absorption of rice flour, the dough was produced by decreasing the amount of water by 8.3% for every 5% decrease in the rice-flour content.

Color and appearance of uncooked noodles

The color of the noodles before and after cooking was measured using a colorimeter (Model CM-5, Minolta Co., Tokyo, Japan) at the stage of the 2.4 mm noodle dough prior to cutting. The Hunter values of lightness (L), redness (a), and yellowness (b) were adjusted using the standard white plate for the color measurements. The color difference (ΔE) was calculated using $\Delta E = \sqrt{L^2 + a^2 + b^2}$, and images of the produced noodles were obtained by placing the noodles on a black stainless plate. The visible differences in appearance were observed by arranging the noodles in sequence.

Textural properties of noodles

To measure the texture of the cooked noodles, the Texture Analyzer™ (TA-XT2, StableMicro System, Godalming, Surrey, England) was used. In the texture profile analysis (TPA) mode, five repeated measurements were taken for each sample using a cylinder probe (P/35, 35 mm dia, circle), and mean values were obtained. After cooking the noodles in 100 °C boiling water for 4 min, the noodles were cooled in running water for 1 min and left at room temperature for 3 min. The measurements were taken after removing the water. The cooking time was set as the time until the internal and external colors became equal. In the case of wheat, the noodles were cooked for 14 min until the internal and external colors became equal. Six strands of cooked noodles with a length of 5 cm were placed in parallel on a plate, and after

Table 1. Formulas for rice noodles with different pregelatinized rice flour contents

Sample	Ingredients (g)						Water (g)
	Rice flour	Wheat flour	PR[1)]	Soybean flour	HPMC[2)]	Salt	
Wheat	-	100	-	2.0	1.0	3.0	37.3
Control	100	-	-	2.0	1.0	3.0	53.3
PR-10	90	-	10	2.0	1.0	3.0	50.0
PR-15	85	-	15	2.0	1.0	3.0	46.7
PR-20	80	-	20	2.0	1.0	3.0	43.3
PR-25	75	-	25	2.0	1.0	3.0	40.0

[1)]PR: pregelatinized rice flour.
[2)]HPMC: hydroxypropyl methyl cellulose.

Table 2. Texture analyzer operating conditions for cooked noodles with different pregelatinized rice flour contents

Item	Condition	
Test type	TPA test	Tensile strength test
Measurement type	Two bite compression	Return to start
Sample size	3.0 × 2.5 × 50 mm	3.0 × 2.5 × 300 mm
Probe	35 mm dia, circle	Spaghetti/Noodle tensile rig
Test speed	5.0 mm/s	2.0 mm/s
Deformation	70%	120 mm
Trigger force	0.049 N	0.049 N

two repeated compressions to induce a 70% change in the overall thickness from the surface, the hardness, springiness, cohesiveness, adhesiveness, gumminess, and chewiness were measured. Table 2 presents the details of the measurement conditions.

Tensile properties of noodles

The Texture Analyzer™ (TA-XT2, StableMicro System, Godalming, Surrey, England) was also used to measure the tensile strength of the cooked noodles. For each sample, three repeated measurements were taken using a noodle tensile rig, and mean values were obtained. The noodles with PR-blended rice flour were cooked in 100 °C boiling water for 4 min, cooled in running water for 1 min, and left at room temperature for 3 min. The measurements were taken after removing the water. In the case of wheat, the noodles were cooked for 14 min, while all the other conditions remained identical. A strand of noodle was wrapped around a tensile rig from the top to the bottom in 20 mm intervals to measure the pulling force (N) required to break the strand, as well as the stretched distance (mm). Table 2 presents the details of the measurement conditions.

Cooking characteristics of noodles

The methods of Kim et al. (1996), where the differences in the weights of noodles before and after cooking were compared, were used with modifications to measure the cooking characteristics of the noodles with rice flour. The weight of the cooked noodles was measured after cooking 25 g of noodles in 500 mL of boiling water for 4 min, cooling the noodles in running water for 1 min, and leaving the noodles at room temperature for 3 min. In the case of wheat, the cooking time was 14 min, while all the other conditions remained identical. After weighing, the cooked noodles were placed in a 250 mL graduated cylinder containing 150 mL of distilled water to measure the increase in volume. The water absorption of the cooked noodles was estimated using the following equation:

$$\text{Water absorption (\%)} = \frac{\text{weight of cooked noodles} - \text{weight of uncooked dnoodles}}{\text{weight of uncooked dnoodles}} \times 100$$

Elution of cooked noodles

To measure the elution of cooked noodles, 25 g batches of noodles with rice flour and noodles with wheat flour were cooked in 500 mL of boiling water for 4 min and 14 min, respectively, after which 500 mL of water was added to measure the turbidity at 675 nm using a spectrophotometer (UV-1080, Shimadzu Co., Kyoto, Japan) and express the elution in terms of the absorbance.

Statistical analysis

All the experiments were independently repeated three times, with the textural properties of the noodles measured five times. The data were thus expressed as the mean±SD. To test the significance, an analysis of variance (ANOVA) was performed using SPSS 23.0 (SPSS Inc., Chicago, IL, USA), and Duncan's multiple range test was performed. The level of significance was set at $p<0.05$.

Results and Discussion

Color and appearance of uncooked noodles

The colors of the gluten-free noodles with PR-blended rice flour are presented in Table 3. The lightness (L) of the uncooked control noodles (with ordinary rice flour) was the highest at 86.3, followed by the wheat noodles at 84.0. However, the lightness did not vary significantly after cooking for the noodles with PR-blended rice flour ($p<0.05$). Jung (2020) reported that the L value of rice flour before gelatinization was high (96.47-96.64), with a white color. In agreement with this, the control in this study, which had the highest content of ordinary rice flour, displayed the highest lightness value. The L values of the noodles with the PR-blended rice flour were low (78.3-78.6), which coincided with

Table 3. Hunter's color values of cooked noodles with different of pregelatinized rice flour contents

Sample[1)]		Hunter's color value			
		L	a	b	ΔE
Uncooked	Wheat	84.0±0.47[b]	0.35±0.03[e]	12.23±0.17[f]	84.9±0.44[b]
	Control	86.3±4.39[c]	0.15±0.38[d]	9.95±4.10[a]	86.9±3.95[c]
	PR-10	78.5±1.30[a]	−1.11±0.02[a]	6.53±0.23[b]	78.8±1.29[a]
	PR-15	78.6±1.55[a]	−1.06±0.01[a]	8.04±0.09[c]	79.0±1.54[a]
	PR-20	78.4±1.02[a]	−0.96±0.02[b]	8.52±0.16[d]	78.8±1.01[a]
	PR-25	78.3±0.96[a]	−0.68±0.04[c]	9.42±0.23[e]	78.9±0.97[a]
Cooked	Wheat	51.2±0.52[a]	−2.44±0.02[a]	−0.45±0.02[a]	51.3±0.51[a]
	Control	ND[2)]	ND	ND	ND
	PR-10	69.4±0.05[e]	−1.39±0.01[e]	4.70±0.06[e]	69.6±0.05[e]
	PR-15	63.3±0.39[d]	−1.70±0.02[a]d	1.69±0.07[d]	63.3±0.39[d]
	PR-20	57.0±0.36[c]	−2.15±0.02[c]	0.62±0.07[c]	57.0±0.35[c]
	PR-25	55.2±0.32[b]	−2.22±0.05[b]	0.46±0.04[b]	55.2±0.32[b]

[1)] The values with different superscripts within a column are significantly different (p<0.05) by Duncan's multiple range test.
[2)] ND: Not detectable.

the results reported by Choi & Jung (2021) that the L value of PR varied according to the rice cultivar, with an influence from the yellow tint of rice. An increasing trend was found for the yellowness (b) as the PR content increased, which was also presumed to be due to the differences in the color of the rice cultivar and PR. The color of the cooked noodles could not be measured for the control because the noodle dough could not be formed. This coincided with the results reported by Park & Eun (2021) that noodle dough could not be formed when the added amount of rice flour increased to a certain level. The brightness of the sample decreased to 69.4 in PR-10 and 55.2 in PR-25. The yellowness increased to 4.71 in PR-10 and then decreased to 1.96 in PR-15. Wadchararat et al. (2006) reported that the viscosity and color varied according to the method of physical treatment used to process α-rice flour, such as the water content and heat-treatment temperature. The PR in this study was yellowish in color, but the yellowness seemed to decrease during the heat treatment. Fig. 1 presents images of the noodles with PR-blended rice flour. Noodle dough could be formed using PR-10, and no significant variation in color or appearance was observed across the groups, except for the wheat group. Thus, the addition of PR was shown to improve the inadequate dough conditioning ability of rice flour and allow noodle dough formation.

Fig. 1. Appearances of noodles with different pregelatinized rice flour contents.

Table 4. Textural profiles of noodles with different pregelatinized rice flour contents

Sample[1)]	TPA					
	Hardness (N)	Springiness	Cohesiveness	Gumminess (N)	Chewiness (N·mm)	Adhesiveness (N·mm)
Wheat	84.6±4.36[a]	0.015±0.004[a]	0.023±0.005[ab]	1.61±0.05[a]	0.021±0.007[a]	−1.76±0.91[d]
PR-10	97.0±4.89[b]	0.016±0.004[a]	0.019±0.002[a]	1.85±0.19[b]	0.030±0.010[ab]	−7.84±1.87[c]
PR-15	108±1.78[c]	0.019±0.001[a]	0.025±0.001[b]	2.28±0.04[c]	0.037±0.005[b]	−11.5±0.45[b]
PR-20	121±5.14[d]	0.017±0.003[a]	0.019±0.001[a]	2.65±0.10[d]	0.051±0.004[c]	−13.6±1.11[ab]
PR-25	141±5.20[e]	0.015±0.001[a]	0.020±0.001[ab]	2.82±0.06[d]	0.059±0.009[c]	−15.9±1.83[a]

[1)]The values with different superscripts within a column are significantly different (p<0.05) by Duncan's multiple range test.

Textural properties of noodles

The texture profiles of the noodles with the PR-blended rice flour are shown in Table 4. As the PR content increased, the hardness increased compared to Wheat (84.6 N), reaching PR-10 (97.0 N), PR-15 (108.0 N), PR-20 (121.0 N), and PR-25 (141.0 N). This agreed with Lee et al. (1995), where an increase in the content of α-rice flour led to an increase in hardness. The result may also be attributed to the strong viscosity of PR. However, the texture approached the level of rice cake as a higher amount of PR was added, which lent support to the trend of a significant increase in adhesiveness, or the force causing a substance to adhere to surfaces. Foods such as rice cake are known to have unique textural properties, including their adhesiveness and tensile strength (Kohyama et al., 2007). Chewiness increased to 0.030 N in PR-10 and 0.059 N in PR-25. Gumminess increased to 1.85 N, 2.28 N, 2.65 N, and 2.82 N in line with an increase in the added amount of PR. This agreed with the results reported by Han et al. (1988) that the hardness, chewiness, and gumminess increased with the added amount of α-rice flour. The springiness and cohesiveness did not vary significantly (p<0.05). The PR-10 and PR-15 resembled the wheat noodles to the highest degree with respect to texture. Thus, PR was shown to play a key role in the formation of noodle dough as an alternative to gluten.

Tensile properties of noodles

The tensile profiles of the noodles with the PR-blended rice flour are presented in Table 5. The tensile strengths of the noodles with the PR-blended rice flour were as follows: wheat (0.312 N), PR-10 (0.061 N), PR-15 (0.138 N), PR-20 (0.092 N), and PR-25 (0.078 N). Thus, the group with the closest tensile strength to that of wheat was PR-15, while noodle dough could not be formed using the control. In producing noodles with a gluten-free material, the appearance, taste, aroma, and texture may show quality degradation (Jo et al., 2020). In this study, the addition of PR and HPMC to overcome the inadequate processability was shown to improve the textural properties.

Table 5. Tension profiles of cooked noodles with different of pregelatinized rice flour contents

Sample[1)]	Tension	
	Force (N)	Distance (mm)
Wheat	0.312±0.018[d]	−65.6±7.58[a]
PR-10	0.061±0.006[a]	−12.5±2.23[e]
PR-15	0.138±0.013[c]	−41.6±3.25[b]
PR-20	0.092±0.001[b]	−31.7±3.02[c]
PR-25	0.078±0.006[ab]	−24.0±2.05[d]

[1)]The values with different superscripts within a column are significantly different (p<0.05) by Duncan's multiple range test.

Jung et al. (2015) reported that noodle molding was difficult using gluten-free dough because noodles with reduced tensile strength tended to break. Thus, the addition of PR in this study was shown to improve the noodle molding and noodle-breaking phenomenon.

Elution and cooking characteristics of noodles

The cooking characteristics of the gluten-free noodles are shown in Table 6. The results demonstrated that the water absorbance values of the noodles with gluten-free rice flour were as follows: wheat (142.2%), PR-10 (72.8%), PR-15 (50.4%), PR-20 (43.8%), and PR-25 (36.9%). Thus, the absorbance decreased as the added amount of PR increased. The volume of the cooked wheat noodles was 211 mL, and the following decreasing trend with an increase in PR was observed: PR-10 (193 mL), PR-15 (188 mL), PR-20 (186 mL), and PR-25 (185 mL). The weight of the cooked noodles also tended to decrease as the added amount of PR increased. This was presumably because the texture of the rice flour and HPMC became more elaborate as the added amount of PR increased, which reduced the overall water absorbance, volume, and weight of the cooked noodles. The turbidity increased as follows: wheat (0.16), PR-10 (0.20), PR-15 (0.26), PR-20 (1.16), and PR-25 (1.49). As an indicator of cooking loss through the elution of noodles during cooking (Park & Eun, 2021), the turbidity was reported to increase as the solid

Table 6. Cooking characteristics of noodles with different pregelatinized rice flour contents

Sample[1)]	Cooked noodle			Cooking water
	Weight (g)	Volume (mL)	Water absorption (%)	Turbidity (675 nm)
Wheat	60.7±1.15[e]	211±1.15[e]	142.2±4.95[e]	0.16±0.02[a]
PR-10	43.3±1.15[d]	193±2.31[d]	72.8±4.59[d]	0.20±0.02[ab]
PR-15	37.7±0.58[c]	188±0.58[c]	50.4±2.29[c]	0.26±0.03[b]
PR-20	36.0±0.00[b]	186±0.58[b]	43.8±0.12[b]	1.16±0.07[c]
PR-25	34.3±0.58[a]	185±1.15[a]	36.9±2.37[a]	1.49±0.06[d]

[1)]The values with different superscripts within a column are significantly different (p<0.05) by Duncan's multiple range test.

content during cooking decreased (Jeong et al., 2019). Thus, a suitable level of PR addition was necessary as an increase in the added amount of PR led to an increase in cooking loss despite an increase in the dough conditioning of the rice flour.

Conclusion

This study established the optimal conditions for producing gluten-free noodles by varying the amount of PR added to ordinary rice flour. The quality characteristics of the produced noodles were also determined. In relation to the color, the lightness of the noodles with the PR-blended rice flour decreased after cooking as the added amount of PR increased. On the other hand, the yellowness was shown to increase. The weight, volume, and water absorption decreased as the content of PR increased. In contrast, the turbidity increased, which indicated an increase in elution. All the measured textural properties of the noodles with PR-blended rice flour increased, from their hardness to their springiness, chewiness, gumminess, and adhesiveness, with the PR-10 and PR-15 groups exhibited textural properties similar to those of the noodles with wheat flour. While the absence of gluten made it difficult to form noodle dough using gluten-free noodles, the addition of PR was shown to improve the noodle processability. The noodles with 10% PR showed a 15% decrease in tensile strength, which suggested that the optimal level of PR for the formation of gluten-free noodle dough would be 15%. The blending conditions for the addition of PR to improve the inadequate processability of gluten-free noodles were established based on the findings of this study. The optimal conditions are expected to be useful in the processed gluten-free food industry.

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