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Full Length Article

Effect of Flour Color and Starch Pasting Properties on Color of Noodle Dough Sheet and Texture of Cooked Noodles in Korean Wheat Cultivars

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Abstract

The purpose of this study was to verify the effect of flour color and starch pasting properties on color of noodle dough sheet and textural characteristics of cooked noodles made with 15 representative Korean wheat cultivated for three years. Year, cultivar and the interaction between the year and cultivar influenced flour properties, starch pasting properties, noodle dough sheet color, and cooked noodles texture. Amylose content in waxy wheat was significantly lower rather than wild type wheat, while that of partial waxy wheat was even lower than them. Peak viscosity and breakdown in waxy and partial waxy wheat were much higher than wild type wheat. Color of noodle dough sheet showed negative correlation with particle size and damaged starch and positive correlation with flour lightness. Polyphenol oxidase did not have significant influence on color of noodle dough sheet. Principal component analysis (PCA) showed positive relationships between flour color and color of noodle dough sheet. Waxy wheat exhibited much softer texture of cooked noodles and lower springiness and cohesiveness compared to wild type wheats, while partial waxy wheat showed similar springiness and cohesiveness compared to them. Hardness, cohesiveness, and springiness of cooked noodles showed positive correlation with amylose contents of flour, and only cohesiveness showed negative correlation with ash content, particle size, and damaged starch content. Texture of cooked noodles showed negative correlation with peak viscosity and breakdown. PCA showed that hardness of cooked noodles is positively correlated with positive correlation between hardness of cooked noodles and negative correlation between springiness and cohesiveness of cooked noodles, particle size and damaged starch. © 2019 Friends Science Publishers

Keywords: Wheat; Starch; Color; Noodle; Quality

Introduction

White salted noodles are made from seasoned dough with salt and extensively consumed in not only Korea but also Japan (Fu, 2008). Wheat flour containing protein content of approximately 10 percent is suitable for dough of the noodles (Fu, 2008). Protein properties including the amount and quality are crucially interrelated to processing parameters of noodle and qualities of cooked noodles with water absorption, noodle dough sheet brightness, hardness of cooked noodles, time for cooking (Baik *et al*., 1994; Yun *et al*., 1996; Hatcher *et al*., 1999; Park *et al*., 2003).

Starch in wheat flour greatly influences the properties of texture for white salted noodles (Oda *et al*., 1980). Wheat flour with decreased starch amylose content is suitable to make white salted noodles since high pasting and swelling properties of starch are essential to achieve satisfactory eating quality of the noodles (Zhao *et al*., 1998). Granule-bound starch synthase I (GBSS I, EC 2.4.1.21) as waxy (Wx) protein controls starch amylose content in wheat (Yamamori *et al*., 1994). There are three GBSS I isoforms in common wheat and each isoform is encoded by *Wx-A1*, -*B1*, and -*D1* alleles (Naranjo *et al*., 1987). Wheat harboring *Wx-B1b* allele is acceptable to produce superior textural quality of white salted noodles (Miura and Tanii, 1994). The flour of wheat with double null alleles at the *Wx-1* loci has amylose content of starch accounted for 15.4 to 18.9% and is possible to make softer and more elastic white salted noodles for eating quality rather than white salted noodles made from flour containing high amylose content (Baik *et al*., 2003). A flour of partial waxy or waxy wheat exhibits short time for cooking rather than the other flour of wild-type wheat harboring *Wx-B1b* allele (Park and Baik, 2004).

For white salted noodles, a desirable color of noodle dough sheet is from white to creamy white level (Fu, 2008). Color of noodle is primarily influenced by the color of the

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flour owing to its easy recipe (Fu, 2008). Flour color has intricate features, including pigments in pericarp, starchy endosperm, and aleurone of wheat grain, protein, particle size, ash content, flour extraction ratio, and microbial contamination (Miskelly, 1984; Mares and Campbell, 2001). Also, delayed discoloration quality is significant since raw noodles frequently are kept for a few days before cooking. Storage of raw noodles can lead to discoloration because of the effect of polyphenol oxidase (PPO) included in seed coat (Hatcher and Kruger, 1993). PPO activity is primarily conditioned by genes on wheat homoeologous chromosome group 2 (Sun *et al*., 2005; Si *et al*., 2012). Wheat lines expressed low activity of PPO should be selected in wheat breeding programs because fast discoloration of noodles is undesirable for noodle makers or consumers.

Quality of white salted noodles genetically interrelates to quantitative factors affected by environment. The factors show high interaction between genotype and environment (Mares and Campbell, 2001; McLean *et al*., 2005). Wheat qualitative improvement is great interest to make noodles with bright color and provide cooked noodles with a soft-elastic textural characteristic for wheat breeders in Korea. GBSS and PPO are biochemical markers related to noodle color and textural qualities of cooked noodles. Both of GBSS and PPO have been utilized to select elite breeding lines in Korean wheat breeding programs. This study had the following objectives: 1) to determine the effect of flour characteristics on the color of noodle dough sheet; 2) to examine the effect of starch pasting properties on texture of cooked noodles; and 3) to identify the effect of genetic variance in *Wx-1* and *PPO* loci for the quality of white salted noodles.

Materials and Methods

Plant Materials and Cultivation

Fifteen representative Korean wheat cultivars were originated from the 1990s. Jokyoung, Joongmo2008, Baekjoong, Baekchal, and Keumkang are hard white winter wheat, while Shinmichal 1, Suan, Hojoong, Joongmo2012, Jojoong, and Jopoom are hard red winter wheat. Younbaek is soft white winter wheat, while Uri, Goso, and Joa are soft red winter wheat. Those Korean wheat cultivars were sown in accordance with randomized complete block design with three replications in Upland Crop Experimental Farm at the National Institute of Crop Science, Rural Development Administration (Republic of Korea) and in late October during three growing seasons (2013/2014, 2014/2015 and 2015/2016) on sandy clay loam soil (50% clay). Each plot was made up of three 4-m rows at interval of 25 cm. Harvest season was in middle of June for the three growing seasons using a combine harvester. Prior to sowing, fertilizer (N:P:K in a ratio of 5:7:5 kg/10a) was applied. Weed and disease and insect pest control were rigorously carried out, and additional irrigation was not applied. Average of temperature and precipitation for the three seasons were 10.4°C and 586.0 mm, respectively. During the three seasons, temperature and precipitation of 2015/2016 season (10.8°C and 702.1 mm, respectively) were higher than those of 2013/2014 (10.4°C and 481.8 mm, respectively) or 2014/2015 (10.0°C and 574.1 mm, respectively). Grains harvested at each plot were dried by a forced air dryer. All grains were melded and then milled to gain flour. Three commercial flours for noodles were purchased in the market and were referred to as Com1, Com2, and Com3.

Analytical Methods

Whole wheat grains were milled with a Bühler experimental mill in accordance with the American Association of Cereal Chemists International (AACCI) Approved Method 26-31.01 (2010). Moisture and ash contents were measured in accordance with AACCI Approved methods 44-15.02 and 08-01.01, sequentially. Damaged starch and amylose contents were measured with reference to the experimental methods by Gibson *et al*. (1992, 1997), using enzymatic assay kits (Megazyme, Bray, Ireland). Distribution of flour particle size was measured using a Laser Diffraction Particle Size Analyzer (LS13320, Beckman Coulter, Brea, CA, USA) in accordance with AACCI Approved method 55-40.01. Color of flour was demonstrated with a colorimeter (CM-2002, Minolta Camera, Osaka, Japan). The measured values of color were recorded in accordance with CIE values: *L*, lightness; *a*, redness-greenness; and *b*, yellowness-blueness.

Starch Pasting Properties

Starch in gluten was briefly extracted from 100 g flour (dry basis) with reference to the experimental method by Czuchajowska and Pomeranz (1993). The isolated starch was refined and dried using air at 24°C for 3 days and milled with a cyclone sample mill (Udy, Fort Collins, CO, USA). Starch pasting properties were identified with a Micro Visco-Amylo-Graph device (Brabender, Duisburg, Germany). Starch (10 g, db) was suspended in 100 mL solution including 0.1% $AgNO_3$ and undergone sequentially heat treatment from 30 to 95°C at an increase in 7.5°C per min, holding at 95°C for 5 min, chilling to 50°C at a decrease in 5.0°C per min, and holding at 50°C during 2 min with continuous stirring at 110 rpm. All measured viscosity values were indicated in Brabender units. Viscosities (peak and final) and holding strength of starch were documented. Breakdown was calculated by subtracting the holding strength from the peak and final viscosities, and temperature at peak viscosity was identified.

Noodle Making

Preparation of white salted noodles was with noodle dough including 34% water absorption in accordance with published method (Park and Baik, 2002). Briefly, wheat flour (100 g, 14.0% moisture basis) was stirred to 34% absorption with 6% sodium chloride solution during 4 min at head speed of 86 rpm by a pin mixer (National Mfg., USA). The dough was passed through rollers with 3 mm gap at 8 rpm of a noodle making machine (Ohtake Noodle Machine Mfg., Japan). The flatted dough was double over and then passed through sheeting rollers. These processing were conducted two times. After resting of the dough sheet during 1 h, it was passed through sheeting rollers thrice at gradually reducing space of 2.40, 1.85 and 1.30 mm. To determine color, a piece of noodle sheet was put in plastic bags. Dough sheet color was measured with Minolta CM-2002 camera (Minolta Camera Co., Japan) with 11 mm measurement aperture. The rest of the dough sheet was cut into 30 cm long strips with cross section of 0.3 × 0.2 cm using no. 12 cutting rolls.

Noodles (20 g) were boiled with 500 mL distilled water during 18 min by chilly water rinsing. Texture profile analysis (TPA) was conducted to evaluate two replicates of cooked noodles with 5 min after the rinsing by a texture analyzer (TA-XT2, Stable Micro Systems, England) within 5 min after cooking. Five strands of boiled noodles as one set were parallelized on a metallic flat plate. It was compressed two times in a cross, up to 70% of its initial thickness. From force-time TPA curves, hardness, cohesiveness, and springiness were evaluated in accordance with published methods (Park and Baik, 2002).

PCR Conditions

Young leaf tissue about two weeks after germination was collected from each plant of Korean wheat cultivar. The collected leaf tissue was directly undergone liquid nitrogen freezing and then kept at -80°C before DNA extraction. DNA was extracted from the 100g leaf tissues with Genomic DNA prep kit (Solgent Co., Korea). DNA concentration was measured with Biodrop as a spectrophotometer (Biodrop Ltd., UK). Allelic variations at *PPO-A1*, *PPO-B1*, and *PPO-D1* loci were determined using procedures described by Sun *et al*. (2005), He *et al*. (2007), and Si *et al*. (2012), respectively. Allelic variance at *Wx-1* loci was determined with reference to the procedure by Nakamura *et al*. (2002).

Statistical Analyses

Analysis of variance (ANOVA), Fisher's least significant difference (LSD) test, and pairwise *t*-test were analyzed with SAS software (SAS Institute, NC, USA). General linear model procedure was used for ANOVA. Year × cultivar component was utilized as error term. Each source of variation in the model was taken fixed-effects account consideration. Correlation of end-use quality with measured traits was analyzed with Pearson's correlation coefficients. Mean values of each allele were compared with one-way ANOVA. Pairwise *t*-test was conducted to compare means at 0.05 level of *P*-value with significant *F*-values. Principal component analysis (PCA) was conducted to load measure traits under visualization using Proc Princomp procedure in SAS. All data were calculated in three time for the accurate determination. All values were averaged. Statistical significance was set at $P < 0.05$ unless otherwise specified.

Results

Analysis of Variance

Influences of year, cultivar, and the interaction between year and cultivar were significant on flour characteristics, starch pasting properties, color of noodle dough sheet, and textural properties of cooked noodles among 15 Korean wheats (Table 1). Year comprised the largest proportion of variance in ash content (80.7%), flour lightness (90.5%), and redness-greenness color (99.3%) of Korean wheat flour. Cultivar comprised the largest proportion (96.8%) of variance in amylose content of flour. Variations in particle size, damaged starch, and yellowness-blueness color of flour were significantly influenced by cultivar rather than by year. Starch pasting properties of Korean wheat cultivars were mainly affected by cultivar. Characteristics of noodle dough sheet except redness-greenness color of flour and textural characteristics of cooked noodles were primarily affected by year. The variance in the redness-greenness color of noodle dough sheet similarly was affected by both year and cultivar (47.8 and 43.2%, respectively).

Allelic Variation of GBSS and PPO

Allelic compositions of granule-bound starch synthase I (GBSS I) and polyphenol oxidase (PPO) in 15 Korean wheat are summarized in Table 2. Results of PCR analysis are shown in Fig. 1 and 2. Baekchal and Shinmichal 1as waxy wheat were harboring *Wx-A1b*, *-B1b*, and *-D1b*. Hojoong, partial waxy wheat exhibited single null allele at *Wx-B1*. Joongmo2012 exhibited double null alleles at *Wx-A1* and *Wx-D1*. Other Korean wheat cultivars were wild-type, non-waxy wheats. Amylose contents of flour were different between wild-type wheat cultivars and other wheat cultivars (waxy and partial waxy wheats) (Table 4). Amylose contents of flour in wild-type Korean wheat cultivars ranged from 27.0 to 29.2%, with an average amylose content of 28.1%. Baekchal and Shinmichal 1 showed significantly lower amylose contents (6.5 and 6.3%, respectively) than wild-type wheat cultivars. Amylose content of Hojoong, single null partial waxy wheat was 23.2%, while that in Joongmo 2012, double null partial waxy wheat was 20.6%. The average amylose content in wild-type wheat cultivars was similar to that of commercial flour 1. However, amylose contents of all wild-type wheat cultivars were higher than those of Com 2 and Com 3,

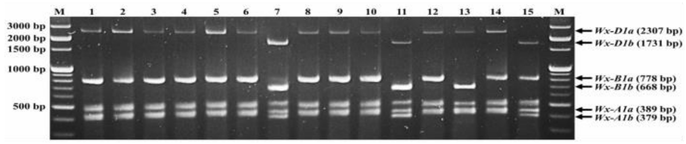

Fig. 1: Agarose gel electrophoresis of PCR amplified *Wx-A1*, *Wx-B1*, and *Wx-D1* alleles among 15 Korean wheat cultivars. M, molecular size marker; 1, Uri; 2, Keumkang; 3, Jokyoung; 4, Suan; 5, Younbaek; 6, Baekjoong; 7, Shinmichal 1; 8, Jopoom; 9, Goso; 10, Joa; 11, Baekchal; 12, Jojoong; 13, Hojoong; 14, Joongmo2008; 15, Joongmo2012

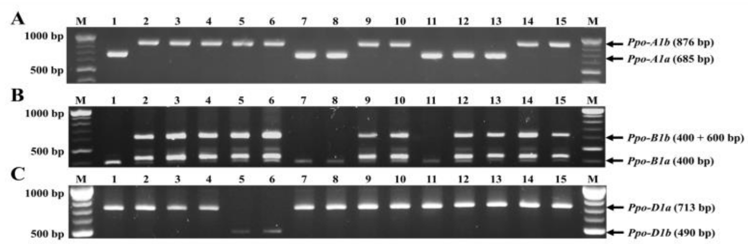

Fig. 2: Polymorphisms of polyphenol oxidase by PCR analysis of DNA markers. *PPO-A1* (A), *PPO-B1* (B), and *PPO-D1* (C) in 15 Korean wheat cultivars. Each number indicates Korean wheat cultivar, in the following order: 1, Baekchal; 2, Baekjoong; 3, Goso; 4, Hojoong; 5, Joa; 6, Jojoong; 7, Jokyoung; 8, Joongmo2008; 9, Joongmo2012; 10, Jopoom; 11, Keumkang; 12, Shinmichal 1; 13, Suan; 14, Uri; 15, Younbaek

Table 1: Analysis of variance for flour characteristics, starch pasting properties, noodle dough sheet color, and texture of cooked noodles for 15 Korean wheat cultivars grown for three years

Parameter	F-value of the source of variation		
	Year	Cultivar	Year × Cultivar
df	2	14	28
Flour characteristics			
Ash	706.00***[a]	139.28***	29.16***
Particle size of flour	881.05***	2043.88***	111.13***
Damaged Starch	785.08***	863.51***	58.07***
Lightness	1352.69***	123.59***	17.91***
Redness-greenness	17991.4***	55.74***	71.33***
Yellowness-blueness	339.43***	775.88***	217.90***
Amylose	35.36***	1171.55***	3.78***
Starch pasting properties			
Peak Viscosity	94.47***	7290.47***	103.73***
Holding Strength	535.13***	2294.07***	269.74***
Final Viscosity	210.23***	607.45***	105.59***
Breakdown	60.51***	4909.98***	24.31***
Setback	5.52**	400.95***	47.70***
Noodle dough sheet color			
Color-L	75.02***	8.71***	6.68***
Color-a	384.26***	347.21***	72.33***
Color-b	158.26***	24.23***	21.62***
Cooked noodles texture			
Hardness	2269.78***	824.09***	51.52***
Springiness	505.49***	32.12***	7.54***
Cohesiveness	187.02***	52.57***	9.85***

[a]** and *** are significant at $P < 0.01$ and $P < 0.001$, respectively

which showed similar amylose contents.

Of the 15 Korean wheat cultivars tested, 6 (40.0%) carried *Ppo-A1a* while 9 (60.0%) carried *Ppo-A1b*. Four (26.7%) Korean wheat cultivars carried *Ppo-B1a* while 11 (73.3%) carried *Ppo-B1b*. Thirteen (86.7%) Korean wheat cultivars carried *Ppo-D1a* while 2 (13.3%) carried *Ppo-D1b*.

Table 2: Allelic variations of granule bound starch synthase I (GBSS I) and polyphenol oxidase (PPO) in Korean wheat cultivars

Cultivar	GBSS I			PPO		
	Wx-A1	*Wx-B1*	*Wx-D1*	*Ppo-A1*	*Ppo-B1*	*Ppo-D1*
Baekchal	*b*	*b*	*b*	*a*	*a*	*a*
Baekjoong	*a*	*a*	*a*	*b*	*b*	*a*
Goso	*a*	*a*	*a*	*b*	*b*	*a*
Hojoong	*a*	*b*	*a*	*b*	*b*	*a*
Joa	*a*	*a*	*a*	*b*	*b*	*b*
Jojoong	*a*	*a*	*a*	*b*	*b*	*b*
Jokyoung	*a*	*a*	*a*	*a*	*a*	*a*
Joongmo2008	*a*	*a*	*a*	*a*	*a*	*a*
Joongmo2012	*b*	*a*	*b*	*b*	*b*	*a*
Jopoom	*a*	*a*	*a*	*b*	*b*	*a*
Keumkang	*a*	*a*	*a*	*a*	*a*	*a*
Shinmichal 1	*b*	*b*	*b*	*a*	*b*	*a*
Suan	*a*	*a*	*a*	*a*	*b*	*a*
Uri	*a*	*a*	*a*	*b*	*b*	*a*
Younbaek	*a*	*a*	*a*	*b*	*b*	*a*

Flour Characteristics

Flour characteristics of the 15 Korean wheats and 3 commercial flours (Com) are summarized (Table 3). Ash content ranged from 0.37 to 0.46%. The average ash content in Coms was 0.43%. Particle size ranged from 45.38 to 83.78 μm. The average particle size in Com was 55.28 μm.

Table 3: Flour characteristics of 15 Korean wheat cultivars and 3 commercial flour samples

Flour	Ash (%)	Particle Size (μm)	Damaged starch (%)	Color[a]		
				L	a	b
Korean wheat						
Baekchal	0.44c[b]	77.16c	5.64d	92.65ef	-0.48b	9.38c
Baekjoong	0.44c	80.05b	6.37c	92.16h	-0.52c	9.67b
Goso	0.37i	53.28i	2.63ij	93.92a	-0.52c	7.28l
Hojoong	0.37i	56.69g	3.01h	93.39c	-0.62f	8.44h
Joa	0.37i	48.05j	2.57j	93.65b	-0.58de	8.11j
Jojoong	0.40f	77.21c	7.50a	92.17h	-0.54cd	9.46c
Jokyoung	0.44cd	76.79c	5.74d	92.76de	-0.59e	9.08d
Joongmo2008	0.43d	73.55d	4.35f	92.19h	-0.42a	8.94e
Joongmo2012	0.39g	54.50h	2.77i	93.57b	-0.73g	8.20i
Jopoom	0.41e	67.50f	3.27g	92.43g	-0.55cd	8.88e
Keumkang	0.42e	76.50c	4.44f	92.53fg	-0.46ab	8.63g
Shinmichal 1	0.46a	83.78a	6.84b	92.63ef	-0.80h	10.28a
Suan	0.43d	68.69e	5.25e	92.84d	-0.59ef	8.78f
Uri	0.38h	45.38k	2.54j	93.71b	-0.56de	7.45k
Younbaek	0.45b	80.23b	6.31c	92.60f	-0.70g	10.23a
Commercial flour[c]						
Com1	0.41a	56.73a	6.65a	92.80a	-0.53b	8.82b
Com2	0.43a	56.66a	6.02b	92.14c	-0.50ab	9.11a
Com3	0.44a	52.45b	6.49a	92.46b	-0.47a	8.65c

[a]L, lightness; a, redness-greenness; b, yellowness-blueness
[b]Values followed by the same letters within each cultivar or commercial flour are not significantly different at $P < 0.05$
[c]Com1, 2 and 3, commercial flour for noodles manufactured with different company

Table 4: Amylose content and starch pasting properties of 15 Korean wheat cultivars and 3 commercial flour samples

Flour	Amylose (%)	Starch pasting properties				
		Peak Viscosity (BU)	Holding Strength (BU)	Final Viscosity (BU)	Breakdown (BU)	Setback (BU)
Korean wheat						
Baekchal	6.5i[a]	678.83a	430.00a	455.33a	362.00b	138.83hi
Baekjoong	28.4bc	92.00hi	68.50fg	195.17ij	22.17i	125.50j
Goso	29.2a	86.67ij	57.50hi	202.67hi	29.83fg	142.00gh
Hojoong	23.2g	163.00d	123.33d	331.33c	61.67c	218.50b
Joa	28.0cde	97.00h	67.17fg	221.83g	26.50ghi	143.83gh
Jojoong	27.7de	115.67f	84.50e	240.67f	24.50hi	145.00g
Jokyoung	29.0ab	81.17jk	54.33i	202.33hi	26.33ghi	135.33i
Joongmo2008	27.5ef	124.67e	63.00gh	260.33e	43.67d	178.50c
Joongmo2012	20.6h	205.00c	157.83c	394.17b	62.17c	247.50a
Jopoom	28.0cde	106.33g	73.33f	264.00e	28.67fgh	171.17d
Keumkang	27.5ef	94.67h	56.67i	237.50f	32.00ef	156.50f
Shinmichal 1	6.3i	628.17b	274.22b	305.28d	432.72a	94.00k
Suan	27.0f	77.17k	44.83j	193.00j	26.00ghi	142.33gh
Uri	29.1ab	112.50fg	81.00e	259.17e	36.83e	164.67e
Younbaek	28.1cd	94.33h	63.00gh	204.67h	28.00fgh	142.00gh
Commercial flour[b]						
Com1	28.4a	144.00b	108.50b	259.33b	35.50a	150.83b
Com2	26.6a	114.33c	96.67c	215.00c	17.67b	118.33c
Com3	26.9a	194.67a	171.67a	364.67a	23.00b	193.00a

[a]Values followed by the same letters within each cultivar or commercial flour are not significantly different at $P < 0.05$
[b]Com1, 2 and 3, commercial flour for noodles manufactured with different company

Damaged starch content ranged from 2.77 to 7.50%. The average of damaged starch in Com was 6.39%. Uri flour showed the lowest average values of particle size and damaged starch content among all Korean wheat flour. The particle size of Shinmichal 1 flour was the highest among all flour samples tested. Jojoong flour showed the highest damaged starch content while Joa flour showed the lowest damaged starch. Average particle size of Goso, Hojoong, or Joongmo2012 flour was similar to that of Com. Baekjoong, Shinmichal 1, and Younbaek flour samples showed damaged starch contents similar to Com.

Flour lightness (FL) scores ranged from 92.16 to 93.92. The average of FL score of Com was 92.47. Redness-greenness scores of flour (Fa) ranged from -0.80 to -0.42. The average of Fa in Com was -0.50. Yellowness-blueness of flour (Fb) ranged from 7.45 to 10.28. The average of Fb in Com was 8.86. Goso showed brighter FL than all other Korean wheats or Com. Baekjoong, Jojoong, and Joongmo2008 showed darker FL than all other Korean wheats. Their FL values were similar to FL of Com2. Most Korean wheats had FL values similar to Coml. Regarding redness-greenness scores of flour (Fa), Joongmo2008 was weaker than other wheats or Com, while Shinmichal 1 was stronger than the rest. Among Korean wheat cultivars, Baekjoong, Goso, and Jojoong flour samples showed color values similar to those of Com1, while Baekchal and Com3 had similar color values. Shinmichal 1 had the highest level of Fb whereas Uri had the lowest level of Fb. Suan, Jokyoung, and Keumkang showed similar levels of color compared to Com.

Starch Pasting Properties

Starch pasting properties of the 15 Korean wheat and 3 Com are summarized in Table 4. Among starch pasting properties, peak viscosity of wild-type wheat cultivars ranged from 77.17 to 124.67 BU with an average of 98.38 BU. Baekchal and Shinmichal 1, waxy wheats showed the highest peak viscosity (678.83 and 628.17 BU, respectively). Hojoong and Joongmo2012, partial waxy wheats showed higher peak viscosity (163.00 and 205.00 BU, respectively) than wild-type Korean wheat cultivars or Com. Peak viscosity values of Jojoong, Joongmo2008, Jopoom, and Uri were similar to those of Com2, while other wheat cultivars showed lower peak viscosity values than Com. Holding strength of wild-type wheat cultivars showed lower levels than Com. The average of final viscosity of those wheat cultivars (225.58 BU) was between that of Com1 (259.33 BU) and that of Com2 (215.00 BU). Baekchal, Shinmichal 1, Hojoong, and Joongmo2012 showed higher holding strength and final viscosity than the average of wild-type wheat cultivars. Breakdown ranged from 22.17 to 43.67 BU, with an average breakdown of 29.50 BU. The average breakdown of Korea wheat cultivars was lower than that of Com 1 (35.50 BU), but higher than that of Com2 or Com3 (17.67 BU and 23.00 BU, respectively). Baekchal and Shinmichal 1 showed the highest breakdown (326.00 and 432.72 BU, respectively), while Hojoong and Joongmo2012 showed higher breakdown (61.67 and 62.17 BU, respectively) than all other wheat cultivars. The average of setback (149.71 BU) was similar to that of Com1 (150.83 BU). Setback of Hojoong and Joongmo2012 showed higher levels than the average setback of wild-type wheat cultivars, whereas Baekchal and Shinmichal 1 shower lower setback levels than the average of wild-type wheat cultivars.

Color of Noodle Dough Sheet

Color of noodle dough sheet color in 15 Korean wheats and 3 Com are summarized in Table 5. Noodle dough sheet lightness (NL) ranged from 76.34 to 83.61 for Korean wheat cultivars. It ranged from 84.74 to 86.67 for Com. Uri and Joa showed similar NL compared to Com2. NL of Jojoong was the darkest among NL of Korean wheat cultivars. It was also darker than Com. Redness-greenness of noodle dough sheet (Na) of Korean wheat ranged from -1.72 to -0.72. It ranged from -1.07 to -0.98 for Com. Redness-greenness of noodle dough sheet (Na) of Jojoong was the highest, while that of Joongmo2012 was the lowest. Jopoom, Baekchal, and Uri showed similar Na values to Com1, Com2, and Com3, respectively. The yellowness-blueness of noodle dough sheet (Nb) of Korean wheat cultivars ranged from 16.06 to 18.08. It ranged from 16.25 to 17.01 for Com. Hojoong and Uri showed the highest and lowest values of Nb, respectively, among Korean wheat. Joongmo2008 showed similar value of Nb compared to Com1. However, Goso and Uri showed lower values that Nb of Com3.

Results of correlation coefficients between color of noodle dough sheet and flour characteristics of Korean wheat are summarized (Table 7). NL was negative correlation with average particle size of flour (r = -0.59, P < 0.05) and damaged starch (r = -0.62, P < 0.05). However, it was positive correlation with FL (r = 0.74, P < 0.01). These correlations showed similar tendency among Korean wheats except Baekchal and Shinmichal 1 waxy wheats. Na was negatively correlated with FL (r = -0.60, P < 0.05), while Nb was negatively correlated with amylose content of

Table 5: Variation of noodle dough sheet color among 15 Korean wheat cultivars and 3 commercial flour samples

Flour	Noodle dough sheet[a]		
	Color		
	L	a	b
Korean wheat			
Baekchal	80.95de[b]	-1.06d	16.84de
Baekjoong	81.49bcde	-1.50g	17.76ab
Goso	82.86abc	-1.63h	16.08g
Hojoong	81.23cde	-1.40ef	18.08a
Joa	83.16ab	-1.65h	16.58ef
Jojoong	76.34g	-0.72a	16.90cde
Jokyoung	81.60bcd	-1.36e	17.93ab
Joongmo2008	78.83f	-0.71a	16.92cde
Joongmo2012	81.73bcd	-1.72i	17.99ab
Jopoom	80.76de	-0.95c	16.69ef
Keumkang	80.61de	-0.89b	17.27c
Shinmichal 1	81.30cde	-1.08d	17.67b
Suan	79.87ef	-0.73a	16.38fg
Uri	83.61a	-1.04d	16.06g
Younbaek	80.55de	-1.42f	17.16cd
Commercial flour[c]			
Com1	85.05b	-0.98a	17.01b
Com2	84.74c	-1.07a	18.04a
Com3	86.67a	-1.01a	16.25c

[a]L, lightness; a, redness-greenness; b, yellowness-blueness
[b]Values followed by the same letters within each cultivar or commercial flour are not significantly different at P < 0.05
[c]Com1, 2 and 3, commercial flour for noodles manufactured with different company

Table 6: Difference in noodle dough sheet color according to polyphenol oxidase (PPO) using pair-wise t-test among15 Korean wheat cultivars

Parameter	*Ppo-A1*		*Ppo-B1*		*Ppo-D1*	
	a	*b*	*a*	*b*	*a*	*b*
Noodle dough sheet						
Lightness	80.53b[a]	81.31a	80.50b	81.17a	81.18a	79.75a
Redness-greenness	-0.97a	-1.34b	-1.01a	-1.26b	-1.19a	-1.19a
Yellowness-blueness	17.17a	17.03a	17.24a	17.03b	17.14a	16.74b

[a]Means followed by different letters are different from same properties at $P < 0.05$

Table 7: Correlation coefficients among flour characteristics, starch pasting properties, and noodle dough sheet color of Korean wheat cultivars

Parameter	Noodle Dough Sheet Color[a]					
	I			II		
	L	a	b	L	a	b
Flour characteristics						
Ash	-0.33	0.34	0.30	-0.40	0.32	0.27
Particle size	-0.59*[b]	0.41	0.38	-0.67*	0.40	0.36
Damaged starch	-0.62*	0.37	0.29	-0.70**	0.35	0.25
Lightness	0.74**	-0.60*	-0.25	0.76**	-0.60*	-0.25
Redness-greenness	-0.21	0.39	-0.41	-0.23	0.55	-0.34
Yellowness-blueness	-0.51	0.25	0.45	-0.61*	0.22	0.43
Amylose	-0.02	-0.05	-0.26	0.04	0.27	-0.57*
Starch pasting properties						
Peak viscosity	0.02	0.09	0.17	-0.02	-0.25	0.48
Holding strength	0.04	0.03	0.16	0.07	-0.38	0.51
Final viscosity	0.03	-0.04	0.27	0.04	-0.19	0.43
Breakdown	0.05	0.11	0.16	0.12	-0.23	0.45
Setback	0.03	-0.21	0.25	0.06	-0.17	0.41

[a]I, wild-type Korean wheats with waxy and partial waxy wheats; II, only wild-type wheats; L, lightness; a, redness-greenness; b, yellowness-blueness
[b]*and ** are significant at $P < 0.05$ and $P < 0.01$, respectively

Table 8: Textural characteristics of cooked noodles of 15 Korean wheat cultivars and 3 commercial flour samples

Flour	Cooked Noodles texture[a]		
	HD (N)	SP (Ratio)	CO (Ratio)
Korean wheat			
Baekchal	1.44i[b]	0.88g	0.64f
Baekjoong	4.28f	0.94abc	0.64ef
Goso	4.20fg	0.93bcde	0.65de
Hojoong	3.86h	0.93cdef	0.66b
Joa	4.51c	0.95a	0.67a
Jojoong	4.87a	0.94ab	0.66b
Jokyoung	4.29ef	0.94bcde	0.64ef
Joongmo2008	4.88a	0.94bcde	0.65def
Joongmo2012	3.93h	0.94bcde	0.67ab
Jopoom	4.71b	0.93ef	0.66bc
Keumkang	4.38de	0.94bcd	0.64f
Shinmichal 1	1.08j	0.88g	0.59g
Suan	4.72b	0.94bc	0.66b
Uri	4.11g	0.93def	0.65cd
Younbaek	4.38d	0.93f	0.64ef
Commercial flour[c]			
Com1	4.51a	0.94a	0.65ab
Com2	4.32b	0.94a	0.65a
Com3	3.91c	0.93a	0.64b

[a]HD, hardness; SP, springiness; CO, cohesiveness
[b]Values followed by the same letters within each cultivar or commercial flour are not significantly different at $P < 0.05$
[c]Com1, 2 and 3, commercial flour for noodles manufactured with different company

Koran wheat cultivars excluding waxy wheat cultivars (r = -0.57, $P < 0.05$).

Principal component analysis (PCA) was conducted for multivariate correlations among flour color, starch pasting properties, and color of noodle dough sheet color among Korean wheat cultivars. Results are shown in Fig. 3A and 3B. Both principal components (PCs) explained 90.4% (PC1, 53.6%; PC2, 36.8%) of color of noodle dough sheet among Korean wheat cultivars excluding waxy wheat cultivars (Fig. 3A). Both PC1 and PC2 showed strong relationship between FL and NL. PC1 explained that amylose content was negatively related to starch pasting properties. PC2 explained that ash content and damaged starch content of flour were negatively related to NL. This means that these factors play significant roles in the superior quality of noodle dough sheet. PC1 showed big difference in flour characteristics between Joongmo2012 and other Korean wheat cultivars which were closely clustered. Both FL and NL of Joa, Goso, Uri were better than those of other Korean wheat cultivars and Com. Baekchal and Shinmichal 1 as a waxy wheat showed difference in characteristics of flour and starch pasting properties in comparison with other Korean wheat cultivars (Fig. 3B).

Texture of Cooked Noodles

Textual of cooked noodles made from 15 Korean wheats and 3 Com are summarized in Table 8. Hardness of cooked noodles (NH) ranged from 4.11 to 4.88 N. That of Com ranged from 3.91 to 4.51 N. NH value of Joa was similar to that of Com1 while NH of Jojoong was similar to that of Com2. Baekchal and Shinmichal 1 exhibited lower NH than other Korean wheat cultivars or Com. NH values of Hojoong and Joongmo2012 were similar to those of Com3. Springiness of cooked noodles (NS) of Korean wheat cultivars ranged from 0.93 to 0.95. That of Com ranged from 0.93 to 0.94. NS values of Com were similar to those of Korean wheat cultivars except Baekchal and Shinmichal 1 with an average NS of 0.88, which was lower than that of other Korean wheat cultivars (average NS: 0.94) or Com (average NS: 0.94). Cohesiveness of cooked noodles (NC) ranged from 0.64 to 0.67. It ranged from 0.64 to 0.65 for Com. Average NC value was 0.65 for Korean wheat. It was the same as that of Com (0.65). Only Shinmichal 1 showed lower NC value (0.59) than Korean wheat cultivars and Com.

Results of correlation coefficient between flour characteristics and starch pasting properties and texture of cooked noodles of Korean wheat are summarized in Table 9. NH and NS were positive correlation with amylose content (r = 0.96, $P < 0.001$ and r = 0.91, $P < 0.001$, respectively). However, NH and NS were negatively correlated with peak viscosity (r = -0.96, $P < 0.001$ and r = -0.95, $P < 0.001$, respectively) and breakdown (r = -0.97, $P < 0.001$ and r = -0.96, $P < 0.001$, respectively). Among Korean wheat cultivars except Baekchal and Shinmichal 1, NH exhibited negative correlation with breakdown (r = -0.57, $P < 0.05$) with a tendency of negative correlation with peak viscosity. NS was not significantly correlated with peak viscosity or breakdown. NC exhibited negative correlation with ash content (r = -0.68, $P < 0.01$), particle size (r = -0.61, $P < 0.05$), and damaged starch (r = -0.55, $P < 0.05$) in flour.

Table 9: Correlation coefficients among flour characteristics, starch pasting properties, and texture of cooked noodles of Korean wheat cultivars

Parameter	Cooked noodle texture[a]					
	I			II		
	HD (N)	SP (Ratio)	CO (Ratio)	HD (N)	SP (Ratio)	CO (Ratio)
Flour characteristics						
Ash	-0.37	-0.43	-0.68**	0.40	0.09	-0.46*
Particle size	-0.27	-0.35	-0.61*	0.47	0.09	-0.60*
Damaged starch	-0.26	-0.32	-0.55*	0.46	0.17	-0.46
Lightness	-0.02	0.12	0.33	-0.65*	-0.15	0.41
Redness-greenness	0.38	0.27	0.32	0.50	0.15	-0.33
Yellowness-blueness	-0.35	-0.41	-0.58*	0.40	0.40	-0.38
Amylose	0.96***[b]	0.91***	0.57*	0.47	-0.04	-0.56*
Starch pasting properties						
Peak viscosity	-0.96***	-0.95***	-0.61*	-0.46	-0.07	0.54
Holding strength	-0.58*	-0.89***	-0.42	-0.91***	-0.11	0.55
Final viscosity	-0.65**	-0.61*	-0.03	-0.46	-0.12	0.56*
Breakdown	-0.97***	-0.96***	-0.72**	-0.57*	-0.20	0.40
Setback	0.32	0.38	0.66**	-0.47	-0.17	0.54

[a]I, wild-type Korean wheats with waxy and partial waxy wheats; II, only wild-type wheats; HD, hardness; SP, springiness; CO, cohesiveness
[b]*, ** and *** are significant at $P < 0.05$, $P < 0.01$ and $P < 0.001$, respectively

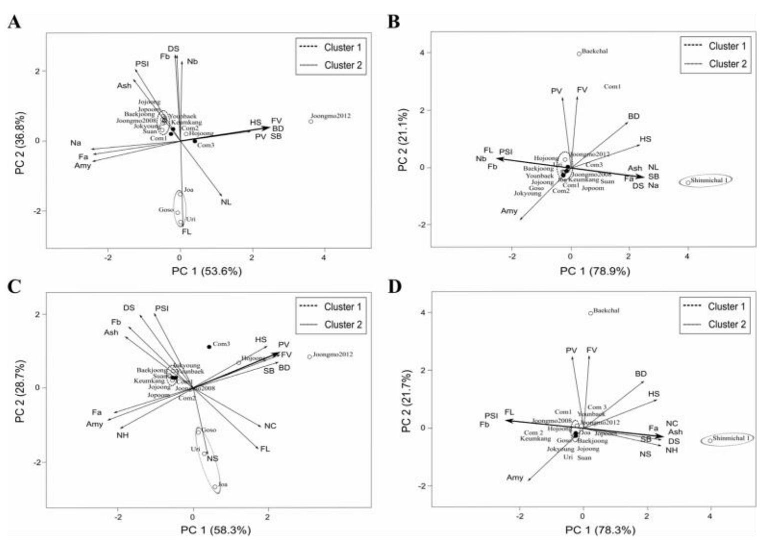

Fig. 3: PCA loading of measured traits and values of component 1 (PC1) and 2 (PC2) corresponding to noodle dough sheet color and texture. PCA for noodle dough sheet color among Korean wheat cultivars excluding Baekchal and Shinmichal 1, waxy wheat cultivars (**A**), Korean wheats including the waxy wheat cultivars (**B**), noodle dough sheet texture among Korean wheat cultivars excluding the waxy wheat cultivars (**C**), and Korean wheat cultivars including the waxy wheat cultivars (**D**). Abbreviations are defined as DS, damaged starch; FL, flour color-L (lightness); Fa, flour color-a (redness-greenness); Fb, flour color-b (yellowness-blueness); TS, total starch; Amy, amylose; PV, peak viscosity in amylogram; HS, holding strength; FV, final viscosity; BD, breakdown; ST, setback; NL, color-L (lightness) of cooked noodles; Na, color-a (redness-greenness) of cooked noodles; Nb, color-b (yellowness-blueness) of cooked noodles; NH, hardness of cooked noodles; NS, springiness of cooked noodles; NC, cohesiveness of cooked noodles

These correlations were similar for Korean wheat cultivars excluding waxy wheat cultivars. NC exhibited positive correlation with amylose content (r = 0.57, P < 0.05). Regarding starch pasting properties, NC exhibited positive correlation with peak viscosity (r = -0.61, P < 0.05) and breakdown (r = -0.57, P < 0.05). These correlations showed an opposite tendency for Korean wheat cultivars excluding waxy wheat cultivars.

PCA was performed for multivariate correlations among flour characteristics, starch pasting properties, and texture of cooked noodles of Korean wheat. PCA revealed the multivariate correlation in Fig. 3C and 3D. Both PCs explained 87.0% (PC1, 58.3%; PC2, 28.7%) of the texture of cooked noodles of Korean wheat cultivars excluding waxy wheat cultivars (Fig. 3C). Both PC1 and PC2 showed strong relationship between NH and amylose content of flour. They also showed negative relationship between amylose content of flour and starch pasting properties. Starch pasting properties of Hojoong and Joongmo2012 were better than those of other Korean wheat cultivars and Com. Joa, Goso, Uri had better NS than other Korean wheat cultivars or Com (Fig. 3C). Baekchal and Shinmichal 1 showed difference in characteristics of texture of noodle dough sheet and starch pasting properties compared with other Korean wheat excluding waxy wheat cultivars (Fig. 3D). PC1 showed that cooked noodle texture was negatively related to particle size. PC2 explained negative relationship between cooked noodle texture and starch pasting properties.

Discussion

Genotype has main influence on the variance of ash content, damaged starch, and color of Canadian spring wheat flour (Finlay *et al*., 2007). However, year mainly influenced the variation of ash content and flour lightness of Korean wheat flour. Souza *et al*. (2004) have reported that pasting properties of wheat flour are only affected by genotype in US spring wheats. In our study, springiness and hardness of cooked noodles are also affected by the environment and genotype while the chewiness of cooked noodles is only affected by genotype in US spring wheats (Souza *et al*., 2004). Graybosch *et al*. (2004) have reported that the environment, genotype, and their interactions can influence the hardness and firmness of yellow alkaline and white salted noodles which are affected by the environment and genotype, respectively. Textural characteristics of Korean cooked noodles were influenced by year.

Typically, low amylose content (0–3%), high amylose content (25–28%), and intermediate amylose content (16–22%) are responsible for waxy type, non-waxy type, and partial waxy type, respectively (Hung *et al*., 2006). Two Korean partial waxy wheats showed even higher amylose contents than the two waxy wheat. However, their amylose contents were slightly lower than wild-type wheat cultivars. According to Sun *et al*. (2005), the frequency of *Ppo-A1b* is higher than that of *Ppo-A1a* in Chinese wheat lines. He *et al*. (2007) have also reported that Chinese wheats are carrying *Ppo-A1b* higher than *Ppo-A1a*. In addition, they have verified that the majority of Chinese wheats do carry *Ppo-D1a* associated with low activity of PPO (He *et al*., 2007). Rasheed *et al*. (2016) have reported that *Ppo-A1a* is the main allele with high PPO activity. They have found that the frequency of *Ppo-D1a* is much higher than *Ppo-D1b* in Pakistani wheat landraces while frequencies of *Ppo-D1a* and *Ppo-D1b* are similar to Pakistani wheat cultivar. Korean wheat cultivars mainly carried *Ppo-A1a*, *Ppo-B1b*, and *Ppo-D1a*.

Korean wheat cultivars showed that damaged starch content is significantly correlated with particle size of flour ($r = 0.90$, $P < 0.001$). Particle size of flour has been reported to be correlated with the level of damaged starch in hard wheat (Hatcher *et al*., 2009). However, there is no correlation between particle size and damaged starch in soft wheats (Stasio *et al*., 2007). Hard wheat generally exhibits higher damaged starch content and particle size than soft wheat during milling process (Barak *et al*., 2014). Furthermore, the proportion of damaged starch in waxy wheat has been reported to be higher than non-waxy wheat (Abdel-Aal *et al*., 2002; Kang *et al*., 2012). Waxy wheat has shown significantly larger particle size than non-waxy wheat (Lee *et al*., 2005). However, particle sizes are not significantly different between waxy wheats and partial waxy wheats with single or double null alleles (Takata *et al*., 2007).

Ash content of flour showed negative correlation with FL ($r = -0.77$, $P < 0.001$), but positive correlation with Fb ($r = 0.88$, $P < 0.001$). However, it had no significant relationship with Fa. Our results were in partially agreement with a previous study showing that ash content of flour has negative correlation with FL. However, it has no correlation with Fa or Fb (Zhang *et al*., 2005). Particle size and damaged starch contents were negatively correlated with FL ($r = -0.89$, $P < 0.001$ and $r = -0.77$, $P < 0.001$, respectively). They exhibited positive correlation with Fb ($r = 0.88$, $P < 0.001$ and $r = 0.90$, $P < 0.001$, respectively). However, they were not correlated with Fa. Our results are similar to a previous study showing that damaged starch is negatively correlated with flour lightness (Miskelly, 1984).

Waxy and partial waxy wheat cultivars with low amylose contents showed remarkably higher peak viscosity and breakdown than wild-type wheat cultivars. Zhang *et al*. (2013) have also reported that peak viscosity and breakdown are significant different between waxy wheats and wild-type wheats. Sahlstrom *et al*. (2006) have reported that peak viscosity and breakdown of waxy wheat are much higher than wild-type wheats and partial waxy wheats. Amylose content showed negative correlation with starch pasting properties such as peak viscosity ($r = -0.99$, $P < 0.001$), holding strength ($r = -0.95$, $P < 0.001$), final viscosity ($r = -0.77$, $P < 0.001$), and breakdown ($r = -0.97$, $P < 0.001$) except setback. Park and Baik (2004) have reported that peak viscosity and breakdown are increased as amylose content is decreased. Consequently, amylose content negatively affected to pasting properties of wheat flour.

Polyphenol oxidase (PPO) is an enzyme that catalyzes the oxidation of polyphenol compounds in wheat related to discoloration of end-use products, particularly Asian noodles (Edwards *et al*., 1989; McCaig *et al*., 1999; Morris *et al*., 2000). Korean wheat cultivars used in this study possessed mainly *Ppo-A1a*, *Ppo-B1b*, *Ppo-D1a* alleles for PPO (Table 2). Values of NL, Na, and Nb according to alleles of *PPO-A1*, *-B1*, and *-D1* were very similar to each other (Table 6). Fuerst *et al*. (2006) have reported that difference of less than 2% of PPO can measure an equivalent amount of homogenized bran. Resultantly, the influence of PPO activity was not significant factor to determine the color of noodle dough sheet, made from flour of Korean wheat cultivars. Flour color is a main factor that determines noodle color (Hou, 2001). When damaged starch is increased, water absorption of flour is increased, thus negatively affect noodle dough sheet lightness (Baik *et al*., 1995). NL of Korean wheat cultivars showed negative correlation with particle size and damaged starch of flour but strongly positive correlation with FL.

PCA results demonstrated that Korean wheat cultivars had highly similar noodle dough sheet color. These results of PCA and variations of PPO could explain the limited genetic background among Korean wheat cultivars. It has been reported that protein contents can influence noodle dough sheet color (Wang *et al*., 2004). Thus, studies on correlations among protein content, noodle color, and genetic diversity are needed for Korean wheat breading program.

Guo *et al*. (2003) have reported that amylose content shows positive correlation with the hardness of cooked noodles. They have also found that amylose content shows negative correlation with springiness and cohesiveness. The correlation between amylose content and hardness found in this study was in accordance with results of Guo *et al*. (2003). Other correlations showed opposite tendency for Korean wheat. It has been reported that peak viscosity of starch is positively interrelated to cohesiveness of Chinese white salted noodles (Hou *et al*., 2013). Kiribuchi-Otobe *et al*. (1997) have also reported that waxy wheats possess distinctive characteristics such as lower pasting temperature, higher peak viscosity, and higher breakdown. These are different from non-waxy wheats. Different characteristics of starch between waxy and non-waxy wheats have also been reported by Abdel-Aal *et al*. (2002). Hence, starch characteristics of Baekchal and Shinmichal 1 waxy wheats might have influenced the textural characteristics of cooked noodles.

Conclusion

Korean wheat cultivars have narrow genetic background because the aim in Korean wheat breeding program has been an increase in grain yield and early maturation for a long time. Hence, Korean wheats showed narrow variations in flour characteristics and cooked noodles texture. Furthermore, discoloration of Korean cooked noodle was influenced by flour color rather than allelic variation of PPO. On the other hand, Korean waxy and partial waxy wheat cultivars showed more suitable characteristics for noodle quality than wild-type Korean wheat cultivars due to their different physicochemical properties. Therefore, flour color and starch pasting properties are important for the quality of Korean cooked noodles. In the future, improving physicochemical properties of grain through broadening genetic diversity to enhance cooked noodle quality is needed for Korean wheat breeding program.

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