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Effects of Blends of Low-Protein Winter Wheat Flour and Barley Byproducts on Quality Changes in Noodles

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ABSTRACT: The physicochemical characteristics of fresh noodles made with blends of low-protein wheat flour and barley byproduct (BBP, 250 μm) were investigated. The crude protein contents (PC) of flour from Goso and Backjoong cultivars were 7.91% and 7.67%, respectively. PC and β-glucan contents from the BBP were 14.10% and 3.11%, respectively, which were higher than those in wheat flour. The water-holding capacity (WHC) of various blends was increased as a function of BBP but not gluten contents. Goso flour had the highest starch content (78.68%), with peak and final viscosities of 3,099 and 3,563 cp, respectively. Peak and final viscosities, trough, breakdown, and setback of the blends were decreased with the addition of BBP. Noodles made with Backjoong had the highest thickness score, while the hardness of noodles made with blends of Goso or Backjoong and 20% BBP were similar to those made from wheat flour only. The WHC of the samples was strongly correlated with PC, crude fiber, and β-glucan. The PC was not correlated with final viscosity, setback, thickness, hardness, gumminess, or chewiness.

Keywords: low-protein wheat, bran, noodle quality, correlation analysis

INTRODUCTION

Wheat (*Triticum aestivum* L.) is a major food source for humans (1) and a staple food ingredient in all nations and cultures worldwide owing to the unique properties of its flour, which forms a cohesive dough and can be used to make bread, noodles, pastas, and other foods (2). Wheat flour rather than other cereal flours contains proteins, such as gluten, that have the ability to form three-dimensional networks (3).

However, environmental factors, such as fertilizer supply, override genotype, and genotype and environmental interactions, cause variations in the protein content (PC) and characteristics of wheat flour (4). Triboi et al. (5) reported that wheat grain composition and total PC in wheat were increased by nitrogen fertilizer supply, which increased the content and ratio of gliadin and glutenin, two components of the gluten network. Notably, low-protein wheat flour produced at farms in Korea is not preferable because it does not positively affect the quality of the final products, such as bread and noodles.

Noodles are a popular major cereal product in Asia due to their ease of handling and cooking (2). The suitability of wheat flour for noodle production has been assessed by measuring the PC of the flour, which is an indicator of noodle quality (6). Wheat flour with a PC greater than 11% is required for processing and acceptable texture (7).

As increasing consumer awareness of health, use of whole grain flour in substitution for refined flour was increased (8). Flours from alternative sources, such as sweet potatoes, water chestnuts, and other tubers including colocasia, are used as potential wheat flour substitutes to add variety and functionality to noodle products (9).

Agricultural byproducts, particularly cereal byproducts, are produced from the outer layer of cereal grains during grain processing. Composed of aleurone and pericarp, cereal byproducts are important components of functional food formulations (10). Bran is a good source of protein and dietary fiber and stores arabinoxylan, β-glucan, phenolic acid, flavonoids, oils (e.g., γ-oryzanol), vitamins, oligosaccharides, folates, and sterols (10,11). Barley (*Hordeum vulgare* L.) has a higher amount of phenolic compounds and antioxidant activity than the more widely consumed wheat and rice cultivars (12). Additionally, barley and oat bran contain β-glucan, a soluble fiber that has antilipidemic properties compared to other byproducts (13).

The purpose of this study was to determine the physicochemical characteristics of blends of low-protein re-

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fined wheat flour and barley bran byproducts. The quality of noodles made with blends of low-protein wheat flour and barley byproducts was also investigated.

MATERIALS AND METHODS

Sample preparation

The low-protein Korean winter wheat cultivars Keumkang, Goso, and Baekjoong were purchased from the Woori-wheat Cooperative of Jeonju and Gwangju, Korea. Harvested wheat cultivars were dried and milled using a milling machine (MLU-202; Bühler AG, Uzwil, Switzerland). Barley byproduct (BBP) was obtained from Saenggeumdeul Co. (Gunsan, Korea) and were produced by milling to 250 μm. The BBP was added to low-protein wheat flour at concentrations of 0%, 10%, and 20% (w/w), and the blends were mixed three times using a sieve. Refined wheat flour and BBP were placed in plastic bags and stored at 10°C until use.

Determination of the proximate composition and total dietary fiber, total starch, and β-glucan contents of wheat flour and barley byproducts

The proximate composition (e.g., moisture, ash, and crude protein) of wheat flour and BBP was analyzed using the official methods of the American Association of Cereal Chemists (14). Total dietary fiber content was determined with a dietary fiber analyzer (Dosi-fiber, J.P Selecta s.a, Barcelona, Spain). β-Glucan content was analyzed using AACCI Approved Method 32-23.01 (14). Total starch (TS) content was measured using AOAC Official Method 996.11 (15).

Water-holding capacity (WHC) and pasting profiles of the blends

The WHC of the blends was measured using the method of Medcalf and Gilles (16), with slight modifications (17). Pasting properties such as peak viscosity (PV), final viscosity (FV), breakdown, setback (SB), and pasting temperature of the starch suspension (3.5 g sample in 25 mL water, 14% moisture basis) were determined with an RVA 4500 Rapid Visco analyzer (Perten Instruments, Kungens Kurva, Sweden) according to the manufacturer's general pasting method.

Evaluation of fresh noodle quality

Noodle preparation was carried out as described by Baik et al. (18) and Kang et al. (19) with some modifications. Evaluation of fresh noodle quality was performed based on the thickness (TK) and color of the noodle sheet and the texture of the boiled noodles. TK was measured using a Model G Peacock dial thickness gauge (Ozaki Mfg. Co., Ltd., Tokyo, Japan). A spectrophotometer (CM-5, Konica Minolta, Osaka, Japan) was used for the analysis of L^*, a^*, and b^* values of the noodle sheet. The texture of the cooked noodles was measured within 3 min after boiling. Textural analysis of the samples was performed using a texture analyzer (TA1, Lloyd Instruments Ltd., Bognor Regis, UK) equipped with a 500-N load cell. The texture profile analysis was carried out with compression of the samples to 70% of the sample height at a crosshead speed of 10 mm/min with a cylindrical stainless steel 20 mm probe.

Statistical analysis

Data were analyzed using SAS software (SAS Institute, Cary, NC, USA). Data are shown as the mean and standard deviation and were compared for significance at the 5% probability level using Duncan's multiple comparison tests. Pearson correlation tests were carried out to determine the relationships between PC, total crude fiber (CF), TS, β-glucan (GLU), WHC, PV, FV, and SB of the flour as well as the TK, hardness (HD), gumminess (GM), and chewiness (CW) at a probability level of $P<0.0001$.

RESULTS AND DISCUSSION

Proximate, CF, TS, GLU, and WHC of samples

The proximate composition of the samples, including water, ash, PC, CF, TS, GLU, and WHC, is shown in Table 1. BBP had higher ash, PC, CF, GLU, and WHC than the low-protein wheat flour. The PC of Keumkang, Goso, and Backjoong low-protein Korean winter wheat flours were 9.15%, 7.91%, and 7.67%, respectively. PC and GLU contents of barley byproducts were 14.10% and 3.11%, respectively. PC, CF, and GLU contents of the Backjoong flour and 40% BBP blend were 10.43%, 2.96%, and 1.40%, respectively. Ash, PC, CF, GLU, and WHC of the blends increased with the addition of BBP. Dry gluten contents of Keumkang, Goso, and Backjoong were 8.30%, 7.00%, and 6.05%, respectively, and wet gluten contents were 23.95%, 20.15%, and 18.35%, respectively. However, blends of Keumkang, Goso, or Backjoong and 20% BBP had dry gluten contents of 3.55%, 4.40%, and 3.70%, respectively; thus, dry and wet gluten contents of blends were not increased by the addition of byproduct (data not shown).

The water and TS contents of BBP (8.03% and 27.82%, respectively) were lower than those of low-protein wheat flour; the addition of barley byproduct into wheat flour decreased these values. WHC values of Keumkang, Goso, and Backjoong were 89.17%, 82.45%, and 92.76%, respectively, which were lower than that of BBP (262.64%). However, the WHC of blends increased with BBP addition, likely due to the higher β-glucan, ash, and CF con-

Table 1. General composition and total crude fiber, total starch, and β-glucan contents, and water-holding capacity of low-protein Korean winter wheat flour and barley byproducts

Sample	Conc. (%)	Water (%)	Ash (%)	PC (%)	CF (%)	TS (%)	GLU (%)	WHC (%)
Barley byproduct		8.03^{f}	3.99^{a}	14.10^{a}	6.66^{a}	27.82^{h}	3.11^{a}	262.64^{a}
Kemkang	0	13.69^{a}	0.65^{h}	9.15^{f}	0.51^{d}	77.56^{b}	0.22^{ef}	89.17^{g}
	20	12.57^{b}	1.35^{e}	10.01^{e}	1.62^{c}	67.15^{e}	0.79^{c}	104.19^{e}
	40	11.51^{d}	2.01^{b}	11.10^{b}	2.75^{b}	56.85^{g}	1.38^{b}	131.52^{b}
Goso	0	13.56^{a}	0.31^{j}	7.91^{h}	0.31^{d}	78.68^{a}	0.17^{f}	82.45^{h}
	20	12.14^{c}	1.11^{g}	9.22^{f}	1.38^{c}	68.06^{de}	0.72^{d}	95.01^{f}
	40	11.20^{d}	1.88^{d}	10.58^{c}	2.70^{b}	58.08^{f}	1.40^{b}	127.66^{c}
Backjoong	0	12.30^{bc}	0.47^{i}	7.67^{i}	0.35^{d}	75.77^{c}	0.23^{e}	92.76^{f}
	20	11.45^{d}	1.26^{f}	8.99^{g}	1.64^{c}	68.64^{d}	0.77^{cd}	107.30^{d}
	40	10.66^{e}	1.95^{c}	10.43^{d}	2.96^{b}	58.78^{f}	1.40^{b}	132.90^{b}
SEM1)		0.128	0.013	0.034	0.082	0.362	0.020	0.980

Different letters (a-j) within the same column differ significantly ($P<0.05$).
Conc., concentration; PC, crude protein content; CF, total crude fiber content; TS, total starch content; GLU, β-glucan content; WHC, water-holding capacity.
1)Standard errors of the mean (n=30).

tents of the latter as compared with that of wheat flour. Hung et al. (20) reported that flour quality is also determined by the properties of dough, which is an intermediate stage in the transformation of wheat flour to end products, such as noodles, bread, and cookies. Dough made from soft wheat flour, which has low PC and gluten quality, exhibits low water absorption, is less stable during mixing, and is less extensible than dough made from strong wheat flour (21). Wheat gluten is the main determinant of the end-use quality of wheat because it improved the quality of dough, including characteristics such as water absorption capacity, cohesivity, and viscoelasticity (3).

The water absorption capacity of wheat flour is increased by adding barley flour which has higher levels of insoluble and soluble fiber, and β-glucan (22). Moreover, the addition of β-glucan and soluble and insoluble fibers to wheat flour increases the water-binding capacity of the product due to the hydroxyl groups found within the structures (12,23). Additionally, increasing the maize bran content results in a higher water absorption index, which can be explained by the high water absorption capacity (24). Taken together, the results of this study showed that BBP had higher GLU and CF contents, thereby increasing the WHC of the blends with low-protein wheat flour and BBP.

Pasting properties of low-protein Korean winter wheat flour and barley byproduct blends

The FVs of Keumkang, Goso, and Backjoong wheat flours were 3,337.00, 3,563.33, and 2,694.33 cP, respectively (Table 2). Goso flour, which had the highest starch content (78.68%) of all samples, had the highest PV and FV (3,099.00 and 3,563.33 cP, respectively). In contrast, BBP had the lowest PV and FV among the samples (232.67 and 338.00 cP, respectively). The low viscosity was likely due to the low TS content (27.82%) and high CF content (6.66%) of the barley byproduct. The PV,

Table 2. Pasting properties of blends with low-protein Korean winter wheat flour and barley byproduct (BBP)

Samples	Conc. (%)	Viscosity (cP)					Peak time (min.)	Pasting temperature (°C)
		Peak	Trough	Breakdown	Final	Setback		
Barley byproduct		232.67^{i}	150.67^{h}	82.00^{g}	338.00^{i}	187.33^{h}	5.00^{f}	94.40^{a}
Kemkang	0	$2,523.33^{b}$	$1,907.33^{a}$	616.00^{de}	$3,337.00^{b}$	$1,429.67^{b}$	6.49^{a}	88.27^{d}
	20	$1,787.33^{e}$	$1,098.67^{d}$	688.67^{cd}	$2,427.00^{d}$	$1,328.33^{c}$	6.11^{b}	89.57^{bc}
	40	$1,174.00^{h}$	694.00^{g}	480.00^{f}	$1,807.67^{f}$	$1,113.67^{e}$	5.82^{cde}	90.48^{a}
Goso	0	$3,099.00^{a}$	$1,958.33^{a}$	$1,140.67^{a}$	$3,563.33^{a}$	$1,605.00^{a}$	6.18^{b}	86.13^{e}
	20	$2,152.00^{d}$	$1,314.00^{c}$	838.00^{b}	$2,403.33^{d}$	$1,089.33^{e}$	5.89^{cd}	89.40^{c}
	40	$1,385.67^{g}$	858.33^{f}	527.33^{ef}	$1,545.33^{g}$	687.00^{g}	5.73^{e}	89.62^{bc}
Backjoong	0	$2,262.00^{c}$	$1,415.67^{b}$	846.33^{b}	$2,694.33^{c}$	$1,278.67^{d}$	6.09^{b}	86.10^{e}
	20	$1,712.00^{f}$	948.33^{e}	763.67^{bc}	$1,909.67^{e}$	961.33^{f}	5.91^{c}	87.73^{d}
	40	$1,210.33^{h}$	721.33^{g}	489.00^{f}	$1,374.00^{h}$	652.67^{g}	5.76^{de}	87.72^{d}
SEM1)		18.050	21.794	30.041	25.123	14.340	0.046	0.334

Different letters (a-i) within the same column differ significantly ($P<0.05$).
1)Standard errors of the mean (n=30).

FV, trough, breakdown, and SB of the blends decreased, whereas the pasting temperature increased with the addition of BBP. Thus, sample viscosity and starch content showed similar trends. This is in agreement with the results of a study by Singh et al. (25), who showed that increasing the proportion of corn bran in the blends reduced the pasting profile and that the PV was higher for corn bran with smaller particle sizes. Moreover, when glucan was incorporated into wheat flour, PV, FV, hold viscosity, and SB were markedly reduced (26).

Changes in the quality of fresh noodles made with blends of low-protein Korean winter wheat flour and barley byproducts

Fresh noodles were prepared with blends of low-protein wheat flour and BBP. The TK and color values of noodle sheets are shown in Table 3. The TKs of noodle sheets made with Keumkang, Goso, and Backjoong were 1.62, 1.54, and 1.70 mm, respectively. Noodles made from Backjoong flour were the thickest, which was presumed to affect the WHC. The addition of BBP decreased the TK of noodle sheets and reduced the lightness values, which were 82.81, 86.96, and 85.65 for noodles sheets made from Keumkang, Goso, and Backjoong flour, respectively. Commercial whole grain pasta had the highest color and appearance scores; for example, increasing the wheat bran content in durum wheat semolina results in a dark, less uniform, and less glossy appearance (27). Conversely, adding oat bran gives samples a lighter and more yellow color (28).

Table 3. Thickness and color value of fresh noodle sheets made from blends of low-protein Korean winter wheat flour and barley byproduct (BBP)

Samples	Conc. (%)	TK (mm)	Color value of noodle sheet		
			L*	a*	b*
Kemkang	0	1.62^{b}	82.81^{c}	0.06^{e}	14.63^{d}
	20	1.55^{c}	72.58^{f}	3.33^{c}	19.66^{b}
	40	1.39^{f}	68.49^{h}	4.51^{a}	21.00^{a}
Goso	0	1.54^{cd}	86.96^{a}	-0.28^{f}	13.07^{e}
	20	1.48^{de}	74.72^{d}	2.95^{d}	18.77^{c}
	40	1.35^{f}	70.00^{g}	4.11^{b}	21.11^{a}
Backjoong	0	1.70^{a}	85.65^{b}	0.07^{e}	14.79^{d}
	20	1.46^{e}	73.25^{e}	3.01^{d}	18.73^{c}
	40	1.28^{g}	65.60^{i}	4.58^{a}	21.47^{a}
SEM[1)]		0.021	0.225	0.069	0.202

Different letters (a-i) within the same column differ significantly ($P<0.05$).
TK: thickness.
[1)] Standard errors of the mean (n=27).

Texture profiles of boiled noodles, such as HD, adhesiveness, springiness, GM, CW, and cohesiveness, are shown Table 4. The HD values of boiled noodles made from Keumkang, Goso, and Backjoong flours were 8.30, 7.39, and 6.14 N, respectively; these values are likely determined by PC (9.15%, 7.91%, and 7.67%, respectively) and dry gluten content (8.30%, 7.00%, and 6.05%, respectively, data not shown). The HD of cooked noodles decreased with the addition of BBP with increase concentrations.

However, HD values of noodles made from Goso or Backjoong flour combined with 20% BBP did not significantly differ from those of noodles made from wheat flour only ($P<0.05$). In our previously study, the gluten index values of Goso and Backjoong plus 20% barley byproduct blends were 96.01 and 98.51, respectively, which were higher than the values for unblended wheat flour (90.32 and 94.87, respectively). Textures such as springiness, GM, CW, cohesiveness, and HD were similar between noodles made from a blend of Goso and 20% barely byproduct and those made from Goso only; this could be due to the TS or GLU contents and WHCs of blended samples. However, noodle HD was markedly decreased by the addition of 40% BBP. In a previous study, Zhou et al. (6) demonstrated that the wet gluten contents

Table 4. Texture profiles of white salted fresh noodles made from blends of low-protein Korean winter wheat flour and barley byproduct (BBP)

Samples	Conc. (%)	HD (N)	Adhesiveness (N·m)	Springiness	GM (N)	CW (N)	Cohesiveness
Kemkang	0	8.30^{a}	0.05^{bc}	0.84^{b}	3.88^{a}	3.23^{a}	0.469^{b}
	20	7.09^{b}	0.04^{bcd}	0.93^{a}	3.28^{b}	3.05^{a}	0.463^{b}
	40	4.62^{d}	0.02^{ed}	0.93^{a}	1.78^{d}	1.65^{c}	0.377^{d}
Goso	0	7.39^{b}	0.03^{bcd}	0.93^{a}	3.30^{b}	3.05^{a}	0.446^{bc}
	20	7.42^{b}	0.07^{a}	0.93^{a}	3.35^{b}	3.12^{a}	0.451^{bc}
	40	4.03^{d}	0.01^{e}	0.92^{a}	1.57^{d}	1.44^{c}	0.394^{cd}
Backjoong	0	6.14^{c}	0.04^{bcd}	0.91^{a}	3.32^{b}	3.03^{a}	0.548^{a}
	20	6.06^{c}	0.05^{ab}	0.91^{a}	2.69^{c}	2.46^{b}	0.447^{bc}
	40	4.62^{d}	0.02^{cde}	0.92^{a}	1.70^{d}	1.57^{c}	0.375^{d}
SEM[1)]		0.255	0.008	0.021	0.104	0.112	0.021

Different letters (a-e) within the same column differ significantly ($P<0.05$).
HD, hardness; GM, gumminess; CW, chewiness.
[1)] Standard errors of the mean (n=27).

Table 5. Correlation coefficients between assays

	PC	CF	TS	GLU	WHC	PV	FV	SB	TK	HD	GM	CW
PC	1	0.906***	0.907***	−0.903***	0.907***	0.874***	−0.801***	−0.736***	−0.616*	−0.497*	−0.748***	−0.748***
CF		1	−0.978***	0.994***	0.969***	−0.930***	−0.921***	−0.841***	−0.835***	−0.703***	−0.877***	−0.837***
TS			1	−0.915***	−0.962***	0.941***	0.920***	0.810***	0.751***	0.734***	0.872***	0.817***
GLU				1	0.970***	−0.930***	−0.922***	−0.838***	−0.808***	−0.726***	−0.886***	−0.838***
WHC					1	−0.954***	−0.922***	−0.827***	−0.759***	−0.796***	−0.903***	−0.877***
PV						1	0.953***	0.829***	0.659**	0.730***	0.782***	0.753***
FV							1	0.937***	0.780***	0.775***	0.817***	0.788***
SB								1	0.832***	0.728***	0.746***	0.714***
TK									1	0.628**	0.814***	0.773***
HD										1	0.868***	0.839***
GM											1	0.920***
CW												1

PC, protein contents; CF, total crude fiber contents; TS, total starch contents; GLU, β-glucan contents; WHC, water-holding capacity; PV, peak viscosity; FV, final viscosity; SB, setback; TK, thickness of noodle sheets; HD, hardness of noodles; GM, gumminess of noodles; CW, chewiness of noodles.
*P<0.001, **P<0.0005, ***P<0.0001.

(amount of bound water) of low-protein wheat flour increased with the addition of konjac glucomannan, which also increased the HD of noodles made from low-protein wheat flour. Additionally, the optimum water absorption capacity is negatively correlated with flour PC, and higher HD values are negatively correlated with water absorption capacity (29). Sobota et al. (27) reported that the high HD and surface stickiness values of pasta made with bran are associated with the disruption of the gluten matrix continuity during dough formation by insoluble CF particles. Our results are in contrast with a report demonstrating that adding oat bran increases the firmness of sausages to a value comparable to that of reference sausages (11.0 N), while the opposite is true when rye bran or barley fiber is added (30). The hardness of meatballs was increased by the addition oat bran (28). Our results showed that BBP can be considered a potential source of CF, GLU contents, and increased WHC of samples. Moreover, texture quality measured as springiness, gumminess, or CW of noodles made with Kemkang and Goso low-protein wheat flour and 20% BBP was improved. Consequently, blends with low-protein wheat flour and BBP can be considered a functional source for quality improvement of noodles made with low-protein wheat flour.

Correlation coefficients between assays

Pearson correlation analysis revealed that the WHC of the samples was strongly correlated with PC ($r=0.907$, $P<0.0001$), CF ($r=0.969$, $P<0.0001$), and GLU ($r=0.970$, $P<0.0001$; Table 5). FV was correlated with TS ($r=0.920$, $P<0.0001$) and PV ($r=0.953$, $P<0.0001$). The highest correlation coefficient was found between CF and GLU ($r=0.994$, $P<0.001$). However, PC was not correlated with GLU, FV, SB, TK, HD, GM, or CW. Addition of barley byproducts influenced each of the correlations compared with those of wheat flour only. Lee and Kang (31) reported that HD was well correlated with PC, dry gluten content, and water binding in gluten from wheat flour ($P<0.01$). In contrast to our study, Kang et al. (19) reported that the HD of cooked noodles was well correlated with PC. However, similar to our findings, Singh et al. (32) reported that higher PC of flour was associated with a higher PV, which was well correlated with SB. These results indicated that BBP possesses functionality such as higher GLU, CF, and WHC compared with low-protein wheat only. Blends of wheat flour and BBP enhance the Ash, PC, CF, GLU, and WHC and decreased FV and SB.

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AUTHOR DISCLOSURE STATEMENT

The authors declare no conflict of interest.

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