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Research Article

Quality Characteristics of Noodles Produced Using Steam-Treated Dough Prepared with Psyllium Husk and Soaked-and-Dried Soybean

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We analyzed the quality characteristics of wheat-free, gluten-free dough, steam-treated dough, and cooked noodles. Dough was prepared from soaked-and-dried soybean (SDS) powder amended with 10%, 25%, or 40% psyllium husk; the SDS was prepared by soaking soybeans for 12 h at room temperature and hot air drying at 60°C for 24 h. Dough was then steam-treated at 120°C for 5, 10, or 15 min and subsequently formed into noodles. Dough and noodle can be made using SDS powder and psyllium husk powder, but it is difficult to maintain noodle shape after cooking without steam treatment. Steam treatment improved the texture of the dough, enabling noodle production. The hardness, gumminess, springiness, cohesiveness, and chewiness of the steam-treated dough were improved compared to nonsteamed dough, yielding a texture similar to wheat flour dough. Moreover, the dough cross-section became denser after steam treatment. As the cooking time increased, the hardness, gumminess, cohesiveness, and chewiness of cooked noodles decreased, and the springiness of cooked noodles increased by increasing of water absorption rate; overall, their form was maintained. Therefore, steam-treated psyllium husk-containing dough enables noodle production without the addition of gluten.

1. Introduction

Soybean *Glycine max* (L.) Merr. (Fabaceae) is among the world's oldest crops; it is native to China and widely cultivated in tropical and temperate regions Onuorah et al. [1]. Soybean contains isoflavones, nutraceuticals that reduce the risk of diseases, e.g., breast cancer, cardiac arrest, osteoporosis, kidney stones, and menopausal depression [2].

During soybean soaking, the isoflavone malonyl is converted into β-glucoside and hydrolyzed by endogenous β-glucosidase in the soybean cotyledon, thereby forming aglycone isoflavones [3]. During this process, glycosides in raw soybeans are assumed to be converted into aglycones. Thus, soybeans with high moisture content are dried for longer periods in hot air, increasing the aglycone content of soaked-and-dried soybeans (SDSs) [4]. The aglycone content is highest when SDSs are dried at 60°C because β-glucosidase activity is optimal at this temperature, which enhances glucoside decomposition and the aglycone content [4, 5]. Tofu prepared using SDS has a higher aglycone content than that prepared from normal soybean [4].

Psyllium (*Plantago ovata* Forssk.) husk is used in India to prevent skin diseases, hemorrhoids, constipation, and diarrhea. Recently, its consumption has increased in Europe and the United States [6, 7]. The soluble and insoluble dietary fiber of psyllium husk has excellent gel-forming ability and high water absorption capacity [8, 9]. The major constituents of psyllium husk are cellulose, lignin, pectin, gum, and mucilage [10]. The dietary fiber arabinoxylan is composed of various monosaccharides and many hydroxyl groups, such as hydrocolloids, which increase its water absorption and viscosity [11, 12]. Preparation of gluten-free bread using psyllium husk and rice flour improved the quality and storage period [13]. In bread production, psyllium husk is used as an enhancer to slow bread curing and to delay starch aging in wheat bread [14, 15]; the loaf volume of gluten-free bread prepared using psyllium husk and chickpeas was higher than that of a control group [16].

Superheated steam, produced by heating saturated vapor, has a temperature of 100–400°C [17]. The temperature of food treated with superheated steam rises rapidly due to the release of large amounts of latent heat condensation from water vapor, which is transferred to the food [18]. Superheated steam blocks oxygen from contacting food, thereby suppressing vitamin C oxidation, fat rancidity, oxygen-induced browning, and changes in the physicochemical properties of food [19], and has an enzyme inactivation and sterilizing effect on microorganisms [20, 21]. Superheated steam also lowers the fat content by removing oil and evenly distributing sodium in food via high heat transfer [22]. In flour treated with superheated steam, enzymes were inactivated, microorganisms were killed, and mycotoxin concentrations were reduced [23]. Oat dough treated with superheated steam had lower fat and starch contents, producing a denser structure that improved the texture [24].

Gluten is the main structure-forming protein in flour. This is because the resulting dough offers high elastic characteristics. Besides, gluten is implicated in several immune-mediated disorders, such as celiac disease [25–27]. Specifically, this kind of disorder demands a gluten-free diet (GFD); however, a GFD can itself be associated with digestive problems due to insufficient intake of dietary fiber and other nutrients [28]. According to the Food and Drugs Administration (FDA), a gluten-free product may be sufficiently defined as having <20 ppm (parts per million) of gluten while considering possible contamination during product creation [29, 30]. Furthermore, due to the absence of gluten protein, which gives acceptable viscoelastic properties to the product, gluten-free products usually have an inferior texture, flavor, and appearance [31]. Thus, hydrocolloids, due to their thickening, water retention, gelling, and emulsifying properties, are often used in the gluten-free formulation. In particular, hydrocolloids such as xanthan gum are added to the dough to stabilize the gluten-free network, increase intermolecular viscosity, and improve the texture of noodles [32, 33]. Additionally, okara flour from chickpea and soy used as thickeners, increased viscosity and enhanced the moistness of gluten-free bread [34]. More so, the addition of hydrocolloids to gluten-free rice bread improved volume, crumb structure, textural properties, and the overall eating quality of gluten-free rice bread [35].

Considering from the reports for improving gel-forming ability of psyllium husk [8, 9] and entanglement effect [36] by increasing of dietary fiber content and steam treatment, we hypothesized that the addition of psyllium husk, which has high water absorption and crosslinking, and the steam treatment, which increase crosslinking in dough produced from SDS, enabling the preparation of noodles that would maintain the noodle shape after cooking. In this study, we produced noodles using steam-treated dough prepared with psyllium husk and SDS and evaluated the quality characteristics and isoflavone contents. We also evaluated the feasibility of manufacturing gluten-free noodles without using wheat flour.

2. Materials and Methods

2.1. Materials. The soybeans (*Glycine max* L. Merrill) used for preparing SDS were obtained from the Chungju Agricultural Technology Center, Republic of Korea. Psyllium husk powder was purchased from Homijaru Co. (Seoul, Korea). Ethanol (99.9%), ethanol (94.9%), acetone, HCl, sulfuric acid (95%), NaOH, and diethyl ether were purchased from OCI Co. (Seoul, Korea). Phenolphthalein solution was purchased from Duksan General Science (Seoul, Korea). Heat-stable α-amylase (3000 U/mL), protease (350 U/mL), and amyloglucosidase (3260 U/mL) were purchased from Megazyme Chemical Co. (Wicklow, Ireland). For isoflavone content analysis, daidzein(16587-10MG), glycitein(43534-10MG), genistein(92136-10MG), MES hydrate (M8250-1KG), Trizma base (T1503-1KG), and Celatom (C8656-1KG) were purchased from Sigma-Aldrich Co. (MD, USA). Malonyldaidzin (132-13821-1MG), malonylglycitin (139-13831-1MG), and malonylgenistin (136-13841-1MG) were purchased from FUJIFILM Wako Pure Chemical Co. (Osaka, Japan). HPLC grade water, methanol, and acetonitrile were purchased from Honeywell, Burdick, and Jackson (NJ, USA).

2.2. Preparation of SDS Powder. SDS powder was prepared according to the procedure reported by Han et al. [4]. The 600 g of soybean was placed into a 10-fold volume of water and soaked at room temperature for 12 h. Swollen soybeans were dried at 60°C to constant weight to prepare SDS. SDS were ground in a grinder (80335, Elec-Tech Zhuhai Co., Xiangzhou, China) and passed through an 80-mesh sieve (Chunggye Sieve Co., Seoul, Korea) to make SDS powder.

2.3. Preparation of Dough, Steam-Treated Dough, and Cooked Noodles. Dough samples were prepared with SDS powder and psyllium husk powder following the formula ratio (Table 1) by kneading machine (WSS-6835P, Shenzhen Co., Ltd., Seoul, Korea) and forming into 4 mm-thick sheets using a noodle-making machine (AT-MOT-220 V, Electric Pasta Machine, MARCATO-AtlasMotor, PD, Italy). The doughs were then treated with steam at 120°C for 5, 10, or 15 min using an autoclave (WACS-1080, Daihan Scientific Co., Wonju, Korea). The steam-treated dough was formed into noodles with a thickness of 1.9 mm and a width of 8 mm using a noodle-making machine. Finally, noodles (40 g) were transferred to 500 mL of boiling water, boiled for 3, 6, or 9 min, and cooled for 1 min.

2.4. Proximate Composition of Nonsteamed- and Steam-Treated Doughs. Proximate composition was determined according to the Association of Official Analytical Chemists [37] and Seo et al. [38]. Moisture content was determined using the atmospheric pressure drying method at 105°C. Crude protein content was determined following the

Table 1: Formula ratio for preparation of dough.

	Wheat flour (g)	SDS powder (g)	Psyllium husk powder (g)	Water (mL)
WD[1)]	100	—	—	45[6)]
Dough-0[2)]	—	100	0	150
Dough-10[3)]	—	90	10	150
Dough-25[4)]	—	75	25	150
Dough-40[5)]	—	60	40	150

[1)]WD: wheat flour dough. [2)]Dough-0: dough added with 0% psyllium husk. [3)]Dough-10: dough added with 10% psyllium husk. [4)]Dough-25: dough added with 25% psyllium husk. [5)]Dough-40: dough added with 40% psyllium husk. [6)]The amount of water for preparing wheat dough based on Yuru and Xianlun [64].

Kjeldahl method using a Kjeldahl autoanalyzer (DKL 20, VELP, Usmate Velate, Italy) and calculated using a nitrogen-to-protein conversion factor of 6.25. Soxhlet extraction was used to determine the crude fat content. Mineral contents were analyzed using an electric furnace (FX-14, Daihan Scientific Co., Wonju, Korea) at 525°C. Carbohydrate weight was determined as the fraction of the total weight of the sample after excluding the moisture, crude protein, crude fat, and mineral contents.

Total dietary fiber content was determined according to AOAC method 991.43 [37]. In duplicate, 1.0 g of sample was weighed and added to 40 mL of MES/Tris buffer (pH 8.2) in a 400 mL tall-form beaker. After complete dispersion, 50 μL of heat-stable α-amylase solution was added and the mixture was incubated with shaking in a water bath (BS-21, Jeio Tech, Daejeon, Korea) at 97°C for 65 min. After cooling to 60°C, 100 μL of protease solution was added and the mixture was stirred at 60°C for 45 min. Subsequently, 5 mL of 0.561 N HCl was added to adjust the pH to 4.0–4.7, 300 μL of amyloglucosidase solution was added, and the solution was incubated at 60°C for 45 min. After completion of the reaction, 225 mL of 95% ethanol at 60°C was added. The test solution was vacuum filtered through a glass filter with Celite. The residue was washed twice with 78% ethanol, 95% ethanol, and acetone. The crude protein content was measured following the Kjeldahl method, and the crude ash content was weighed after heating at 525°C for 5 h using an electric furnace. The crude protein and crude ash contents minus the weight after drying were calculated as the dietary fiber content. The blank was calculated as follows:

$$\text{Blank (mg)} = \frac{BR_1 + BR_2}{2} - P_B - A_B, \qquad (1)$$

where BR_1 is weight of blank residue 1 (mg), BR_2 is the weight of blank residue 2 (mg), P_B is the weight of the crude protein content of BR_1 (mg), and A_B is the weight of the crude ash content of BR_2 (mg). Total dietary fiber was calculated as follows:

$$\text{Total dietary fiber (g/100 g)} = \frac{(R_1 + R_2)/2 - P - A - B}{(M_1 + M_2)/2} \times 100, \qquad (2)$$

Table 2: Operating conditions of texture analyzer.

Classification	Conditions
Type	TPA (texture profile analyzer)
Probe type	20 mm flat probe
Test speed	1.0 mm/s
Pretest speed	1.0 mm/s
Posttest speed	1.0 mm/s
Distance	70% of sample thickness
Trigger force	5 g

where R_1 and R_2 are the residue weights of samples 1 and 2 after enzyme treatment (mg), M_1 and M_2 are the weights of samples 1 and 2 (mg), P is the weight of the crude protein content of R_1 (mg), and A is the weight of the crude ash content of R_2 (mg).

2.5. Quality Characteristics of Nonsteamed- and Steam-Treated Doughs. The pH, total acidity, chromaticity, texture profile, isoflavone contents, and structure were analyzed to determine the quality characteristics of nonsteamed- and steam-treated doughs. For pH, total acidity, and chromaticity, the nonsteamed- and steam-treated doughs were grounded using a grinder and passed through a 50-mesh sieve (Chunggye Sieve Co., Seoul, Korea). To determine the pH and total acidity, 30 mL of distilled water was added to 1 g of each sample and homogenized for 1 min using a vortex mixer (VM-96A, Jeio tech, Deajeon, Korea). After centrifugation at 3000 rpm for 10 min (Union 5kr, Hanil Science Industrial Co., Incheon, Korea), 10 mL of the supernatant was decanted. The pH was measured using a pH meter (Docu-pH meter, Sartorius, Göttingen, Germany), and the total acidity was measured by adding 5 μL of 1% phenolphthalein and neutralizing titration with 0.1 N NaOH. Chromaticity was determined using a colorimeter (CR-300, Minolta Co., Tokyo, Japan) calibrated with a standard white plate ($L = 92.700$, $a = 0.313$, $b = 0.396$). The color difference value (ΔE) was calculated based on the measured L, a, and b values.

The texture profiles of nonsteamed- and steam-treated doughs were evaluated using a texture analyzer (TA-XT2, Stable Micro Systems Lyd., Surrey, England), and the operating conditions are listed in Table 2.

Nonsteamed- and steam-treated doughs were cut into $2 \times 2 \times 2\ cm^3$ pieces and transferred to a Petri dish. Hardness, springiness, chewiness, gumminess, and cohesiveness were tested using a 20.0 mm-diameter probe. The structures of the nonsteamed- and steam-treated doughs were analyzed using scanning electron microscopy (SEM) according to Jin et al. [39]. The doughs were dried using an oven (WFO-450PD, SEYELA, Tokyo, Japan) and cut into $1 \times 1 \times 5\ mm^3$ pieces. A dough sample was affixed to the observation area using double-sided tape, coated with gold, and visualized by SEM (ULTRA PLUS, Carl Zeiss AG, Oberkochen, Germany) at 5.00 K magnification.

For isoflavone content analysis, nonsteamed- and steam-treated doughs were pretreated according to Kim et al. [40] and Han et al. [4] with modifications. Samples were

Table 3: Operating conditions of HPLC.

	Conditions		
Instrument	Shimadzu Corporation LC-2030C		
Column	YMC-pack ODS-AM-303 (5 μm, 12 nm, 250 × 4.6 mm I.D.)		
Oven temperature	30°C		
Mobile phase	Time (min)	Gradient condition: 0.1% acetic acid in water	Gradient condition: 0.1% acetic acid in acetonitrile
	0	85	15
	50	70	30
	60	70	30
	65	0	100
	75	85	15
	85	85	15
Flow rate	0.1 mL/min		
Infection volume	20 μL		
Detector	UV-vis (254 nm)		

Table 4: Comparison of proximate composition among doughs with various psyllium husk contents, SDS powder, and psyllium husk powder.

	Moisture (%)	Crude protein (%)	Crude fat (%)	Crude ash (%)	Carbohydrate (%)	Total dietary fiber (%)
SDS powder	1.79 ± 0.57^{f}	37.41 ± 1.77^{a}	15.13 ± 0.22^{a}	3.03 ± 0.16^{a}	42.66 ± 2.26^{c}	15.81 ± 0.70^{bc}
Psyllium husk powder	9.86 ± 0.72^{e}	3.64 ± 0.77^{g}	0.42 ± 0.07^{f}	2.95 ± 0.25^{ab}	83.13 ± 1.50^{a}	80.41 ± 1.04^{a}
WD[1)]	32.04 ± 0.65^{d}	9.61 ± 0.37^{f}	1.30 ± 0.03^{e}	0.63 ± 0.03^{f}	56.42 ± 0.85^{b}	2.80 ± 0.10^{d}
Dough-0[2)]	31.15 ± 1.11^{d}	35.65 ± 0.13^{b}	14.64 ± 0.63^{a}	2.35 ± 0.23^{de}	16.21 ± 0.73^{f}	15.59 ± 0.50^{c}
Dough-10[3)]	38.59 ± 0.38^{c}	25.41 ± 0.22^{c}	12.14 ± 0.56^{b}	2.70 ± 0.08^{bc}	21.17 ± 0.90^{e}	17.25 ± 0.77^{b}
Dough-25[4)]	42.86 ± 0.86^{b}	21.41 ± 0.04^{d}	10.21 ± 0.22^{c}	2.59 ± 0.04^{cd}	22.92 ± 1.05^{e}	21.05 ± 0.59^{bc}
Dough-40[5)]	49.14 ± 0.26^{a}	16.31 ± 0.14^{e}	7.05 ± 0.42^{d}	2.11 ± 0.02^{e}	25.39 ± 0.14^{d}	23.06 ± 0.18^{bc}
F value	1837.89^{***}	846.98^{***}	772.22^{***}	94.09^{***}	1170.63^{***}	4448.18^{***}

[1)]WD: wheat flour dough. [2)]Dough-0: dough added with 0% psyllium husk. [3)]Dough-10: dough added with 10% psyllium husk. [4)]Dough-25: dough added with 25% psyllium husk. [5)]Dough-40: dough added with 40% psyllium husk. [a-f]Means represented by different superscripts in the same column are significantly different at $p < 0.05$. ***Significant at $p < 0.001$.

pulverized using a grinder. The powder was passed through an 80-mesh sieve. For each sample, powder (1 g) and 20 mL of 80% ethanol (20 mL) were added to a 50 mL conical tube, and ultrasonic extraction was performed using an ultrasonic cleaner (WUC-A, Daihan Scientific Co., Wonju, Korea) at 50°C for 1 h. The extracted sample was centrifuged at 3500 × *g* for 10 min, and the supernatant was passed through a 0.45 μm syringe filter (Millipore, Billerica, MA, USA). Isoflavones were quantified using high-performance liquid chromatography (HPLC; LC-2030C, Shimadzu Corporation, Kyoto, Japan) with ultraviolet–visible detection connected to a YMC-Pack ODS-AM-303 column (YMC, Kyoto, Japan). The analysis was performed at a wavelength of 254 nm, and the HPLC conditions are listed in Table 3.

2.6. Quality Characteristics of Cooked Noodles. The weight, water absorption, volume, and turbidity of cooked noodles were analyzed following the method of Min et al. [41] with modifications. Cooked noodles were placed in a 250 mL mesh cylinder, and the volume change (mL) was measured. After removing moisture for 10 min, the weight change (g) was measured. Water absorption (%) by the noodles was calculated as the percentage of the initial weight to the postdrying weight of the noodles. The turbidity of the noodle soup was determined at 675 nm using a visible-light spectrophotometer.

$$\text{Water absorption (\%)} = \frac{\text{cooked noodles (g)} - \text{uncooked noodles (g)}}{\text{uncooked noodles (g)}} \times 100. \tag{3}$$

pH, total acidity, and chromaticity were measured as for the nosteamed- and steam-treated doughs. The texture properties of the noodles were determined according to Tang et al. [42] using a TA-XT2 texture analyzer. Three cooked noodle strands were cut to 10 cm length and placed side by side on a flat platform. The texture analysis conditions are listed in Table 2.

2.7. Statistical Analysis. *F* values and *p* values were calculated using Statistical Analysis System (SAS) ver. 9.4 software

Table 5: Comparison of pH, total acidity, chromaticity, and texture profiles among doughs with various psyllium husk contents.

pH		WD[1)] 5.63 ± 0.15^{b}	Dough-0[2)] 5.55 ± 0.13^{b}	Dough-10[3)] 6.03 ± 0.08^{a}	Dough-25[4)] 6.10 ± 0.03^{a}	Dough-40[5)] 6.14 ± 0.03^{a}	*F* value 23.84^{***}
Total acidity		0.052 ± 0.00^{a}	0.056 ± 0.00^{a}	0.044 ± 0.00^{b}	0.042 ± 0.00^{b}	0.040 ± 0.00^{b}	14.56^{***}
Chromaticity	*L* value	75.25 ± 1.86^{a}	48.40 ± 0.91^{b}	44.07 ± 4.14^{c}	42.88 ± 1.15^{c}	35.41 ± 1.43^{d}	141.47^{***}
	a value	-1.54 ± 0.12^{e}	3.82 ± 0.22^{d}	4.38 ± 0.18^{c}	5.12 ± 0.18^{b}	6.29 ± 0.18^{a}	857.5^{***}
	b value	14.80 ± 0.72^{b}	17.78 ± 0.63^{a}	12.45 ± 0.47^{c}	7.71 ± 0.18^{d}	4.88 ± 0.44^{e}	304.7^{***}
	ΔE	—	27.56 ± 2.47^{c}	31.84 ± 3.36^{bc}	33.81 ± 1.93^{b}	41.80 ± 0.61^{a}	19.9^{***}
Texture profiles	Hardness (g)	4721.49 ± 419.20^{a}	1643.84 ± 88.05^{c}	1709.31 ± 464.32^{c}	1844.33 ± 485.31^{bc}	2212.56 ± 792.22^{b}	92.58^{***}
	Springiness	0.77 ± 0.04^{a}	0.25 ± 0.02^{e}	0.33 ± 0.19^{d}	0.48 ± 0.04^{c}	0.53 ± 0.05^{b}	397.38^{***}
	Gumminess	1840.69 ± 421.73^{a}	626.48 ± 78.15^{c}	688.96 ± 328.46^{c}	872.76 ± 207.56^{bc}	1141.43 ± 357.62^{b}	29.95^{***}
	Cohesiveness	0.52 ± 0.07^{ab}	0.38 ± 0.05^{c}	0.40 ± 0.14^{c}	0.48 ± 0.02^{b}	0.52 ± 0.02^{a}	45.48^{***}
	Chewiness	1892.00 ± 346.43^{a}	159.91 ± 28.83^{d}	275.70 ± 354.24^{d}	414.98 ± 82.21^{c}	606.85 ± 199.92^{b}	187.92^{***}

[1)]WD: wheat flour dough. [2)]Dough-0: dough added with 0% psyllium husk. [3)]Dough-10: dough added with 10% psyllium husk. [4)]Dough-25: dough added with 25% psyllium husk. [5)]Dough-40: dough added with 40% psyllium husk. [a-e]Means represented by different superscripts in the same row are significantly different at $p < 0.05$. ***Significant at $p < 0.001$.

(SAS Institute Inc., Cary, NC, USA). Means and standard deviations were calculated by analyzing three or more replicates, and differences were considered significant at $p < 0.05$ using Duncan's multiple range test.

3. Results and Discussion

3.1. Dough Prepared with SDS and Psyllium Husk

3.1.1. Proximate Composition of Dough. The moisture content of dough increased significantly as the content of psyllium husk increased ($p < 0.05$) (Table 4), likely because of the high water absorption capacity of psyllium husk [8, 9]. The crude protein content decreased significantly as the content of psyllium husk increased ($p < 0.05$). SDS had a crude protein content of 41.55% [4], compared to 2.08% for psyllium husk [43]). The crude fat content decreased significantly as the psyllium husk content increased ($p < 0.05$). SDS had a crude fat content of 16.91% [4], compared to 0.09% for psyllium husk [43]. The carbohydrate content increased significantly as the psyllium husk content increased ($p < 0.05$); the carbohydrate content of SDS was 34.46% [4], compared to 88.9% for psyllium husk [44]. The total dietary fiber content increased significantly as the psyllium husk content increased ($p < 0.05$), likely because of the high total dietary fiber content of psyllium husk (78%) [44].

3.1.2. pH and Total Acidity of Dough. As the psyllium husk content of dough increased, total acidity decreased and pH increased (Table 5). After addition of psyllium husk to yogurt, followed by heating under pressure, water loss from the husk by evaporation lowered the total acidity [45]. The pH may have increased because of dilution. As the psyllium husk content increased, the moisture content and pH of dough increased.

3.1.3. Chromaticity and Texture of Dough. The *L*, *a*, and *b* values of psyllium husk powder were 66.64, 4.01, and 12.36, respectively [46]. With increasing psyllium husk content of dough, the *L* value significantly decreased ($p < 0.05$), the *a* value significantly increased ($p < 0.05$), and the *b* value significantly decreased ($p < 0.05$) (Table 5). In a previous study, the *L* and *a* values increased, and the *b* value decreased, as the content of psyllium husk added to sponge cake increased [47]. Addition of psyllium husk to dough caused a decrease in its brightness, as evidenced by the decrease in *L* value. Moreover, given that psyllium husk powder had a higher *a* value (redness) and lower *b* value (yellowness) than dough without psyllium husk, addition of psyllium husk to dough increased its redness and its yellowness. Moreover, the addition of psyllium husk likely affected nonenzymatic browning, as shown the increase in redness and decrease in yellowness.

The hardness, springiness, chewiness, gumminess, and cohesiveness of dough significantly increased as the psyllium husk content increased ($p < 0.05$) (Table 5); however, they were lower value than the wheat flour dough (WD). Similarly, the hardness, chewiness, springiness, and gumminess of donuts increased as the psyllium husk content increased [48]. Considering from the reports for improving gel-forming ability [8, 9] and entanglement effect [36, 49] by increasing of dietary fiber content, we thought that the hardness of dough was increased by increase of dietary fiber content of psyllium husk. Therefore, the addition of psyllium husk improved the dough texture, possibly due to enhanced gelation caused by the dietary fiber in psyllium husk.

3.1.4. Isoflavone Contents of Dough. The aglycone isoflavone contents of doughs prepared with psyllium husk and SDS were higher than those of soybean dough prepared with only soybean powder (SD) (Table 6). Glycitein was detected in doughs prepared with psyllium husk and SDS but not in SD. During the manufacture of SDS, the aglycone isoflavone contents of SDS increase because prolonged hot air drying promotes the conversion of glycoside isoflavones to aglycone isoflavones [4]. Moreover, as the psyllium husk content

Table 6: Changes of isoflavone content at doughs with various psyllium husk contents.

	Malonyldaidzin (μg/g)	Malonylglycitin (μg/g)	Malonylgenistin (μg/g)	Daidzein (μg/g)	Glycitein (μg/g)	Genistein (μg/g)
WD[1)]	ND	ND	ND	ND	ND	ND
SD[2)]	447.09 ± 58.86^{a}	81.13 ± 4.55^{a}	$1,028.84 \pm 128.92^{a}$	37.27 ± 2.09^{e}	ND	24.65 ± 0.16^{e}
Dough-0[3)]	175.11 ± 2.08^{b}	56.48 ± 5.55^{b}	852.63 ± 88.49^{b}	146.54 ± 5.81^{a}	14.19 ± 0.62^{a}	153.64 ± 2.41^{a}
Dough-10[4)]	136.28 ± 8.33^{bc}	44.21 ± 0.48^{c}	696.06 ± 40.27^{c}	124.47 ± 0.62^{b}	11.78 ± 0.10^{b}	126.00 ± 4.26^{b}
Dough-25[5)]	94.03 ± 2.74^{cd}	32.92 ± 1.18^{d}	454.17 ± 22.89^{d}	90.55 ± 1.15^{c}	9.61 ± 0.28^{c}	94.73 ± 1.41^{c}
Dough-40[6)]	55.01 ± 0.95^{d}	21.10 ± 0.95^{e}	335.36 ± 8.91^{d}	71.20 ± 4.45^{d}	8.97 ± 1.43^{c}	82.68 ± 2.14^{d}
F value	101.79***	147.73***	45.17***	467.49***	26.46***	1162.61***

[1)]WD: wheat flour dough. [2)]SD: soybean dough prepared with only soybean powder. [3)]Dough-0: dough added with 0% psyllium husk. [4)]Dough-10: dough added with 10% psyllium husk. [5)]Dough-25: dough added with 25% psyllium husk. [6)]Dough-40: dough added with 40% psyllium husk. [a-e]Means represented by different superscripts in the same column are significantly different at $p < 0.05$. ***Significant at $p < 0.001$.

Table 7: Comparison of proximate composition among steam-treated doughs with various psyllium husk contents according to steam treatment time.

	Steam time (min)	Moisture (%)	Crude protein (%)	Crude fat (%)	Crude ash (%)	Carbohydrate (%)	Total dietary fiber (%)
WD[1)]	—	32.04 ± 0.65^{fg}	9.61 ± 0.37^{g}	1.30 ± 0.03^{i}	0.63 ± 0.03^{d}	56.42 ± 0.85^{a}	2.80 ± 0.10^{i}
STD-0[2)]	0	31.15 ± 1.11^{g}	35.65 ± 0.13^{a}	14.64 ± 0.63^{a}	2.35 ± 0.23^{b}	16.21 ± 0.73^{gh}	$15.59 \pm 0.50f^{gh}$
	5	32.89 ± 0.63^{f}	35.64 ± 0.18^{a}	14.07 ± 0.05^{b}	2.12 ± 0.05^{c}	15.28 ± 0.54^{h}	15.07 ± 0.17^{h}
	10	32.94 ± 0.40^{f}	35.31 ± 0.10^{a}	14.07 ± 0.12^{b}	2.11 ± 0.11^{c}	15.56 ± 0.47^{h}	15.36 ± 0.27^{gh}
	15	33.10 ± 0.47^{f}	35.41 ± 0.23^{a}	14.06 ± 0.19^{b}	2.10 ± 0.02^{c}	15.35 ± 0.64^{h}	15.19 ± 0.23^{gh}
STD-10[3)]	0	38.59 ± 0.38^{e}	25.41 ± 0.22^{b}	12.14 ± 0.56^{c}	2.70 ± 0.08^{a}	21.17 ± 0.90^{ef}	17.25 ± 0.77^{d}
	5	43.08 ± 1.02^{d}	25.02 ± 0.81^{bc}	11.50 ± 0.03^{d}	2.66 ± 0.01^{a}	17.73 ± 0.20^{g}	16.65 ± 0.54^{de}
	10	43.50 ± 1.16^{d}	24.88 ± 0.22^{bc}	11.48 ± 0.21^{d}	2.64 ± 0.05^{a}	17.50 ± 1.48^{g}	16.18 ± 0.08^{ef}
	15	43.90 ± 1.70^{d}	24.63 ± 0.41^{c}	11.43 ± 0.18^{d}	2.62 ± 0.03^{a}	17.41 ± 1.75^{g}	16.03 ± 0.21^{efg}
STD-25[4)]	0	42.86 ± 0.86^{d}	21.41 ± 0.04^{d}	10.21 ± 0.22^{e}	2.59 ± 0.04^{a}	22.92 ± 1.05^{cd}	21.05 ± 0.59^{b}
	5	45.80 ± 0.92^{c}	20.05 ± 0.68^{e}	9.40 ± 0.11^{f}	2.47 ± 0.02^{b}	22.28 ± 0.43^{cde}	19.60 ± 0.36^{c}
	10	46.13 ± 0.52^{c}	20.66 ± 0.11^{e}	9.36 ± 0.01^{f}	2.44 ± 0.03^{b}	21.40 ± 0.59^{def}	19.38 ± 0.73^{c}
	15	47.05 ± 0.57^{c}	20.51 ± 0.42^{e}	9.34 ± 0.09^{f}	2.41 ± 0.03^{b}	20.69 ± 1.10^{f}	19.24 ± 0.21^{c}
STD-40[5)]	0	49.14 ± 0.26^{b}	16.31 ± 0.14^{f}	7.05 ± 0.42^{g}	2.11 ± 0.03^{c}	25.39 ± 0.14^{b}	23.06 ± 0.18^{a}
	5	51.99 ± 0.44^{a}	16.05 ± 0.14^{f}	6.60 ± 0.45^{gh}	2.05 ± 0.00^{c}	23.31 ± 0.25^{c}	21.27 ± 0.29^{b}
	10	52.39 ± 0.62^{a}	16.07 ± 0.74^{f}	6.56 ± 0.06^{h}	2.04 ± 0.01^{c}	22.94 ± 0.69^{cd}	21.23 ± 0.24^{b}
	15	52.93 ± 0.53^{a}	16.08 ± 0.64^{f}	6.52 ± 0.04^{h}	2.03 ± 0.01^{c}	22.43 ± 1.08^{cde}	21.22 ± 1.23^{b}
F value		266.36***	1161.64***	501.81***	138.4***	354.05***	262.35***

[1)]WD: wheat flour dough. [2)]STD-0: steam treated dough added with 0% psyllium husk. [3)]STD-10: steam-treated dough added with 10% psyllium husk. [4)]STD-25: steam-treated dough added with 25% psyllium husk. [5)]STD-40: steam-treated dough added with 40% psyllium husk. [a-i]Means represented by different superscripts in the same column are significantly different at $p < 0.05$. ***Significant at $p < 0.001$.

increased, the total isoflavone content of dough significantly decreased, likely because of the higher isoflavone contents of SDS decreased, whereas that of psyllium husk increased.

3.2. Steam-Treated Dough

3.2.1. Proximate Composition of Steam-Treated Dough. The moisture content of steam-treated dough increased after steam treatment (Table 7), likely due to the high water-absorption capacity of the dietary fiber of psyllium husk [50–52]. A similar finding of increased moisture content was reported for Chinese steamed bread [53]. Steaming did not alter the crude protein content. The protein content of lightly milled rice was reportedly unaffected by treatment with superheated steam [21]. Likewise, steam treatment did not alter the protein content of soybean. The crude fat content was decreased by steam treatment. Indeed, treatment of chicken sausage with superheated steam led to loss of fat on

Table 8: Changes of pH and total acidity of steam-treated doughs with various psyllium husk contents according to steam treatment time.

		Nonsteam	5 min	10 min	15 min	F value
STD-0[1)]	pH	5.55 ± 0.13^{d}	5.73 ± 0.02^{c}	5.98 ± 0.11^{b}	6.16 ± 0.07^{a}	25.05**
	Total acidity	0.056 ± 0.00^{a}	0.052 ± 0.00^{a}	0.045 ± 0.00^{b}	0.040 ± 0.00^{b}	12.39**
STD-10[2)]	pH	6.03 ± 0.08^{c}	6.22 ± 0.04^{b}	6.25 ± 0.04^{ab}	6.32 ± 0.03^{a}	18.75***
	Total acidity	0.044 ± 0.00^{a}	0.036 ± 0.00^{b}	0.034 ± 0.00^{bc}	0.030 ± 0.00^{c}	17.67***
STD-25[3)]	pH	6.10 ± 0.03^{b}	6.28 ± 0.09^{a}	6.29 ± 0.03^{a}	6.31 ± 0.05^{a}	9.31***
	Total acidity	0.042 ± 0.00^{a}	0.032 ± 0.00^{b}	0.032 ± 0.00^{b}	0.030 ± 0.00^{b}	19.52***
STD-40[4)]	pH	6.14 ± 0.03^{b}	6.40 ± 0.08^{a}	6.44 ± 0.04^{a}	6.46 ± 0.05^{a}	25.45***
	Total acidity	0.040 ± 0.00^{a}	0.026 ± 0.00^{b}	0.021 ± 0.00^{c}	0.020 ± 0.00^{c}	57.33***

[1)]STD-0: steam-treated dough added with 0% psyllium husk. [2)]STD-10: steam-treated dough added with 10% psyllium husk. [3)]STD-25: steam-treated dough added with 25% psyllium husk. [4)]STD-40: steam-treated dough added with 40% psyllium husk. [a-d]Means represented by different superscripts in the same row are significantly different at $p < 0.05$. ** and ***Significant at $p < 0.01$ and $p < 0.001$, respectively.

Table 9: Changes of the chromaticity of steam-treated doughs with various psyllium husk contents according to steam treatment time.

		Nonsteam	5 min	10 min	15 min	F value
STD-0[1)]	L	58.40 ± 0.91^{a}	49.76 ± 0.34^{b}	48.32 ± 0.23^{c}	47.75 ± 0.87^{c}	169.04***
	a	3.82 ± 0.22^{b}	5.08 ± 0.20^{a}	5.22 ± 0.03^{a}	5.37 ± 0.07^{a}	63.82***
	b	17.78 ± 0.63^{a}	15.47 ± 0.04^{b}	14.75 ± 0.42^{bc}	14.36 ± 0.31^{c}	41.88***
	ΔE	—	9.06 ± 0.84^{b}	10.65 ± 0.70^{ab}	11.31 ± 1.03^{a}	5.29*
STD-10[2)]	L	54.07 ± 4.14^{a}	45.30 ± 0.82^{b}	45.23 ± 0.22^{b}	44.42 ± 1.20^{b}	12.92***
	a	4.38 ± 0.18^{b}	5.15 ± 0.41^{a}	5.19 ± 0.20^{a}	5.23 ± 0.16^{a}	7.48***
	b	12.45 ± 0.47^{a}	8.89 ± 0.42^{b}	8.76 ± 0.26^{b}	8.61 ± 0.24^{b}	78.87***
	ΔE	—	9.53 ± 3.89	9.65 ± 3.85	10.47 ± 4.6	0.05
STD-25[3)]	L	52.88 ± 1.15^{a}	41.22 ± 1.22^{b}	40.75 ± 0.90^{b}	40.00 ± 1.09^{b}	93.94***
	a	5.12 ± 0.18^{b}	6.33 ± 0.12^{a}	6.43 ± 0.22^{a}	6.55 ± 0.09^{a}	51.54***
	b	7.71 ± 0.18^{a}	4.85 ± 0.45^{b}	4.75 ± 0.28^{b}	4.40 ± 0.19^{b}	81.54***
	ΔE	—	12.08 ± 2.27	12.56 ± 0.79	13.38 ± 1.64	0.46
STD-40[4)]	L	45.41 ± 1.43^{a}	37.66 ± 0.94^{b}	37.15 ± 1.15^{b}	36.78 ± 0.64^{b}	43.52***
	a	6.29 ± 0.18^{b}	7.42 ± 0.19^{a}	7.62 ± 0.34^{a}	7.73 ± 0.07^{a}	28.23***
	b	4.88 ± 0.44^{a}	3.29 ± 0.23^{b}	3.03 ± 0.11^{b}	2.72 ± 0.53^{b}	20.4***
	ΔE	—	7.99 ± 2.16	8.59 ± 0.39	9.02 ± 0.94	0.42

[1)]STD-0: steam-treated dough added with 0% psyllium husk. [2)]STD-10: steam-treated dough added with 10% psyllium husk. [3)]STD-25: steam-treated dough added with 25% psyllium husk. [4)]STD-40: steam-treated dough added with 40% psyllium husk. [a-c]Means represented by different superscripts in the same row are significantly different at $p < 0.05$. * and ***Significant at $p < 0.05$ and $p < 0.001$, respectively.

the surface [54]. The crude fat content decreased as a result of loss of surface fat because of the high cooking temperature. The carbohydrate content decreased after steam treatment, possibly because of the increase in moisture content. As the steam treatment duration increased, the carbohydrate content decreased. The total dietary fiber contents of steam-treated dough containing 0% and 10% psyllium husk did not differ after steam treatment. However, after steam treatment, the total dietary fiber contents of steam-treated dough containing 25% and 40% psyllium husk differed with increasing psyllium husk content. The total dietary fiber content decreased with increasing steam treatment duration. Total dietary fiber content of steam-treated dough added with 40% psyllium husk content was the most sufficient dietary fiber content within the daily intake.

3.2.2. pH and Total Acidity of Steam-Treated Dough. Steam treatment of dough resulted in decrease in total acidity and increase in pH (Table 8). Moreover, as the steam treatment duration increased, the moisture content of steam-treated dough increased, the total acidity decreased, and the pH increased. Similarly, when yogurt was added to psyllium

Table 10: Comparison of texture profiles among steam treated doughs with various psyllium husk contents according to steam treatment time.

	Steam time (min)	Hardness (g)	Gumminess	Cohesiveness	Springiness	Chewiness
WD[1)]	—	4721.49 ± 419.20^{a}	1840.69 ± 421.73^{def}	0.52 ± 0.07^{d}	0.77 ± 0.04^{d}	1892.00 ± 346.43^{cd}
STD-0[2)]	0	1643.84 ± 88.05^{d}	626.48 ± 78.15^{k}	0.38 ± 0.05^{e}	0.25 ± 0.02^{g}	159.91 ± 28.83^{g}
	5	2906.18 ± 111.28^{c}	1261.64 ± 91.9^{ghi}	0.43 ± 0.02^{d}	0.43 ± 0.02^{f}	542.56 ± 51.06^{f}
	10	3047.46 ± 169.56^{bc}	1340.02 ± 82.32^{ghi}	0.44 ± 0.02^{d}	0.44 ± 0.05^{f}	584.40 ± 53.58^{f}
	15	3153.54 ± 291.01^{bc}	1428.84 ± 117.68^{fgh}	0.45 ± 0.03^{d}	0.45 ± 0.02^{f}	649.72 ± 70.69^{f}
STD-10[3)]	0	1709.31 ± 464.32^{d}	688.96 ± 328.46^{jk}	0.40 ± 0.14^{e}	0.33 ± 0.19^{g}	275.70 ± 354.24^{g}
	5	3218.76 ± 398.92^{b}	1638.80 ± 873.53^{efg}	0.51 ± 0.02^{d}	0.82 ± 0.05^{d}	1347.65 ± 724.20^{e}
	10	3317.56 ± 755.95^{b}	1824.98 ± 1005.66^{de}	0.55 ± 0.02^{d}	0.84 ± 0.03^{ab}	1541.55 ± 855.78^{de}
	15	3405.66 ± 888.63^{bc}	1938.61 ± 1069.11^{d}	0.57 ± 0.01^{d}	0.88 ± 0.03^{a}	1691.65 ± 924.12^{de}
STD-25[4)]	0	1844.33 ± 485.31^{d}	872.76 ± 207.56^{ijk}	0.48 ± 0.02^{d}	0.48 ± 0.04^{e}	414.98 ± 82.21^{cd}
	5	4638.96 ± 984.17^{a}	2861.68 ± 638.04^{c}	0.62 ± 0.01^{c}	0.79 ± 0.05^{cd}	2263.24 ± 544.46^{c}
	10	4872.18 ± 441.49^{a}	3049.85 ± 373.00^{bc}	0.63 ± 0.05^{c}	0.81 ± 0.07^{ab}	2476.49 ± 365.06^{b}
	15	5026.26 ± 208.25^{a}	3329.31 ± 234.29^{ab}	0.66 ± 0.03^{bc}	0.83 ± 0.04^{bcd}	2753.69 ± 174.82^{ab}
STD-40[5)]	0	2212.56 ± 792.22^{d}	1141.43 ± 357.62^{hij}	0.52 ± 0.02^{d}	0.53 ± 0.05^{e}	606.85 ± 199.92^{f}
	5	4576.12 ± 934.63^{a}	3365.74 ± 284.38^{abc}	0.68 ± 0.03^{abc}	0.83 ± 0.04^{bcd}	2781.34 ± 279.20^{ab}
	10	4686.16 ± 928.21^{a}	3377.16 ± 715.16^{a}	0.72 ± 0.04^{ab}	0.84 ± 0.02^{abc}	2839.96 ± 656.18^{ab}
	15	4807.14 ± 602.63^{a}	3501.71 ± 519.83^{a}	0.73 ± 0.05^{a}	0.85 ± 0.02^{ab}	2971.74 ± 406.51^{a}
F value		51.76***	51.04***	31.75***	171.22***	81.62***

[1)]WD: wheat flour dough. [2)]STD-0: steam-treated dough added with 0% psyllium husk. [3)]STD-10: steam-treated dough added with 10% psyllium husk. [4)]STD-25: steam-treated dough added with 25% psyllium husk. [5)]STD-40: steam-treated dough added with 40% psyllium husk. [a-k]Means represented by different superscripts in the same row are significantly different at $p < 0.05$. ***Significant at $p < 0.001$.

husk, followed by heating under pressure, water loss from husks via evaporation lowered the total acidity [45].

3.2.3. Chromaticity and Texture of Steam-Treated Dough. Steam treatment resulted in decreased *L* and *b* values and increased *a* values of dough (Table 9). Biscuit containing psyllium husk reportedly showed a similar effect, possibly as a result of the color of psyllium husk promoting nonenzymatic browning [46]. Therefore, the increase in the *a* value with increasing psyllium husk content in steam-treated dough may have been caused by nonenzymatic browning.

Steam treatment increased the hardness, gumminess, cohesiveness, springiness, and chewiness of dough (Table 10). Psyllium husk has a high dietary fiber content and excellent water-binding and gelation abilities [11, 12, 51]. Gelation increased as the psyllium husk content of donuts increased, enhancing hardness and chewiness; overall, enhanced springiness and gumminess improved the donut texture ([48] Moreover, the hardness of oat dough was increased by adding psyllium husk to enhance gelation [55]. Hence, in the present study, the improved texture of steam-treated dough was the result of enhanced gelation and crosslinking due to the dietary fiber content of psyllium husk and steam treatment.

3.2.4. Isoflavone Contents of Steam-Treated Dough. The changes of isoflavone contents of steam-treated dough were shown as Table 11. As the steam treatment duration increased, the contents of glycoside isoflavones (malonyldaidzin, malonylglycitin, and malonylgenistin) decreased, and those of aglycone isoflavones (daidzein, genistein, and glycitein) increased. After steaming at 95°C, the content of malonyl group glycosides decreased as the steam treatment time increased ([56]). Steamed soybeans at both 60°C and 80°C analyzed the content of isoflavone reported an increase in the content of aglycone isoflavones [57].

3.2.5. Structure of Steam-Treated Dough. Images of scanning electron microscopy for structure of nonsteamed and steamed dough treated at 120°C for 10 min with various psyllium husk contents are shown in Figure 1. Nonsteamed dough had a porous structure. Intermolecular electrostatic repulsion results in molecular chains becoming fully extended and forming intermolecular crosslinks, thereby triggering gelation [58]. Thus, this porosity was likely caused by gelation of the dietary fiber in psyllium husk. Steam treatment increased the crosslinking of dough, stabilizing the surface. Steam-treated dough containing ≥10% psyllium husk had a gelated and stable surface, whereas steam-treated dough containing ≥25% psyllium husk had a more stable surface. Similarly, rice dough containing psyllium husk had a gelated surface, as observed by SEM [48]. Also, the texture of dough was improved by incorporating psyllium husk [59]. Psyllium husk particles interlinked the SDS

Table 11: Changes of isoflavone content of steam-treated doughs with various psyllium husk contents according to steam treatment time.

	Steam time (min)	Malonyl-daidzin (μg/g)	Malonyl-glycitin (μg/g)	Malonyl-genistin (μg/g)	Daidzein (μg/g)	Glycitein (μg/g)	Genistein (μg/g)
WD[1)]	—	ND	ND	ND	ND	ND	ND
STD-0[2)]	0	175.11 ± 2.08^{a}	56.48 ± 5.55^{a}	852.63 ± 88.49^{a}	146.54 ± 5.81^{a}	14.19 ± 0.62^{a}	153.64 ± 2.41^{a}
	5	124.00 ± 0.50^{c}	41.33 ± 0.64^{bc}	685.16 ± 3.99^{b}	98.75 ± 1.10^{bcde}	9.97 ± 0.13^{de}	87.14 ± 1.46^{fgh}
	10	119.02 ± 0.55^{c}	38.36 ± 3.73^{c}	593.95 ± 19.06^{c}	103.80 ± 1.23^{bcd}	10.28 ± 0.27^{de}	89.54 ± 0.55^{efg}
	15	111.14 ± 0.61^{d}	33.92 ± 0.13^{d}	547.31 ± 4.71^{d}	110.66 ± 0.12^{bc}	10.81 ± 0.15^{d}	93.32 ± 2.07^{def}
STD-10[3)]	0	136.28 ± 8.33^{b}	44.21 ± 0.48^{b}	696.06 ± 40.27^{b}	124.47 ± 0.62^{ab}	11.78 ± 0.10^{c}	126.00 ± 4.26^{b}
	5	72.18 ± 3.15^{f}	33.94 ± 1.99^{d}	517.65 ± 18.53^{d}	80.52 ± 18.67^{def}	8.48 ± 0.18^{g}	79.34 ± 8.80^{i}
	10	65.28 ± 6.85^{g}	31.00 ± 1.96^{de}	434.07 ± 14.78^{ef}	90.81 ± 24.31^{cdef}	9.02 ± 0.39^{fg}	83.28 ± 7.32^{ghi}
	15	61.71 ± 2.10^{g}	29.46 ± 0.80^{e}	391.96 ± 5.51^{f}	103.52 ± 27.26^{bcd}	9.82 ± 0.11^{ef}	90.50 ± 5.82^{ef}
STD-25[4)]	0	94.03 ± 2.74^{e}	32.92 ± 1.18^{de}	454.17 ± 22.89^{e}	90.55 ± 1.15c^{def}	9.61 ± 0.28^{ef}	94.73 ± 1.41^{de}
	5	52.16 ± 4.15^{h}	19.84 ± 0.46^{f}	344.69 ± 8.95^{g}	51.34 ± 37.06^{gh}	5.19 ± 0.39^{h}	52.89 ± 1.01^{j}
	10	42.22 ± 1.43^{i}	19.17 ± 1.88^{fg}	324.63 ± 3.19^{gh}	95.25 ± 2.98^{cdef}	10.00 ± 0.88^{de}	98.64 ± 0.41^{cd}
	15	33.06 ± 1.06^{j}	14.47 ± 1.50^{h}	308.54 ± 2.97^{gh}	104.84 ± 10.59^{bcd}	12.77 ± 0.35^{b}	103.27 ± 0.81^{c}
STD-40[5)]	0	55.01 ± 0.95^{h}	21.10 ± 0.95^{f}	335.36 ± 8.91^{gh}	71.20 ± 4.45^{fg}	8.97 ± 1.43^{fg}	82.68 ± 2.14^{hi}
	5	39.90 ± 0.82^{i}	20.92 ± 1.19^{f}	293.52 ± 1.26^{hi}	42.26 ± 0.29^{h}	4.93 ± 0.04^{h}	52.31 ± 0.50^{j}
	10	36.68 ± 1.25^{ij}	18.95 ± 0.60^{fg}	261.96 ± 4.55^{ij}	75.79 ± 1.08^{efg}	9.36 ± 0.08^{efg}	86.70 ± 0.27^{fgh}
	15	31.70 ± 0.68^{j}	16.06 ± 1.07^{gh}	236.79 ± 1.79^{j}	82.29 ± 1.03^{def}	10.79 ± 0.15^{d}	89.76 ± 0.63^{efg}
F value		539.96***	102.26***	137.84***	9.81***	67.42***	134.68***

[1)]WD: wheat flour dough. [2)]STD-0: steam-treated dough added with 0% psyllium husk. [3)]STD-10: steam-treated dough added with 10% psyllium husk. [4)]STD-25: steam-treated dough added with 25% psyllium husk. [5)]STD-40: steam-treated dough added with 40% psyllium husk. [a-j]Means represented by different superscripts in the same column are significantly different at $p < 0.05$. ***Significant at $p < 0.001$.

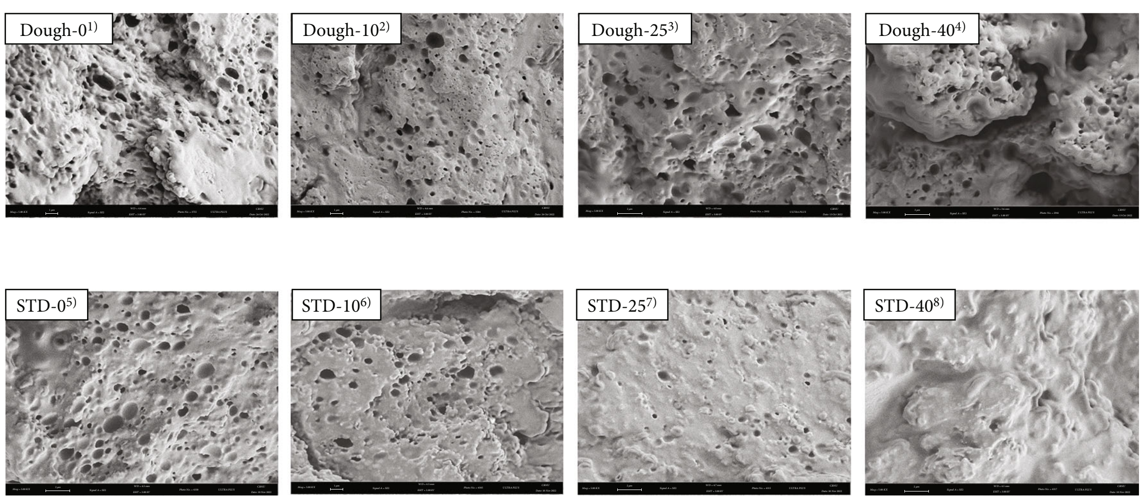

Figure 1: Images of scanning electron microscopy for structure of dough and steamed dough treated at 120°C for 10 min with various psyllium husk contents (Magnification: 5,000x). [1)]Dough-0: dough added with 0% psyllium husk. [2)]Dough-10: dough added with 10% psyllium husk. [3)]Dough-25: dough added with 25% psyllium husk. [4)]Dough-40: dough added with 40% psyllium husk. [5)]STD-0: steam-treated dough added with 0% psyllium husk. [6)]STD-10: steam-treated dough added with 10% psyllium husk. [7)]STD-25: steam-treated dough added with 25% psyllium husk. [8]STD-40: steam-treated dough added with 40% psyllium husk.

powder particles, thereby enhancing the stability and texture of steam-treated dough.

3.3. Cooked Noodles

3.3.1. Weight, Water Absorption, Volume, and Turbidity. Control noodles prepared with only soybean powder did not maintain a noodle shape after cooking, whereas noodles with a psyllium husk content ≥10% retained their shape (Figure 2). The weight of cooked noodles increased with increasing psyllium husk content and cooking duration (Table 12). The weight of noodle-10, 25, and 40 was greater than that of wheat flour noodles (WNs). As the content of *Angelica gigas* N Leaf powder in noodles increased, the fiber

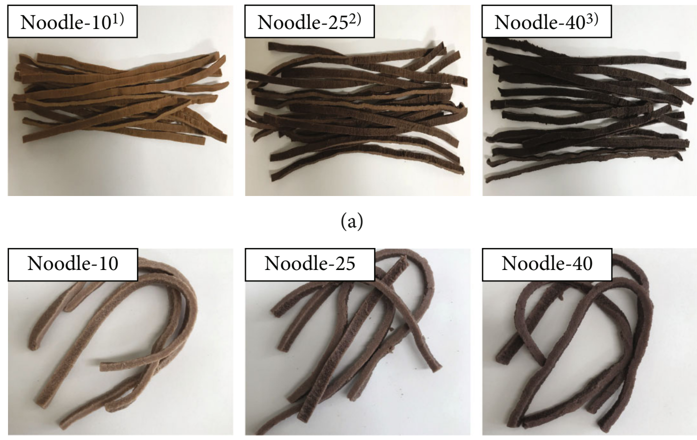

FIGURE 2: Images of uncooked noodles (a) and cooked noodles (b). [1)]Noodle-10: noodles added with 10% psyllium husk. [2)]Noodle-25: noodles added with 25% psyllium husk. [3)]Noodle-40: noodles added with 40% psyllium husk.

TABLE 12: Comparison of weight, water absorption, volume, and turbidity among cooked noodles with various psyllium husk contents.

	Cooking time (min)	Weight (g)	Water absorption (%)	Volume (mL)	Turbidity of the noodle soup (O.D. at 675 nm)
WN[1)]	3	8.22 ± 0.41^{h}	63.44 ± 1.82^{h}	3.17 ± 0.29^{i}	2.41 ± 0.11^{f}
	6	9.07 ± 0.17^{g}	66.93 ± 0.63^{ab}	3.73 ± 0.03^{h}	3.15 ± 0.04^{a}
	9	9.52 ± 0.10^{g}	68.48 ± 0.34^{ab}	4.03 ± 0.25^{g}	3.26 ± 0.10^{a}
Noodle-10[2)]	3	16.04 ± 0.20^{f}	59.47 ± 1.79^{g}	4.17 ± 0.29^{fg}	2.54 ± 0.06^{def}
	6	16.15 ± 0.21^{ef}	61.65 ± 2.17^{ef}	4.67 ± 0.58^{e}	2.74 ± 0.08^{c}
	9	16.97 ± 0.18^{bc}	64.08 ± 1.29^{cd}	4.83 ± 0.29^{e}	2.98 ± 0.13^{b}
Noodle-25[3)]	3	16.33 ± 0.37^{def}	63.67 ± 1.24^{de}	4.33 ± 0.29^{f}	2.52 ± 0.07^{def}
	6	16.65 ± 0.14^{cde}	64.57 ± 1.31^{cd}	4.67 ± 0.58^{e}	2.58 ± 0.09^{de}
	9	16.68 ± 0.21^{cd}	66.31 ± 1.09^{bc}	5.17 ± 0.29^{d}	2.63 ± 0.11^{cd}
Noodle-40[4)]	3	16.58 ± 0.20^{cde}	64.16 ± 1.32^{cd}	6.67 ± 0.58^{c}	2.48 ± 0.03^{ef}
	6	17.27 ± 0.60^{ab}	68.05 ± 3.10^{ab}	7.33 ± 0.58^{b}	2.51 ± 0.07^{def}
	9	17.48 ± 0.18^{a}	69.21 ± 0.15^{a}	8.67 ± 0.58^{a}	2.58 ± 0.04^{de}
F value		486.93^{***}	33.73^{***}	639.6^{***}	39.63^{***}

[1)]WN: wheat flour noodles. [2)]Noodle-10: noodles added with 10% psyllium husk. [3)]Noodle-25: noodles added with 25% psyllium husk. [4)]Noodle-40: noodles added with 40% psyllium husk. [a-i]Means represented by different superscripts in the same column are significantly different at $p < 0.05$. ***Significant at $p < 0.001$.

content and weight increased because of moisture absorption during cooking [35]. Hence, as the psyllium husk content increased, the weight of noodles increased. The dietary fiber in psyllium husk absorbed more moisture as cooking duration increased, thereby increasing noodle weight. Water absorption increased with increasing psyllium husk content and with increasing cooking duration. In a previous study, with addition of increasing quantities of *Capsosiphon fulvescens* powder to noodles, the moisture absorption capacity increased [60]. In addition, noodle volume increased with increasing psyllium husk content and cooking duration.

Finally, the turbidity of the noodle soup significantly increased with increasing psyllium husk content and cooking duration. Another study observed enhanced loss of solids resulting in an increase in soup turbidity as the mushroom powder or chlorella extract content of flour noodles increased [61, 62]. Therefore, loss of solids and increasing cooking duration increased the turbidity of noodle soup.

3.3.2. pH and Total Acidity of Cooked Noodles. The pH of cooked noodles increased and total acidity decreased with increasing cooking duration (Table 13). Considering from reports that the dietary fiber of psyllium husk has high water absorption capacity [8, 9] and the pH of cooked noodles increased as level of added hydrocolloids of fiber increased [63], we thought that these results were caused because the noodle water content increased with increasing immersion time in boiling water for cooking.

Table 13: Changes of pH, total acidity, and chromaticity of cooked noodles with various psyllium husk contents.

		Uncooked noodles	Cooked noodles 3 min	6 min	9 min	F value
Noodle-10[2)]	pH	6.56 ± 0.11^{c}	6.70 ± 0.02^{b}	6.75 ± 0.02^{ab}	6.81 ± 0.02^{a}	11.53^{**}
	Total acidity	0.021 ± 0.00^{a}	0.018 ± 0.00^{b}	0.016 ± 0.00^{b}	0.014 ± 0.00^{b}	62.66^{***}
	L	42.53 ± 0.40^{a}	42.95 ± 0.41^{a}	38.92 ± 0.55^{b}	35.31 ± 0.10^{c}	240.45^{***}
	a	1.91 ± 0.08^{d}	2.70 ± 0.09^{c}	3.37 ± 0.22^{b}	3.50 ± 0.17^{a}	90.56^{***}
	b	6.42 ± 0.17^{c}	8.40 ± 0.13^{a}	8.28 ± 0.12^{ab}	8.15 ± 0.07^{b}	162.02^{***}
	ΔE	—	2.06 ± 0.07^{c}	4.09 ± 0.51^{b}	7.43 ± 0.46^{a}	138.92^{***}
Noodle-25[3)]	pH	6.64 ± 0.05^{c}	6.78 ± 0.04^{b}	6.83 ± 0.02^{ab}	6.87 ± 0.01^{a}	28.54^{***}
	Total acidity	0.018 ± 0.00^{a}	0.015 ± 0.00^{b}	0.013 ± 0.00^{bc}	0.012 ± 0.00^{c}	44.41^{***}
	L	36.73 ± 0.11^{a}	36.98 ± 0.23^{a}	33.53 ± 1.03^{b}	31.03 ± 0.72^{c}	58.14^{***}
	a	3.68 ± 0.13^{b}	4.15 ± 0.07^{a}	4.18 ± 0.06^{a}	4.23 ± 0.07^{a}	26.81^{**}
	b	4.09 ± 0.15^{d}	5.65 ± 0.20^{a}	5.07 ± 0.22^{b}	4.46 ± 0.17^{c}	40.25^{***}
	ΔE	—	1.67 ± 0.37^{c}	3.43 ± 0.86^{b}	5.74 ± 0.67^{a}	28.32^{***}
Noodle-40[4)]	pH	6.72 ± 0.07^{c}	6.80 ± 0.03^{b}	6.85 ± 0.01^{ab}	6.88 ± 0.01^{a}	9.63^{**}
	Total acidity	0.016 ± 0.00^{a}	0.014 ± 0.15^{ab}	0.013 ± 0.22^{bc}	0.012 ± 0.00^{c}	9.99^{**}
	L	32.30 ± 0.07	32.60 ± 0.97	31.07 ± 0.72	30.54 ± 0.70	5.89
	a	5.11 ± 0.07	5.13 ± 0.17	5.25 ± 0.12	5.30 ± 0.13	3.19
	b	2.06 ± 0.03^{c}	3.50 ± 0.17^{a}	2.94 ± 0.0^{b}	2.74 ± 0.25^{b}	43.91^{***}
	ΔE	—	2.49 ± 0.10^{a}	2.14 ± 0.56^{a}	2.05 ± 0.65^{a}	0.64

[1)]Noodle-0: noodles added with 0% psyllium husk. [2)]Noodle-10: noodles added with 10% psyllium husk. [3)]Noodle-25: noodles added with 25% psyllium husk. [4)]Noodle-40: noodles added with 40% psyllium husk. [a-d]Means represented by different superscripts in the same row are significantly different at $p < 0.05$. ** and ***Significant at $p < 0.01$ and $p < 0.001$, respectively.

Table 14: Changes of texture profiles of cooked noodles with various psyllium husk contents.

	Cooking time (min)	Hardness (g)	Springiness	Gumminess	Cohesiveness	Chewiness
WN[1)]	3	2138.10 ± 423.97^{a}	0.52 ± 0.11^{abc}	1105.39 ± 269.34^{a}	0.52 ± 0.13^{bc}	572.83 ± 144.79^{a}
	6	2014.97 ± 621.14^{b}	0.50 ± 0.05^{bcd}	1087.92 ± 242.80^{a}	0.52 ± 0.03^{bc}	544.74 ± 94.56^{ab}
	9	1598.84 ± 483.47^{cd}	0.49 ± 0.11^{bcd}	981.74 ± 170.24^{bc}	0.46 ± 0.05^{ef}	511.16 ± 92.52^{bc}
Noodle-10[2)]	3	1570.52 ± 215.98^{cd}	0.53 ± 0.04^{ab}	747.81 ± 127.08^{de}	0.48 ± 0.04^{cde}	397.08 ± 84.14^{ef}
	6	1336.52 ± 405.26^{ef}	0.53 ± 0.07^{abc}	603.97 ± 186.16^{fg}	0.45 ± 0.02^{ef}	318.06 ± 91.51^{f}
	9	1122.08 ± 136.08^{f}	0.55 ± 0.04^{a}	494.84 ± 87.96^{g}	0.44 ± 0.05^{f}	273.12 ± 44.12^{f}
Noodle-25[3)]	3	1634.16 ± 60.57^{cd}	0.49 ± 0.27^{cd}	853.63 ± 85.39^{cd}	0.52 ± 0.04^{ab}	408.38 ± 265.19^{cde}
	6	1525.32 ± 112.15^{cd}	0.54 ± 0.06^{ab}	782.47 ± 83.51^{de}	0.51 ± 0.02^{bcd}	419.03 ± 20.50^{cde}
	9	1424.42 ± 85.81^{ed}	0.55 ± 0.05^{a}	687.79 ± 85.26^{ef}	0.48 ± 0.04^{def}	381.00 ± 55.66^{def}
Noodle-40[4)]	3	1834.62 ± 105.39^{bc}	0.43 ± 0.05^{d}	1071.22 ± 74.41^{ab}	0.58 ± 0.03^{a}	464.29 ± 77.24^{bcd}
	6	1744.14 ± 62.85^{c}	0.45 ± 0.03^{cd}	954.70 ± 34.86^{bc}	0.55 ± 0.03^{ab}	433.53 ± 31.11^{cde}
	9	1670.04 ± 82.99^{cd}	0.51 ± 0.03^{abc}	861.62 ± 46.57^{cd}	0.52 ± 0.02^{b}	435.68 ± 32.50^{cde}
F value		14.08^{***}	4.63^{**}	22.59^{***}	10.32^{***}	9.8^{***}

[1)]WN: wheat flour noodles. [2)]Noodle-10: noodles added with 10% psyllium husk. [3)]Noodle-25: noodles added with 25% psyllium husk. [4)]Noodle-40: noodles added with 40% psyllium husk. [a-g]Means represented by different superscripts in the same column are significantly different at $p < 0.05$. ** and ***Significant at $p < 0.01$ and $p < 0.001$, respectively.

3.3.3. Chromaticity and Texture of Cooked Noodles. With increasing psyllium husk content, the L and b values decreased, and the a value increased in cooked noodles (Table 13). Similarly, addition of buckwheat sprout powder, which had low brightness, decreased the L value of cooked noodles containing buckwheat sprout powder; meanwhile, the b value of noodles decreased because of leaching of yellow pigment during cooking and the a value was caused by browning during heating [65]. Thus, in the cooked noodles made of SDS and psyllium husk, the decrease in the L value after cooking was due to a decrease in the brightness of psyllium husk powder, the increase in the *a* value was caused by browning, and the decrease in the *b* value was caused by leaching of yellow pigment.

The hardness, gumminess, cohesiveness, and chewiness of cooked noodles (noodle-10, 25, and 40) were lower than that of the wheat flour noodles (WNs) and the hardness, gumminess, cohesiveness, chewiness of cooked noodles decreased with increasing cooking duration (Table 14). The springiness of cooked noodles increased with increasing cooking duration. After cooking the noodles, texture profiles of the noodles added with 40% psyllium husk content are similar to that of wheat noodles.

4. Conclusions

Steam treatment of noodle dough made from SDS and psyllium husk significantly improved its quality and texture and increased structural compactness, similar to wheat flour dough. Comparing soybean dough prepared with only soybean powder (SD) and doughs prepared with psyllium husk and SDS, the aglycone isoflavone contents of doughs prepared with psyllium husk and SDS were higher; glycitein was detected in doughs prepared with psyllium husk and SDS but not in SD. As cooking duration increased, the weight, volume, water absorption, volume change, and soup turbidity of cooked noodles increased. Moreover, as cooking duration increased, the hardness, gumminess, cohesiveness, and chewiness of noodles decreased, their springiness increased, and their shape was maintained. Finally, we thought that the overall best formular and steam treatment time were 40% psyllium husk content and 10 min, respectively, considering from dietary fiber content and texture profile of cooked noodle. Consequently, without steam treatment, the shape of the noodle did not maintain after cooking. On the other hand, it was confirmed that the shape of the noodles after cooking can be maintained through steam treatment. Therefore, the steam treatment of dough made from SDS and psyllium husk enables the preparation of noodles without the addition of gluten. These findings offer a new method for manufacturing gluten-free noodles which will help improve the value of use in the noodle industry such as in gluten-free noodles.

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Additional Points

Novelty Impact Statement. Noodles are typically prepared by making dough from wheat flour, forming noodles, and boiling the noodles. However, in this study, the dough was prepared with soaked-and-dried soybean powder instead of wheat flour and supplemented psyllium husk powder instead of gluten. Additionally, the dough was treated with steam to improve crosslinking. This process enabled the production of gluten-free noodles with steam-treated dough made with soaked-and-dried soybean and psyllium husk without using wheat flour.

Conflicts of Interest

The authors have declared no conflicts of interest for this article.

Authors' Contributions

Se-Lim Bak carried out the formal analysis (lead), investigation (lead), writing—original draft (lead), and writing—review and editing (lead); Seung-Hyeon Cha carried out the data curation (equal) and formal analysis (equal); Sang-Beom Park carried out the formal analysis (supporting); Shangle Jiang carried out the formal analysis (supporting); Tae Kyung Hyun carried out the conceptualization (equal), methodology (equal), writing—original draft (equal), and writing—review and editing (lead); and Keum-Il Jang carried out the conceptualization (lead), funding acquisition (lead), methodology (lead), project administration (lead), writing—original draft (lead), and writing—review and editing (lead).

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