Effects of Different Fertilization Treatments on the Physicochemical and Noodle-making Properties of Korean Winter Wheat Cultivars

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Abstract Changes in the quality of white salted noodles prepared with different types of Korean winter wheat were examined. Crude protein and amylose contents of various wheat cultivars ranged from 7.17 to 9.97 and 24.78 to 29.37%, respectively. The water holding capacities of Jokyeong with base N-fertilizer (NF) and Keumkang with 40% increased NF compared with NF at the supplementary manuring (SM) were 95.70 and 70.69%, respectively. The dry gluten content of the Keumkang with 20% increased NF compared with SM at the panicle initiation stage (PS) was 12.5%, and the final viscosities of several cultivars with NF, PS, and SM did not differ. PS treatment increased the thickness of the noodle sheet, and the hardnesses of cooked noodles prepared using Goso, Baekjoong, Younbaek, and Keumkang wheat with PS or SM treatment were increased. The thickness was strongly positively correlated with dry gluten content (DG) and water binding in wet gluten. In order to improve the quality of fresh noodles, wheat flour prepared using Hojung, Goso, and Baekjoong cultivars under PS cultivation condition or wheat flour with higher protein content, DG contents, and WBG should be used.

Keywords: Korean winter wheat, wheat protein, noodle, fertilization, wheat flour

Introduction

Noodles are a widely popular staple food in many countries owing to their simple preparation, desirable sensory attributes, and low price (1,2). Noodles are generally prepared using wheat flour, and in several countries, 50% of total wheat flour consumption accounted for the manufacture of noodles (3).

The quality of noodles is evaluated as a combination of appearance, texture, eating quality, cooking, and textural properties (4). The textural properties of noodle are generally considered the most important quality parameter (5). The requirements for starch and protein characteristics differ for various types of noodles (6). The distribution of starch granules influences the starch-to-protein ratio in the endosperm, thereby affecting flour composition and quality (7). The development and distribution of starch granules have been shown to be controlled largely by wheat genotype (8,9).

Wheat (*Triticum aestivum* L.) is one of the most important crops worldwide and is used as a main component to produce various food products, such as noodles, baked good, and cookies. Wheat flour is the main ingredient used in manufacturing of noodles; therefore, the characteristics of wheat flour are important for noodle making (10).

Application technique and N-fertilizer (NF) source influence wheat grain proteins and noodle quality (11). Ma *et al.* (12) reported that NF at 270–360 kg N/ha improves the texture of noodles in field experiments. N-fertilization increases the concentrations of micronutrients such as Fe, Zn, and Cu, and protein contents in wheat grain. Therefore, the management of NF and its environmental effects are major concerns in crop production (13). Additionally, the amount of NF applied and duration of supplementary manuring, which affects protein content, is important during plant growth (14). Kim *et al.* (15) reported that increased fertilization enhances the culm length, thousand grain weight, and protein content but decrease the spike length and ash content.

The objective of this study was to investigate the physicochemical characteristics of Korean winter wheat flour grown using different N-fertilization methods. Additionally, changes in the quality of noodles prepared using the different types of wheat flour were evaluated. Finally, the relationships among crude protein contents (PC), amylose contents (AM), damaged starch contents (DS), water holding capacity (WHC), dry gluten content (DG), water binding in wet gluten (WBG), peak viscosity (PV), final viscosity (FV), thickness of the noodle sheet, and hardness of cooked noodles were determined.

Materials and Methods

Sample preparation The Korean winter wheat cultivars cv. Jokjung, Hojung, Goso, Baekjoong, Younbaek, and Keumkang were obtained from the Department of Rice and Winter Cereal Crop, National Institute of Crop Science (Iksan, Jeonbuk, Korea). In order to compare these cultivars with foreign varieties having different protein contents, the Canadian western red spring (CWRS), Australia hard (AH), and white hard (WH) cultivars were used as controls. The fertilizer used in this study was based on N, P, and K source, supplied at 22.0, 65.1, and 15.3 g/m², respectively. These varieties were cultivated under different conditions, such as base N-fertilizer (NF), 40% increased N-fertilizer compared with NF as supplementary manuring (SM), and 20% increased N-fertilizer compared with SM at the panicle initiation stage (PS). Wheat cultivars were propagated during the 2013–2014 season in Iksan region in Jeonbuk, Korea. Samples were milled using a Buhler milling machine (MLU-202; Buhler, Uzwil, Switzerland) according to Approved Methods 26–31.01 (16). The samples were placed in plastic bags and stored at 10°C until use.

Chemical composition of wheat flour The moisture, ash, and crude protein contents of the sample were determined using the official methods of the American Association of Cereal Chemists (16). The amylose contents were determined by the iodine colorimetric procedure described by Juliano (17). The damaged starch contents were determined according to the method reported by Gibson *et al.* (18) using a starch damage assay kit (Megazyme International, Bray, Ireland).

Water holding capacity The water holding capacity (WHC) of the sample was determined using the methods of Medcalf and Gilles (19) and a slightly modified version of the method reported by Kim and Shin (20). The samples (1 g) were mixed with 40 mL of distilled water, stirred at room temperature for 1 h and centrifuged at 2,000×g for 30 min. The water holding capacity was calculated using the following equation:

$$\text{Water holding capacity (\%)} = (\text{weight of precipitate} - \text{weight of samples} / \text{weight of samples}) \times 100$$

Gluten properties and pasting profile Gluten properties of wheat flour such as gluten index (GI), wet gluten contents, dry gluten contents, and water binding in wet gluten, were analyzed using a Glutomatic system (Glutomatic; Perten Instruments., Hägersten, Sweden).

The pasting properties of the sample were determined with a Rapid Visco Analyzer (RVA-4), using the RVA General Pasting Method (Newport Scientific Pty. Ltd., Warriewood, Australia). The sample-water suspension (12%, w/w) was heated to 50°C, held at 50°C for 1 min, and then heated to 95°C at a heating rate of 11.25°C/min. The

sample was held at 95°C for 2.5 min and finally cooled to 50°C at a cooling rate of 11.86°C/min. The peak viscosity, final viscosity, breakdown, setback, and pasting temperature were obtained from the pasting curve.

Scanning electron microscopy (SEM) The microstructural properties of the samples were measured using a scanning electron microscope (S4800EDS; Hitachi Ltd., Tokyo, Japan). The samples were dried, mounted on aluminum stubs using double-sided tape, and coated with a thin film of gold. The microstructures of the cutting plane were observed by SEM under an acceleration voltage of 15.0 kV at a magnification of 5,000×.

Noodle preparation The noodles were prepared following the methods described by Baik *et al.* (21) and modified based on the method reported by Kang *et al.* (22). For noodle formulation, 100 g wheat flour (based on 14% water contents) was added to a salt solution (final concentration of salts: 2%) and blended using a KitchenAid food processor (5KPM50; KitchenAid, Benton Harbor, MI, USA). The amount of water was 36% (v/w). The roll space for preparation of the noodle sheet was 2 mm. The noodle sheet was prepared using 2 mm roller, ripened at 20°C for 1 h, and then rolled to thicknesses of 1.60, 1.40, and 1.00 mm progressively using a KitchenAid pasta roller. The noodle sheet was cut into 2 mm in size using a pasta cutter attached to the KitchenAid food processor.

Evaluation of fresh noodle quality Fresh noodle quality, including thickness and color of the noodle sheet, and textural properties of boiled noodle were measured. Thickness was measured using a Dial thickness gauge (Model G Peacock dial thickness gauge; Ozaki Mfg Co., Ltd., Tokyo, Japan). Color values of the noodle sheet were determined using a spectrophotometer (CM-5; Konica Minolta Inc., Tokyo, Japan). The noodle sheet was incubated at 20°C for 1 h and the color of the sheet surface was measured at three points for each sample. The values were averaged, and the numerical values representing the color were expressed as L*, a*, and b* values.

The noodles (2 mm space) were boiled in distilled water (500 mL) at 100°C for 5 min. After boiling, the noodles were immediately cooled in water at room temperature. Textural properties of cooked noodles were measured within 3 min after boiling. Textural analysis for the five noodle strands was performed using a texture analyzer (TA1; Lloyd Instruments Ltd., Fareham, UK). TPA tests were carried out using a 500 N-load cell for cooked samples. The sample was compressed up to 70% of its original height at a crosshead speed of 10 mm/min with a cylindrical stainless steel probe (diameter 20 mm).

Statistical analysis One-way analysis of variance was performed using SAS software (version 7.0; SAS Institute Inc., Cary, NC, USA) with Duncan's post hoc tests to compare the differences among the mean values. Each data point entry represents the mean of three

different experiments with three measurements for each experiment. The mean values and standard errors of the means were reported, and difference with p value of less than 0.05 was considered significant. Comparisons of PC, AM, DS, WHC, DG, WBG, PV, FV, thickness, and hardness were carried out with Pearson correlation tests at a probability level of $p < 0.0001$.

Results and Discussion

General components, amylose, damaged starches, and WHC of Korean winter wheat flour The general components, amylose content, damaged starches, and WHC of Korean wheat flour are shown Table 1. The physicochemical properties of Korean winter wheat flour varied depending on the application rate and time of N-fertilization during cultivation. Additionally, the properties differed according to the wheat variety. The crude protein contents of samples with PS and SM increased, except in the Goso cultivar. In this study, Goso cultivar did not differ in terms of protein contents after addition of N-fertilizer. The crude protein contents of Jokyung, Hojung, and Younbaek cultivars with PS were 9.79, 9.59, and 11.31%, respectively; these values were higher than those prepared with NF or SM. However, the crude protein content of the Goso variety did

not differ according to the fertilization time or method ($p > 0.01$). Ash contents of Baekjoong and Keumkang cultivars with PS and SM were increased compared with those in the samples with NF. However, the ash contents of Younbaek cultivar with PS (0.56%) and SM (0.69%) were decreased compared with those of the samples with NF (0.92%). The amylose contents of the samples ranged from 25.98 to 29.37%. The damaged starch content of AH cultivar was 6.63%; this value was the highest of all the samples measured. Damaged starch contents of Younbaek cultivar with PS (protein, 11.31%) and SM (protein, 11.05%) were 5.77 and 5.57%, respectively; these values were higher than those of the samples with NF by 4.49% (protein, 9.97%). The samples with higher damaged starch tend to show increased WHCs. In Baekjoong cultivar, glutamic acid contents with NF, SM, and PS were 238.79, 3,618.6, and 3,557.8 mg%, respectively. The cysteine contents of Baekjoong with SM and PS were 93.1 and 104.5 mg%, respectively, and no cysteine was detected for Baekjoong with NF (data not shown). The WHCs of Hojung and Younbaek with NF were 91.41 and 90.32%, respectively, and the values tended to decrease in the samples with PS and SM. In contrast, the WHCs of Baekjoong with PS and SM were 83.70 and 90.63%, respectively; these values were higher than that of Baekjoong cultivar with NF (78.08%).

Kang *et al.* (23) reported that the protein contents of soft white

Table 1. Chemical compositions and water holding capacity of various Korean wheat varieties cultivated with different fertilizing treatments (unit: %)

Samples	Treatment	Water contents	Ash contents	Crude protein contents	Amylose contents	Damaged starch	Water holding capacity
Control	CWRS ¹⁾	14.43 ^{a2)}	0.62 ^a	13.73 ^a	26.77 ^b	4.74 ^b	84.79 ^b
	AH	12.96 ^b	0.53 ^b	11.08 ^b	27.21 ^b	6.63 ^a	208.80 ^a
	WH	14.57 ^a	0.42 ^c	8.22 ^c	29.81 ^a	2.66 ^c	74.03 ^b
Jokyung	NF	14.56 ^a	0.84 ^a	8.48 ^c	27.01 ^a	5.31 ^b	95.70 ^a
	PS	14.14 ^a	0.66 ^b	9.79 ^a	27.76 ^a	3.77 ^c	81.23 ^b
	SM	14.17 ^a	0.84 ^a	8.87 ^b	26.97 ^a	5.87 ^a	89.47 ^{ab}
Hojung	NF	14.23 ^b	0.52 ^b	8.22 ^c	25.98 ^a	2.95 ^b	91.41 ^a
	PS	14.35 ^a	0.63 ^a	9.59 ^a	24.78 ^b	3.71 ^a	87.85 ^a
	SM	14.72 ^a	0.38 ^c	8.66 ^b	26.73 ^a	3.52 ^a	77.56 ^a
Goso	NF	13.33 ^a	0.37 ^b	9.01 ^a	29.37 ^a	2.47 ^c	76.14 ^b
	PS	13.39 ^a	0.41 ^a	9.01 ^a	28.24 ^b	3.22 ^a	91.38 ^a
	SM	13.43 ^a	0.36 ^b	9.01 ^a	28.58 ^b	2.63 ^b	78.74 ^{ab}
Baekjoong	NF	14.26 ^a	0.54 ^c	7.52 ^b	27.83 ^a	4.64 ^b	78.08 ^b
	PS	14.30 ^a	0.61 ^b	8.86 ^a	27.14 ^a	5.23 ^a	83.70 ^b
	SM	14.00 ^a	0.72 ^a	9.18 ^a	26.83 ^a	4.96 ^a	90.63 ^a
Younbaek	NF	14.73 ^a	0.92 ^a	9.97 ^b	26.22 ^b	4.49 ^a	90.32 ^a
	PS	14.78 ^a	0.56 ^c	11.31 ^a	26.56 ^{ab}	5.77 ^a	87.64 ^a
	SM	14.02 ^b	0.69 ^b	11.05 ^a	26.94 ^a	5.57 ^a	87.84 ^a
Keumkang	NF	13.59 ^b	0.31 ^c	7.17 ^b	27.69 ^a	4.07 ^b	79.21 ^a
	PS	14.27 ^a	0.61 ^b	8.84 ^a	27.28 ^a	3.36 ^c	86.09 ^a
	SM	14.09 ^a	0.72 ^a	8.98 ^a	26.77 ^a	4.73 ^a	70.69 ^a
SEM ³⁾		0.163	0.009	0.104	0.202	0.322	4.221

¹⁾CWRS, Canadian western red spring; AH, Australia hard; WH, white hard cultivars.

²⁾a-c Different letters within the same column differ significantly ($p < 0.01$).

³⁾Standard errors of the means ($n=63$).

wheat flour (9.42%) and commercial flour (9.80%) used for baking cookies were similar to those of Korean wheat cultivars, such as Baekjoong, Jinpoom, Milsung, Olgeuru, Saeol, and Uri, and that the protein contents differed according to the wheat variety and environmental conditions during cultivation. The grain quality as measured by the protein content and quality may be substantially improved by crop management practices, particularly the NF level (24). Bouacha *et al.* (25) demonstrated that NFs enhanced protein content and reduced 1,000 kernel weight. Baik *et al.* (26) reported that the protein contents of 12 types of wheat flour were correlated with different absorption values and mixing time of the dough.

Gluten properties of Korean winter wheat flour Gluten properties were also different depending on wheat variety and cultivation conditions (Table 2). The GI of the samples with PS and SM tended to decrease except for that of Younbaek cultivar; this observation may be associated with the high dry gluten contents of Younbaek cultivar. However, the GIs of Younbaek, Jokyoung, and Baekjoong did not differ ($p>0.05$). The wet gluten and DG of CWRS were 41.00 and 14.55 g/100 g, respectively. The DGs of Jokyoung, Hojung, Goso, and Keumkang with PS were 9.60, 10.65, 9.25, and 12.35 g/100 g, respectively. Wet gluten contents of Jokyoung, Hojung, Goso, and Keumkang with PS were highest compared with those of the samples cultivated under NF or SM conditions. The WBGs of Jokyoung, Hojung, Goso,

Baekjoong, and Keumkang with PS were 18.50, 20.35, 19.65, 18.75, and 21.15 g/100 g, respectively. The wet gluten contents, DGs, and WBGs of Jokyoung, Hojung, and Keumkang with PS, which had higher protein contents, were higher than those of the other samples.

The GI is an indicator of the quantity of polydispersed polymers present in the developed gluten and is correlated with extractable monomeric and polymeric protein (2,11). Singh *et al.* (27) reported that GI is positively related to polymeric protein and negatively related to monomeric protein. Gluten strength is controlled by genotypic effect and varies with environmental factors (25). Rozbicki *et al.* (24) reported that several analyzed traits, *e.g.*, grain protein content, were highly positively correlated with wet gluten and highly correlated with rheological properties, *i.e.*, positively with dough development and dough stability and negatively with dough softening. In this study, dry gluten ($p<0.001$) and water binding in wet gluten content ($p<0.0001$) of wheat flour was correlated with protein contents.

SEM and pasting properties of different types of Korean winter wheat flour The microstructure of dough samples is shown in Fig. 1. Samples of Canadian western red spring (Fig. 1A), white wheat (Fig. 1B), Hojung with NF (Fig. 1C), Hojung with PS (Fig. 1D), Backjung with NF (Fig. 1E), and Backjung with PS (Fig. 1F) were used. The microstructures of Hojung and Backjoong flours with PS has higher

Table 2. Gluten properties of various Korean wheat varieties cultivated with different fertilizing treatments

Samples	Treatments	Gluten index	Wet gluten content (g/100 g)	Dry gluten content (g/100 g)	Water binding in wet gluten (g/100 g)
Control	CWRS	76.47 ^{a1)}	41.00 ^a	14.55 ^a	26.45 ^a
	AH	77.46 ^a	29.10 ^b	9.75 ^b	19.35 ^b
	WH	49.68 ^b	22.15 ^c	7.45 ^c	14.70 ^c
Jokyoung	NF	98.15 ^a	21.55 ^b	7.65 ^c	13.90 ^b
	PS	93.86 ^a	28.10 ^a	9.60 ^a	18.50 ^a
	SM	95.73 ^a	23.10 ^b	7.95 ^b	15.15 ^b
Hojung	NF	92.39 ^a	23.35 ^b	8.20 ^b	15.15 ^b
	PS	82.09 ^b	31.00 ^a	10.65 ^a	20.35 ^a
	SM	76.15 ^b	24.30 ^b	8.25 ^b	16.05 ^b
Goso	NF	89.19 ^a	20.70 ^b	7.30 ^b	13.40 ^b
	PS	53.46 ^b	28.90 ^a	9.25 ^a	19.65 ^a
	SM	79.40 ^a	21.65 ^b	7.60 ^b	14.05 ^b
Baekjoong	NF	87.74 ^a	24.35 ^b	8.40 ^b	15.95 ^a
	PS	82.63 ^a	28.15 ^a	9.40 ^a	18.75 ^a
	SM	87.87 ^a	28.05 ^a	9.65 ^a	18.40 ^a
Younbaek	NF	89.43 ^a	27.15 ^a	9.05 ^a	18.10 ^a
	PS	92.38 ^a	22.95 ^c	7.75 ^b	15.20 ^b
	SM	94.23 ^a	25.95 ^b	8.90 ^a	17.05 ^a
Keumkang	NF	93.28 ^b	26.05 ^b	9.35 ^b	16.70 ^b
	PS	93.14 ^b	33.50 ^a	12.35 ^a	21.15 ^a
	SM	96.76 ^a	26.20 ^b	9.50 ^b	16.70 ^b
SEM ²⁾		3.264	0.440	0.126	0.427

^{1)a-c}Different letters within the same column differ significantly ($p<0.01$).

²⁾Standard errors of the means ($n=63$).

Fig. 1. Scanning electron micrograph of Korean winter wheat flour. (A) Canadian western red spring (CWRS), (B) white wheat (WW), (C) Hojung with NF, (D) Hojung with PS, (E) Backjung with NF, (F) Backjung with PS. Magnified at 5,000 $\times$.

uniform and round compared with that of NF treatment. The samples of Hojung and Backjoong with PS showed higher water binding values in wet gluten compared with NF or SD treatment. Tomic *et al.* (28) reported that the water was probably mostly bound within swollen starch granules appearing as tightly embedded molecules in a continuous protein matrix.

The peak viscosities of Hojung cultivar with NF, PS, and SM were 247.68, 250.88, and 202.21 RVU, respectively. The peak and final viscosities of Jokyung, Baekjoong, and Keumkang with PS and SM did not differ from those of the samples prepared with NF ($p>0.01$; Table 3). The peak and final viscosities of Hojung and Younbaek with SM were lower than those of the samples with NF and PS ($p<0.05$). The final viscosities of Jokyung, Goso, Baekjoong, and Keumkang cultivar with NF, PS, and SM were not different ($p>0.05$). The setbacks of Hojung cultivar with NF, PS and SM were -8.38 , -20.31 , and -12.02 , respectively, with those of the samples with PS being significantly lower than those of the samples with NF and SM. Singh *et al.* (27) reported that flour samples having higher protein contents show high peak viscosities and that the setback viscosity is negatively correlated with extractable polymeric protein (Ex-PP) ($r=-0.573$,

$p\leq 0.05$) and positively correlated with extractable monomeric protein (Ex-MP; $r=-0.565$, $p\leq 0.005$). Singh and Singh (29) reported that breakdown of durum wheat varieties showed lower scores, indicating their greater resistance towards shear thinning and may be attributed to their higher protein content. The peak and breakdown viscosity have been shown to be positively correlated with polymeric protein (27). In contrast to these studies, our study indicated that protein content was not well correlated with PV or FV. The decrease in breakdown due to proteins was attributed to the stabilization of continuous matrix or strengthening of the links (30). The increase in amylose in starch as a result of damaged starch disrupts the connection with starch granules and protein matrix in the qualities of whole wheat noodles (31). Sun *et al.* (32) reported that the protein contents of wheat germ flour (WGF) could affect pasting viscosity and properties.

Change in the quality of white salted noodles prepared using various types of Korean winter wheat flour

The thickness of the noodle sheet using CWRS (protein contents 13.73%) was the highest of all the samples at 1.80 mm (Table 4). The thickness tended to be

Table 3. Pasting properties of various Korean wheat varieties cultivated with different fertilizing treatments

Sample	Treatment	Viscosity (RVU)					Peak time (min)	Pasting tem. (°C)
		Peak visc.	Trough	Break down	Final visc.	Setback		
Control	CWRS	160.76 ^{b1)}	109.77 ^b	50.99 ^b	191.27 ^b	30.51 ^a	6.20 ^{ab}	64.55 ^{ab}
	AH	204.20 ^a	132.45 ^a	71.76 ^a	209.22 ^a	5.02 ^b	6.34 ^a	62.85 ^b
	WH	147.08 ^c	99.03 ^c	48.04 ^b	182.19 ^c	35.12 ^a	5.94 ^b	66.90 ^a
Jokyung	NF	152.72	108.53	44.19	192.26	39.55	6.10	64.13
	PS	161.96	117.02	44.94	207.77	45.81	6.10	64.15
	SM	167.97	123.03	44.94	209.09	41.13	6.24	64.50
Hojung	NF	247.68 ^a	168.14 ^a	79.55	239.31 ^a	-8.38 ^a	6.70 ^a	90.98 ^a
	PS	250.88 ^a	149.15 ^a	101.73	230.56 ^a	-20.31 ^b	6.43 ^{ab}	89.00 ^a
	SM	202.21 ^b	104.22 ^b	98.00	190.19 ^b	-12.02 ^a	6.07 ^b	65.48 ^b
Goso	NF	193.63 ^{ab}	138.91 ^a	54.72	232.93	39.30 ^b	6.30	90.50 ^a
	PS	201.59 ^a	145.00 ^a	56.59	242.46	40.87 ^b	6.34	90.15 ^a
	SM	173.94 ^b	118.85 ^b	55.09	220.74	46.80 ^a	6.10	66.25 ^b
Baekjoong	NF	149.03	99.78 ^b	49.25	180.82	31.80 ^b	6.04 ^b	88.60 ^a
	PS	166.65	125.81 ^a	40.83	196.66	30.02 ^b	6.50 ^a	91.30 ^a
	SM	148.07	98.25 ^b	49.83	187.16	39.09 ^a	5.97 ^b	64.65 ^b
Younbaek	NF	169.42 ^a	121.50	47.92 ^b	206.65 ^a	37.23	6.27	90.13 ^a
	PS	169.09 ^a	114.54	54.55 ^a	211.41 ^a	42.32	6.10	89.38 ^a
	SM	149.89 ^b	101.44	48.46 ^b	190.98 ^b	41.08	6.07	64.93 ^b
Keumkang	NF	171.37	124.11 ^a	47.26	222.61	51.24	6.27 ^{ab}	88.68 ^a
	PS	159.47	103.06 ^b	56.42	207.31	47.84	5.74 ^b	64.23 ^b
	SM	172.53	134.19 ^a	38.35	223.02	50.49	6.47 ^a	90.90 ^a
SEM ²⁾		5.501	5.043	4.240	4.862	2.192	0.110	0.775

¹⁾a-c Different letters within the same column differ significantly ($p < 0.01$).

²⁾Standard errors of the means ($n=63$).

higher in wheat flour with PS. Additionally the thickness of Jokyung with PS and Keumkang with SM were 1.63 and 1.65 mm, respectively, which were higher than those of the samples with NF. The thicknesses of the noodle sheet of Jokyung, Hojung, Goso, and Younbaek cultivars with PS were improved compared with those of the other samples. In this study, the thicknesses of noodle sheets using the samples with higher protein contents tended to increase, and thicknesses of the noodle sheets were correlated with protein contents ($p < 0.01$). The lightness values of Baekjoong cultivar with NF, PS, and SM were 83.33, 81.52, and 84.81, respectively; these values were higher than those of the other samples. The texture profiles of cooked white salted noodles prepared using different types of wheat flour were then measured. The hardness values of cooked noodles prepared using Jokyung cultivar with PS tended to be lower than those of the other samples (1,258 g), and the hardness value of Goso cultivar with PS was higher (1,735 g). The hardness value of cooked noodles prepared using Hojung, Baekjoong, and Younbaek cultivars did not differ ($p > 0.05$). For Jokyung cultivar, the hardness values were 1,752 and 1,258 g for the samples prepared with wheat cultivated with NF or PS; the hardness value for the samples with PS was significantly lower than that of the samples with NF. For Keumkang cultivar, the hardness values with PS and SM were 1,561 and 1,712 g, respectively. There were no differences in the springiness of wheat flour, except for that of Younbaek cultivar. Additionally, the

cohesiveness and chewiness of cooked noodles made with Goso, Baekjoong, and Younbaek cultivars did not differ ($p > 0.05$). The relationship between the protein content and textural properties of the samples showed different results depending on the variety. However, the dry gluten and water binding in wet gluten of the samples were correlated with hardness of cooked noodles ($p < 0.01$). Kang *et al.* (22) reported that use of wheat flour containing low protein contents for preparation of noodles would require addition of more water in order to improve protein matrix formation and textural properties. Moreover, the protein content and protein quality parameters are highly correlated with the TPA of noodles (6). Increased protein contents may result in lower swelling of starch granules in flour, preventing excessive leaching of protein during cooking (33). Additionally, Kaur *et al.* (2) reported that the firmness of noodles was positively correlated with WG, DG, and protein content. Thus, these results indicated that wheat flour properties differed according to the wheat variety and cultivation conditions such as added NF. Korean winter wheat flour cultivated with SM or PS exhibited beneficial properties, such as increased protein content, DG, WBG, thickness, and hardness or decreased setback. Consequently, in order to improve the quality of white salted noodles, wheat flour prepared using Hojung, Goso, and Baekjoong cultivars under PS cultivation condition or wheat flour with higher protein content, DG contents, and WBG should be used.

Table 4. Quality properties of white salted noodles of various Korean wheat varieties cultivated with different fertilizing treatments

Samples	Treatments	Thickness (mm)	L*	a*	b*	Hardness (Kg)	Springiness (%)	Cohesiveness (%)	Chewiness (Kg)
Control	CWRS	1.80 ^{a1)}	79.78 ^c	0.19 ^a	15.37 ^a	1.712 ^c	71 ^b	60 ^a	0.416 ^c
	AH	1.66 ^b	83.29 ^b	-0.17 ^b	15.07 ^a	1.064 ^b	82 ^a	53 ^a	0.566 ^b
	WH	1.38 ^c	84.47 ^a	-0.57 ^c	13.39 ^b	1.580 ^a	87 ^a	56 ^a	0.878 ^a
Jokyoung	NF	1.57 ^a	83.35 ^a	0.55 ^a	14.28 ^b	1.752 ^a	86 ^a	56 ^a	0.982 ^a
	PS	1.63 ^a	82.41 ^b	0.01 ^b	14.48 ^b	1.258 ^b	83 ^a	54 ^a	0.676 ^b
	SM	1.56 ^a	82.31 ^b	0.50 ^a	15.06 ^a	1.671 ^a	86 ^a	57 ^a	0.960 ^a
Hojung	NF	1.51 ^b	83.33 ^b	0.01 ^b	14.58 ^b	1.265 ^a	85 ^a	51 ^a	0.642 ^a
	PS	1.62 ^a	81.52 ^c	0.52 ^a	15.63 ^a	1.267 ^a	85 ^a	51 ^a	0.651 ^a
	SM	1.47 ^b	84.81 ^a	-0.42 ^c	12.92 ^c	1.167 ^a	84 ^a	48 ^b	0.554 ^b
Goso	NF	1.43 ^b	85.47 ^a	-0.31 ^b	12.93 ^a	1.598 ^b	84 ^a	48 ^a	0.758 ^a
	PS	1.52 ^a	84.03 ^b	0.12 ^a	13.24 ^a	1.735 ^a	75 ^a	45 ^a	0.783 ^a
	SM	1.41 ^b	85.16 ^a	-0.24 ^b	12.35 ^b	1.665 ^{ab}	86 ^a	50 ^a	0.829 ^a
Baekjoong	NF	1.46 ^b	91.86 ^a	-0.50 ^a	0.82 ^b	1.360 ^a	86 ^a	53 ^a	0.714 ^a
	PS	1.55 ^a	91.72 ^b	-0.49 ^a	0.84 ^a	1.421 ^a	83 ^a	53 ^a	0.748 ^a
	SM	1.40 ^b	91.84 ^a	-0.51 ^b	0.81 ^b	1.390 ^a	85 ^a	51 ^a	0.703 ^a
Younbaek	NF	1.45 ^a	81.79 ^a	0.08 ^a	15.04 ^a	1.304 ^a	82 ^b	52 ^a	0.674 ^a
	PS	1.48 ^a	82.49 ^a	0.07 ^a	13.79 ^b	1.350 ^a	86 ^a	52 ^a	0.696 ^a
	SM	1.42 ^a	81.81 ^a	-0.20 ^b	14.35 ^{ab}	1.483 ^a	86 ^a	53 ^a	0.775 ^a
Keumkang	NF	1.62 ^a	81.78 ^a	0.09 ^b	14.94 ^a	1.561 ^b	88 ^a	53 ^a	0.820 ^b
	PS	1.63 ^a	80.76 ^b	0.51 ^a	15.34 ^a	1.561 ^b	87 ^a	55 ^a	0.852 ^b
	SM	1.65 ^b	81.30 ^a	0.45 ^a	15.38 ^a	1.712 ^a	86 ^a	56 ^a	0.959 ^a
SEM ²⁾		0.0001	0.0001	0.0001	0.0001	0.0001	0.1740	0.0001	0.0001

¹⁾a-c Different letters within the same column differ significantly ($p < 0.01$).

²⁾Standard errors of the means ($n=63$).

Table 5. Correlation coefficients between assays

	PC ¹⁾	AM	DS	WHC	DG	WBG	PV	FV	TK	HD
PC	1	-0.317	0.395* ²⁾	0.309	0.551**	0.606***	-0.058	-0.135	0.481*	-0.4366*
AM		1	-0.458*	-0.117	-0.371	-0.379	-0.324	-0.033	-0.392	0.175
DS			1	0.502**	0.128	0.172	-0.286	-0.357	0.378	-0.203
WHC				1	0.099	0.181	0.224	0.023	0.385	-0.377
DG					1	0.945***	-0.052	-0.102	0.732***	-0.417*
WBG						1	-0.020	-0.118	0.687***	-0.459*
PV							1	0.716***	0.116	-0.106
FV								1	0.074	0.335
TK									1	-0.330
HD										1

¹⁾PC, protein contents; AM, amylose contents; DS, damaged starch contents; WHC, water holding capacity; DG, dry gluten contents; WBG, water binding in wet gluten contents; PV, peak viscosity; FV, final viscosity; TK, thickness of noodle sheets; HD, hardness of noodles.

²⁾* $p < 0.01$, ** $p < 0.001$, *** $p < 0.0001$

Correlation coefficients between assays Pearson correlation analysis revealed that the WBG of the samples was strongly correlated with PC ($r=0.606$, $p < 0.0001$) and DG ($r=0.945$, $p < 0.0001$; Table 5). Protein contents of Jokyoung, Hojung, and Younbaek cultivars with PS were higher than those of NF or SD. Moreover, thickness was positively correlated with DG ($r=0.732$, $p < 0.0001$) and WBG ($r=0.687$, $p < 0.0001$). FV was correlated with PV ($r=0.716$, $p < 0.0001$). The highest correlation coefficient was found between the WHC and DS ($r=0.502$, $p < 0.001$). Additionally, DG of the samples was positively

correlated with PC ($r=0.551$, $p < 0.001$) and hardness was correlated well with PC, DG, and WBG ($p < 0.01$). However, no correlation was found between AM, DS, WHC, PV, and FV of the samples ($p > 0.01$). Similar to our study, the amount of fertilization was positively correlated with thousand kernel weight and protein content ($r=0.159$, $p < 0.05$ and $r=0.212$, $p < 0.01$, respectively) (15). Katyal *et al.* (34) reported that protein content was positively correlated with GI, WG, and DG ($r=0.403$, 0.442 , and 0.753 , respectively, $p \leq 0.005$). Our study indicated that protein content was not correlated with PV and

FV. In contrast to our study, Singh *et al.* (27) reported that flour having higher protein content also has a higher peak viscosity ($r=0.326$, $p\leq 0.05$) and that peak viscosity is positively correlated with setback viscosity ($r=0.332$, $p\leq 0.05$). Moreover, the hardness of cooked noodles is correlated with protein contents (22).

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