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Flour Characteristics and End-Use Quality of Korean Wheats with 1Dx2.2+1Dy12 Subunits in High Molecular Weight Glutenin

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Abstract

White salted noodles and pan bread were prepared from Korean wheats with 1Dx2.2+1Dy12 subunits in high molecular weight glutenin subunits (HMW-GS) to evaluate the suitability for end-use products through the comparison with US wheats with various classes and commercial wheat flours. Korean wheat flours with 1Dx2.2+1Dy12 subunits showed higher SDS sedimentation volume than US wheat flours with similar protein content. Compared to wheat flours with similar protein content and SDS sedimentation volume, water absorption percent of Korean wheat flours using a mixograph was higher than that of US wheat flours, but similar to commercial wheat flours. Mixograph mixing time was similar to hard wheat flours and commercial noodle flours. Optimum water absorption percent of noodle dough from Korean wheat flours was higher than that of US wheat flours. Noodle sheets from Korean wheat flours with 1Dx2.2+1Dy12 subunits showed lower L values, higher a values and similar b values compared to commercial noodle flours. Hardness of cooked noodles from Korean wheat flours 1Dx2.2+1Dy12 subunits correlated positively with protein content, NIRS hardness, mixograph water absorption and gluten yield of flours. Korean wheat flours with 1Dx2.2+1Dy12 subunits showed lower loaf volume and harder crumb firmness than hard wheat flours and commercial bread wheat flours in spite of similar protein quantity and quality to hard wheat flours.

Key words: wheat flour, high molecular weigh glutenin subunits (HMW-GS), white salted noodles, bread

INTRODUCTION

Glutenins are major seed storage proteins in wheat gluten. Glutenins contain high molecular weight polymers formed by inter-chain disulfide bonds (1). The proportion of glutenins with high molecular weight polymers (above about 1×10^6 unit) was positively correlated with gluten elasticity. High molecular weight glutenin subunits (HMW-GS) may play a key role in determining flour quality because these polymers are enriched in the high molecular weight glutenin subunits (2).

HMW-GS are controlled by genes at three loci, called *Glu-A1, Glu-B1* and *Glu-D1,* located on the long arms of chromosomes 1A, 1B and 1D, respectively (3). Each locus consists of two genes encoding a high molecular weight x-type subunit and a low molecular weight y-type subunit. These subunits are tightly linked, and inherited as pairs (3). The *Glu-A1* loci only codes for one subunit (1Ax) or no subunit at all, the *Glu-B1* loci codes for one or two subunits (1Bx or 1Bx+1By), and the *Glu-D1* loci codes for two subunits (1Dx+1Dy) (1). Therefore, each wheat line had three to five HMW-GS; a strong relationship between bread-baking quality and HMW-GS allelic variation has been reported (1,4). Shewry et al. (4) proposed that wheat varieties with good bread baking quality might require allelic subunits 1Ax1 or 1Ax2* on the *Glu-A1* loci, 1Bx17+1By18 or 1Bx7+1By8 on the *Glu-B1* loci and 1Dx5+1Dy10 on the *Glu-D1* loci. However, no Korean wheat cultivars or lines have all these allelic combinations (5).

The allelic subunits of 1Dx5+1Dy10 were associated with better quality in bread baking than 1Dx2+1Dy12 subunits, which are related to poor rheological properties (4). Korean wheats had a higher frequency of 1Dx2.2 +1Dy12 subunits than any other subunits coded by *Glu-D1* loci, although rheological properties of these

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subunits are not well elucidated (5). The high frequency of 1Dx2.2+1Dy12 subunits was also found in Japanese wheat cultivars (6). There was a high co-occurrence (36.5%) of 1Dx2.2+1Dy12 subunits and friabilin (a starch granule with which surface proteins strongly associate affecting kernel hardness) in Korean wheats (7). The relationships between 1Dx2.2+1Dy12 subunits and kernel hardness were also found in Japanese wheats (8). There was no difference in bread loaf volume between Korean wheats with 1Dx2.2+1Dy12 subunits and 1Dx5+1Dy10 or 1Dx2+1Dy12 subunits, although flours with 1Dx2.2+1Dy12 subunits showed lower SDS-sedimentation volume and shorter mixing time by a mixograph than those of cultivars with 1Dx5+1Dy10 or 1Dx2+1Dy12 subunits (9,10). Cooked noodles prepared from wheat flours with 1Dx2.2+1Dy12 subunits showed softer texture than other subunits compositions coded by *Glu-D1* loci (11).

Recently, intensive breeding efforts have attempted to develop Korean wheat varieties suitable for various end-use products. However, little information is available for evaluation of flours and end-use quality of wheats with 1Dx2.2+1Dy12 subunits, although the significant relationship between the presence and absence of specific HMW-GS and bread-baking quality of wheat varieties has been now well established. Therefore, the objective of this study was to evaluate wheat flour and end-use quality, including pan bread and white salted noodles, of Korean wheats with 1Dx2.2+1Dy12 subunits, and Korean wheats with 1Dx2.2+1Dy12 subunits were compared to various US wheats and commercial flours for suitability for baking bread and making white salted noodsles.

MATERIALS AND METHODS

Materials

Eight Korean wheat cultivars and lines, which have 1Dx2.2+1Dy12 subunits in high molecular weight glutenin subunits (HMW-GS) compositions (Table 1) and 14 American wheat flours, including three club, three soft white spring (SWS), two soft white winter (SWW), four hard white spring (HWS) and two hard red spring

Table 1. High molecular weight glutenin subunit (HMW-GS) compositions of Korean wheats, US wheats with various classes and commercial wheat flours

Class[1)]	Cultivar & line	HMW-GS compositions[2)]			
		Glu-A1	*Glu-B1*	*Glu-D1*	Score[3)]
Korea	Eunpamil	Null[4)]	1Bx7+1By9	1Dx2.2+1Dy12	?
	Geurumil	Null	1Bx7+1By8	1Dx2.2+1Dy12	?
	Jinpoommil	Null	1Bx7+1By8	1Dx2.2+1Dy12	?
	Joeunmil	Null	1Bx13+1By16	1Dx2.2+1Dy12	?
	Olgeurumil	1Ax2*	1Bx7+1By8	1Dx2.2+1Dy12	?
	Urimil	Null	1Bx7+1By8	1Dx2.2+1Dy12	?
	Suwon278	Null	1Bx13+1By16	1Dx2.2+1Dy12	?
	Suwon280	Null	1Bx7+1By8	1Dx2.2+1Dy12	?
Club	Calowa	Null	1Bx7+1By8	1Dx2+1Dy12	6
	Bruehl	Null	1Bx6+1By8	1Dx2+1Dy12	6
	Hiller	Null	1Bx6	1Dx2+1Dy12	4
SWS	Treasure	1Ax2*	1Bx6+1By8	1Dx2+1Dy12	6
	Vanna	1Ax1	1Bx17+1By18	1Dx2+1Dy12	8
	Alpowa	Null	1Bx7+1By9	1Dx5+1Dy10	7
SWW	Stephens	1Ax2*	1Bx7+1By9	1Dx2+1Dy12	7
	OR939526	1Ax2*	1Bx7+1By9	1Dx2+1Dy12	7
HWS	Winsome	1Ax2*	1Bx17+1By18	1Dx5+1Dy10	10
	Nuwest	1Ax2*	1Bx7+1By9	1Dx5+1Dy10	9
	Klasic	1Ax1	1Bx17+1By18	1Dx5+1Dy10	10
	IDO377S	1Ax2*	1Bx17+1By18	1Dx5+1Dy10	10
HRS	WA7839	1Ax2*	1Bx17+1By18	1Dx5+1Dy10	10
	WPB926	1Ax2*	1Bx17+1By18	1Dx5+1Dy10	10
COM[5)]	Com1	1Ax1	1Bx17+1By18	1Dx2+1Dy12	8
	Com2	1Ax1/1Ax2*	7Bx+8By/1Bx17+1By18	1Dx2+1Dy12/1Dx5+1Dy10	>8
	Com3	1Ax1/1Ax2*	1Bx7+1By8	1Dx5+1Dy10	10

[1)]SWS=Soft white spring, SWW=Soft white winter, HWS=Hard white spring, HRS=Hard red spring, COM=Commercial flours.
[2)]Nomenclature according to Payne and Lawrence (1983).
[3)]Scoring according to Payne et al. (1987).
[4)]Null allele.
[5)]Com1 and Com2=Commercial noodle flours from Japan and Korea, respectively; Com3=Commercial bread baking flours from Western Wheat Quality Lab.

(HRS) wheat, with various HMW-GS compositions (Table 1), which obtained from the Western Wheat Quality Laboratory (Pullman, WA), were used for this study. Wheat was milled using a Bühler experimental mill, and flour of about 60% extraction was prepared by blending millstreams. Two commercial wheat flours suitable for making upon noodles (Com1) and for making Korean dry noodles (Com2) were obtained from Nissin Flour Milling (Tokyo, Japan) and were provided from Dr. Park WJ, U.S. Wheat Associates in Seoul through the Wheat Marketing Center (Portland, OR). A commercial blend of HRS wheat, used as a standard for baking pan bread, was obtained from Western Wheat Quality Laboratory and is herein referred to as Com3.

Analytical methods

Moisture, protein and ash contents of wheat flours were determined according to AACC methods 44-15A, 46-30 and 08-01 (12). The determination of amylose content was performed according to the procedure described by Gibson et al. (13) using an enzymatic assay kit (Megazyme Pty., North Rocks, Australia). The SDS sedimentation test was performed according to the procedure of Baik et al. (14). The SDS sedimentation volume of flour was determined both on a constant flour weight (3 g) basis and on a constant protein (300 mg) basis. NIRS hardness of flours was determined by a Technicon 400 InfraAlyzer (Technicon, Tarrytown, NY). The flour mixing characteristics were determined using a 10 g mixograph (National Mfg. Co., Lincoln, NE), according to AACC approved methods 54-40A (12). Wet gluten of wheat flours was isolated according to AACC-approved methods 38-10 (12). After being lyophilized, the protein quantity of dry gluten was determined and multiplied by the weight of the gluten. The gluten yield was calculated by dividing the protein quantity of the isolated gluten by flour weight. To determine the composition of HMW-GS, protein was extracted from 40 mg of flour with 500 μL of extraction buffer [0.125 M Tris-HCl, pH 6.8, 1% (w/v) SDS, 6.7% (v/v) glycerol, 0.003% (w/v) bromophenol blue, and 5% (v/v) β-mercaptoethanol] by shaking for 2 hr at room temperature. SDS-PAGE of HMW-GS was run according to the procedures described by Laemmli (15). The separating gel (pH 8.3) was prepared from 12% SDS-polyacrylamide with 1.27% bisacrylamide. After running the SDS-PAGE for 12 hr at 20 mA/gel, the gel was stained overnight with a commassie blue R-250 and destained in 10% trichloroacetic acid. The HMW-GS subunits were evaluated with the scoring system proposed by Payne et al. (16).

Preparation of white salted noodles

White salted noodles were prepared using the optimum water absorption percent of noodle dough. Determination of the optimum water absorption percent for making white salted noodles was based on appearance and sheeting and handling properties of the dough during the noodle making process by experienced personnel, through trial and error. Com1 and 2, which required 35% absorption to make uniform, smooth and nonsticky dough, was used as a reference to be compared with other flours during the determination of optimum water absorption percent.

Flour (100 g, 14% mb) was mixed with the predetermined amount of 2.0% sodium chloride solution in a pin mixer (National Mfg. Co., Lincoln, NE) for 4 min, with a head speed of 86 rpm. The concentration of sodium chloride solution for making noodles with different absorption was adjusted to have 2.0% sodium chloride in the noodle dough. Dough was passed through the rollers of a noodle machine (Ohtake Noodle Machine Mfg. Co., Tokyo, Japan) at 8 rpm and a 3 mm gap; dough was folded and put through the sheeting rollers. The folding and sheeting were repeated twice. The dough sheet was allowed to stand for 1 hr and then put through the sheeting rollers three times at progressively decreasing gaps of 2.40, 1.85 and 1.30 mm. Immediately after the last sheeting, thickness of the dough sheet was measured by a micrometer dial thickness gauge (Peacock Dial Thickness Gauge G, Ozaki Mfg. Co., Ozaki, Japan). A piece of noodle sheet was placed in a plastic bag for determination of color. The rest of the dough sheet was cut through no. 12 cutting rolls into strips about 30 cm in length. The color of the dough sheet was measured by a Minolta CM-2002 (Minolta Camera Co., Ltd, Osaka, Japan) with an 11 mm measurement aperture. Color differences of noodle sheets were recorded as CIE-LAB L (lightness), a (redness-greenness) and b (yellowness-blueness) values. The rest of the dough sheet was cut through No. 12 cutting rollers into noodle strands of about 30 cm in length, with a 0.3×0.2 cm cross section.

Textural properties of cooked noodles

Raw noodles (20 g) were cooked at the determined cooking time in 500 mL of boiling distilled water for 18 min and then rinsed with cold water. Two replicates of cooked noodles were evaluated by texture profile analysis (TPA) using a TA-XT2 Texture Analyser (Stable Micro Systems, Haslemeres, England) within 5 min after cooking. A set of five strands of cooked noodles was placed parallel on a flat metal plate and compressed crosswise twice to 70% of their original height using a 3.175 mm metal blade at a speed of 1.0 mm/sec. From force-time curves of the TPA, hardness, springiness, cohesiveness and adhesiveness were determined according to the description of Park and Baik (17).

Pan bread baking

Bread was baked from Korean wheats, HWS, HRS and Com3 according to the straight-dough methods described by Finney (18). The ingredients of baking formula were: 100 g (14% moisture) flour, 6 g sugar, 3 g shortening, 1.5 g salt, 5.0 g fresh yeast, 50 mg ascorbic acid, and 0.25 g barley malt (about 50 DU/g, 20°C). The optimum water absorption and mixing time were determined by the feel and appearance of the dough during the mixing. The dough was fermented in a cabinet at 30°C and 85% relative humidity for 70 minutes with two punches and a proof period of 60 minutes, and then baked at 210°C for 18 minutes. Bread loaf volume was measured by rapeseed displacement in a graduated chamber and weighed immediately after the bread was taken out of the oven. After cooling for two hours at room temperature, a slice 2.0 cm thick was cut from the center portion of the bread. Firmness of the bread crumb was evaluated with a compression test using a TA-XT2 Texture Analyser (Stable Micro Systems, Haslemeres, England). The slice was placed on a flat metal plate and compressed to 25% of its thickness at a speed of 1.0 mm/sec, using a plastic plunger with a flat surface of 2.5 cm diameter. Statistical analysis of data was performed by SAS software (SAS 2000) using Fisher's least significant difference procedure (LSD) and analysis of variance (ANOVA). All data were determined at least in duplicate and all were averaged.

RESULTS AND DISCUSSION

Characteristics of flour

Genetic variations of high molecular weight glutenin subunits (HMW-GS) compositions in Korean and US wheat cultivars by SDS-PAGE are shown in Fig 1. In *Glu-A1* loci, null allele, associated with poor rheological properties, was mostly found in Korean wheat and club wheats. A high frequency of 1Ax2* subunit was found among US soft and hard wheat cultivars (Table 1). In *Glu-B1* loci, Korean wheats had a high frequency of 1Bx7+1By8 subunits, while 1Bx17+1By18 subunits mostly found in hard wheats and club and soft wheat showed a higher frequency of the subunits 1Bx7+1By9. In *Glu-D1* loci, all of the hard wheat cultivars had the subunits 1Dx5+1Dy10, but club and soft wheats had a high frequency of the subunits of 1Dx2+1Dy12, except Alpowa. Com1, 2 and 3 are probably a mixture of wheat cultivars

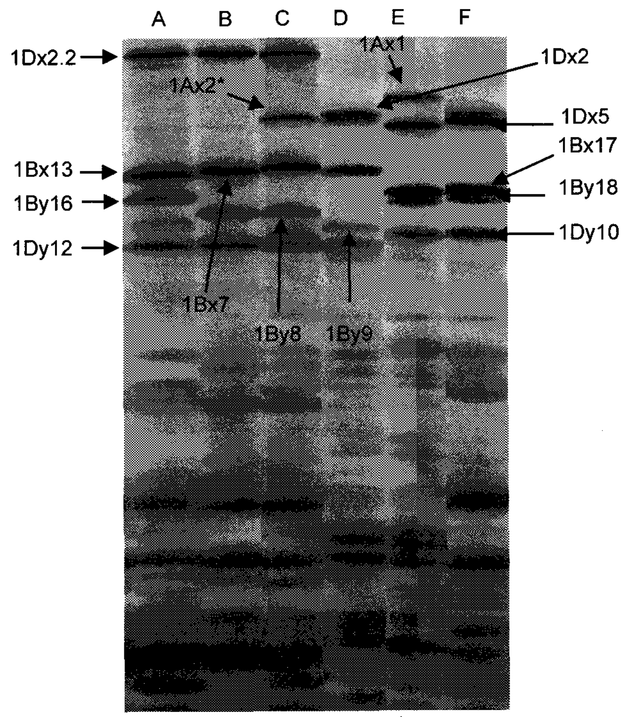

Fig. 1. SDS-PAGE patterns of HMW-GS compositions for a number of Korea with 1Dx2.2+1Dy12 subunits in HMW-GS and US wheats to illustrate the alleles. A, Joeunmil (Null, 1Bx13+1By16, 1Dx2.2+1Dy12); B, Urimil (Null, 1Bx7+1By8, 1Dx2.2+1Dy12); C, Olgeurumil (1Ax2*, 1Bx7+1By8, 1Dx2.2 +1Dy12); D, Stephens (1Ax2*, 1Bx7+1By9, 1Dx2+1Dy12); E, Klasic (1Ax1, 1Bx17+1By18, 1Dx5+1Dy10); F, Winsome, (1Ax2*, 1Bx17+1By18, 1Dx5+1Dy10).

since more than five subunits were found of which two alleles were identified at *Glu-A1* loci (1Ax1 and 1Ax2*), two at *Glu-B1* loci (1Bx7+1By8 and 1Bx17+1By18) and two at *Glu-D1* loci (1Dx2+1Dy12 and 1Dx5+1Dy10). Payne et al. (16) established the scoring system of HMW-GS composition for predicting the potential of bread-baking quality in wheat breeding programs based on the significant relationship between the specific HMW-GS composition and bread making quality. According to this system, the score of HMW-GS composition of hard wheat cultivars was >9 points, while club and soft wheat cultivars showed <8 points. However, Korean wheats cannot be evaluated by the HMW-GS scoring system because the effects of 1Dx2.2+1Dy12 subunits on bread-baking quality were not elucidated.

Characteristics of 8 Korean wheat flours with 1Dx2.2+1Dy12 subunits in HMW-GS, 14 US wheat flours of various classes of wheat and Com1, 2 and 3 are summarized in Table 2. Ash content of Korean wheat flours was 0.39%~0.54%, which was similar to ash content of the 14 US wheat flours (0.43~0.54%) and Com1, 2 and 3 (0.36~0.45%). No difference in amylose content between Korean wheat flours and US wheat flours with

Table 2. Flour characteristics of Korean wheats with 1Dx2.2+1Dy12 subunits in HMW-GS, US wheats with various classes and commercial wheat flours

Class[1)]	Cultivar & line	Ash (%)	Amylose (%)	Protein (%)	SDS-Sedimentation[2)]		NIR hardness	Gluten yield (%)	Mixograph	
					Flour (mL)	Protein (mL)			Water absorption (%)	Mixing time (sec)
Korea	Eunpamil	0.45	27.0	15.3	64.5	39.0	53.0	10.3	62.5	180.0
	Geurumil	0.54	27.9	13.2	56.0	39.0	46.0	9.1	61.0	145.0
	Jinpoommil	0.45	27.7	11.4	55.5	45.5	38.0	7.8	60.0	180.0
	Joeunmil	0.50	27.5	15.0	49.5	32.5	58.0	10.6	67.5	167.5
	Olgeurumil	0.39	28.2	11.6	58.0	47.5	11.0	7.6	60.5	172.5
	Urimil	0.47	29.0	10.2	44.0	43.0	14.7	6.1	53.0	202.5
	Suwon278	0.41	28.8	14.1	70.5	47.0	51.6	10.2	67.0	255.0
	Suwon280	0.40	28.3	15.6	68.0	43.0	49.9	11.2	70.0	142.5
Club	Calowa	0.49	28.9	11.4	29.0	31.5	27.6	8.4	55.5	95.0
	Bruehl	0.54	27.7	8.9	17.5	27.0	30.8	5.9	53.0	60.0
	Hiller	0.54	29.2	8.2	11.0	22.0	34.1	5.6	52.5	47.5
SWS	Treasure	0.53	25.6	10.3	24.5	33.5	35.0	6.8	54.5	95.0
	Vanna	0.53	27.8	11.7	36.5	40.5	28.1	7.9	57.0	85.0
	Alpowa	0.43	28.2	8.9	31.0	44.5	28.7	6.4	54.0	60.0
SWW	Stephens	0.48	27.3	12.2	32.5	34.0	45.6	8.8	57.5	85.0
	OR939526	0.49	27.4	11.9	32.5	35.0	47.2	8.7	57.0	90.0
HWS	Winsome	0.50	27.3	14.2	48.5	36.0	80.2	10.9	62.0	210.0
	Nuwest	0.54	26.8	10.9	34.0	35.5	78.4	8.2	57.5	205.0
	Klasic	0.46	20.9	14.9	44.0	40.0	56.0	11.7	62.0	330.0
	IDO377S	0.51	21.8	13.6	32.5	31.5	86.7	10.1	60.0	180.0
HRS	WA7839	0.51	26.4	16.9	69.0	44.0	69.1	12.9	65.0	195.0
	WPB926	0.55	29.0	17.5	73.5	46.0	71.5	12.9	65.5	200.0
COM[3)]	Com1	0.36	23.1	10.1	29.0	39.0	33.4	7.4	60.0	210.0
	Com2	0.41	23.7	10.8	36.5	40.0	34.6	7.8	60.0	197.5
	Com3	0.45	26.7	14.4	75.5	47.0	86.7	13.0	65.0	210.0
LSD[4)]		0.07	2.33	0.14	2.22	2.04	1.49	0.28	0.87	11.09

[1)]SWS=Soft white spring, SWW=Soft white winter, HWS=Hard white spring, HRS=Hard red spring, COM=Commercial flours.
[2)]Flour=SDS sedimentation test was conducted on a constant flour weight (3.0 g); Protein=SDS sedimentation test was conducted on a constant protein weight (300 mg).
[3)]Com1 and Com2=Commercial noodle flour from Japan and Korea, respectively; Com3=Commercial bread baking flours from Western Wheat Quality Lab.
[4)]Least significant difference ($p<0.05$); Differences between two means exceeding this value are significant.

various classes was found, except for Klasic (20.9%) and IDO377S (21.8%) in HWS. Klasic and IDO377S have *Wx-B1* null allele in granule bound starch synthase (GBSS), which are responsible for the synthesis of amylose molecule during grain development (19). Com1 and 2 showed similar amylose content to Klasic and IDO377S.

Protein content of flours was 10.2%~15.6% in Korean wheat flours, 8.2%~12.2% in club and soft wheat cultivars, and >13.6% in hard wheats, except in Nuwest (10.9%). Protein content of Com3 (14.4%) was higher than Com1 and 2 (<10.79%). SDS sedimentation volume performed with constant flour weight (3.0 g) of Korean wheat flours was higher (>44.0 mL) than club and soft wheat flours (<36.5 mL) and Com1 and 2 (<36.5 mL). SDS sedimentation volume based on constant flour weight is influenced by protein content and quality. Therefore, it was necessary to run the SDS sedimentation test standardized to a constant content of protein to determine protein quality independent of protein content (20). Compared to sedimentation volume based on constant flour weight, differences in sedimentation volume based on constant protein weight within Korean wheat flours and different US wheat flours became smaller. SDS sedimentation volume of most Korean wheat flours (>43.0 mL), except Eunpamil, Geurumil and Joeunmil (39.0, 39.0 and 32.5 mL, respectively), were within a similar rage as HRS wheat flours (44.0~46.0 mL). Eunapmil and Geurumil showed similar SDS sedimentation volume to HWS wheat flours (35.5~40.0 mL), except IDO377S, and Com1 and 2 (39.0~40.0 mL). Joeunmil Korean wheat (32.5 mL) showed exceptionally low sedimentation volume. Compared to wheat flours with similar protein content, Korean wheat flours showed higher SDS sedimentation volume based on a constant flour weight and on a constant protein weight. SDS sedimentation volume conducted both on a constant flour weight basis and on a constant protein basis increased as protein content increased in US wheat flours.

NIRS hardness score of Korean wheat flours was 38.0 ~58.0, which was higher than that of club, SWS wheat flours and Com1 and 2 (<35.0), and lower than hard wheat flours and Com3 (>69.1), except Klasic (56.0) in HWS. Olgeurumil and Urimil showed extremely low NIRS hardness score (11.0~14.7). Gluten yield of flours was 6.1~11.2% in Korean wheat flours and 5.6~11.7% in club, soft and HWS wheat flours, while HRS wheat (12.9%) had similar gluten yield to Com3 (13.0%). Gluten yield of Com1 and 2 was 7.4~7.8%, and was similar to the range of gluten yield in club and soft wheat flours. NIRS hardness and gluten yield increased as protein content increased in Korean and US wheat flours.

Mixograph parameters were used to compare wheat flours for their differences in protein quality, since dough mixing properties of flours are mainly controlled by quantity and quality of protein (21). Mixograph water absorption of Korean wheat flours (60.0~67.5%), except in Urimil (53.0%), was higher than that of club and soft wheats (<57.5%) and was similar to that of hard wheat flours (60.0~65.5%), except for HWS wheat cv. Nuwest, which had 57.5% of mixograph water absorption. Mixograph water absorption increased as protein content and NIRS hardness increased. Compared to wheat flours with similar protein content and SDS sedimentation volume, mixograph absorption of Com1, 2 and 3 (65% and 60%, respectively) was similar to that of Korean wheat flours, but much higher than that of US wheat flours. Com1, 2 and 3 had smaller particle size of flours, higher damaged starch content and water retention capacity (17), which contributed to the relatively high mixograph absorption. Compared to wheat flours with similar protein content and quality, Korean wheat flours had higher water retention capacity than US wheat flours (unpublished data). Higher water absorption in the mixograph of Korean wheat flours should be studied because water absorption of flours could have an influence on the food processing and quality. Mixograph mixing time >142.5 sec, of Korean wheat flours was much longer, than that of club and soft wheat flours (<95.0 sec) and similar to that of hard wheat flours (180.0~330.0 sec) and Com1 and 2 (197.5~210.0 sec). Compared to similar protein content and SDS sedimentation volume, Korean wheat flours with 1Dx2.2+1Dy12 subunits in HMW-GS showed longer mixograph mixing time than soft wheat flours, but shorter mixing time than hard wheat flours. No significant difference between mixograph mixing time and protein content was found in Korean wheat flours, although mixograph mixing time increased with increasing protein content in US wheat flours.

Characteristics of white salted noodles

Optimum water absorption percent of noodle dough and thickness and color of noodle dough sheet of Korean wheat flours, US wheats and Com1 and 2 are shown in Table 3. Optimum water absorption percent of noodle dough was 33~37% in Korean wheat flours, 34~37% in club and soft wheat flours, and was <34% in hard wheat flours, except in cv. Nuwest, which was lowest in protein content among hard wheat flours. Compared to wheat flours with similar protein content and SDS sedimentation volume, optimum water absorption percent of noodle dough from Korean wheat flours was higher than that of US wheat flours. Optimum water absorption percent of noodle dough prepared from Korean wheat flours negatively correlated with protein content, SDS sedimentation volume based on flour weight, NIRS hardness, gluten yield and mixograph water absorption, each of these relationships also applied to US wheats (Table 4). Optimum water absorption percent of noodle dough prepared from US wheat flours positively correlated with amylose content and SDS sedimentation volume based on protein weight, but there were no significant relationships in Korean wheats. Optimum water absorption percent of noodle dough decreased as protein content increased, since flours with low protein content require more water for forming a uniform protein matrix and making a continuous noodle sheet with good handling properties (17,20). Further evaluation of flour characteristics related to water holding capacity needed to elucidate high water absorption in making noodle dough.

Thickness of noodle dough sheets prepared with optimum water absorption percent was 1.68~1.86 mm in Korean wheat flours, was 1.55~1.71 in club, SWS and SWW wheat flours, and was >1.82 mm in HW and HRS wheat flours, except in cv. Nuwest (1.70 mm). Com1 and 2 had 35% water absorption of noodle dough, and thickness of dough sheets was <1.73 mm. Thickness of noodle dough sheet from Olgeurumil and Urimil, which had similar protein contents to soft wheats and similar SDS sedimentation volume to hard wheat flours, were comparable to those of Com1 and 2. Thickness of noodle dough sheets from Korean wheats positively correlated with NIRS hardness, gluten yield and mixograph water absorption of Korean wheats. Thickness of noodle dough sheets prepared from US wheat flours showed positive relationships with protein content, SDS sedimentation volume, NIRS hardness, gluten yield and mixograph properties, and negative relationships with amylose content (Table 4).

In color of noodle sheet prepared from Korean wheat flours, L value of noodle sheets prepared with optimum

Table 3. Characteristics of noodle dough sheets and texture profile analysis parameters of cooked noodles prepared from Korean wheats with 1Dx2.2+1Dy12 subunits in HMW-GS, US wheats with various classes and commercial wheat flours

Class[1)]	Cultivar & line	Noodle dough sheet		Color of noodle sheet[3)]			Texture profiles of cooked noodles			
		Abs[2)] (%)	Thickness (mm)	L	A	b	Hardness (N)	Adhesiveness (N×mm)	Springiness (Ratio)	Cohesiveness (Ratio)
Korea	Eunpamil	33	1.83	75.7	1.4	18.1	5.58	-0.06	0.90	0.62
	Geurumil	35	1.79	73.5	1.2	16.4	5.47	-0.08	0.90	0.62
	Jinpoommil	35	1.76	78.9	0.9	17.2	4.93	-0.08	0.89	0.61
	Joeunmil	33	1.80	77.3	1.2	15.4	5.80	-0.10	0.90	0.60
	Olgeurumil	35	1.68	79.6	0.7	16.5	4.24	-0.05	0.91	0.63
	Urimil	37	1.69	79.2	0.9	16.9	4.15	-0.06	0.89	0.63
	Suwon278	33	1.86	77.2	1.2	17.6	5.88	-0.08	0.90	0.62
	Suwon280	33	1.80	76.3	1.2	16.4	5.63	-0.06	0.92	0.63
Club	Calowa	35	1.66	78.6	0.7	19.1	5.36	-0.07	0.90	0.59
	Bruehl	37	1.64	81.4	0.3	19.5	4.00	-0.05	0.88	0.61
	Hiller	37	1.55	81.0	0.2	18.6	3.17	-0.04	0.88	0.60
SWS	Treasure	35	1.67	79.9	0.7	18.0	4.64	-0.06	0.92	0.61
	Vanna	34	1.67	78.9	0.8	21.2	4.94	-0.06	0.90	0.61
	Alpowa	36	1.64	81.3	0.3	16.5	4.45	-0.06	0.89	0.62
SWW	Stephens	34	1.69	78.6	0.8	21.9	4.85	-0.04	0.93	0.62
	OR939526	35	1.71	77.7	1.0	22.9	5.22	-0.06	0.91	0.64
HWS	Winsome	34	1.87	78.5	0.9	17.0	5.29	-0.06	0.91	0.65
	Nuwest	35	1.70	79.4	0.1	21.7	4.94	-0.07	0.91	0.61
	Klasic	31	2.01	81.6	0.7	15.3	5.42	-0.05	0.90	0.66
	IDO377S	33	1.82	79.5	0.6	18.2	5.21	-0.06	0.91	0.64
HRS	WA7839	32	1.89	75.1	1.5	19.5	6.28	-0.07	0.91	0.61
	WPB926	32	1.93	76.2	1.2	18.0	6.73	-0.09	0.91	0.60
COM[4)]	Com1	35	1.65	81.6	-0.2	18.5	3.95	-0.03	0.90	0.63
	Com2	35	1.73	81.2	0.3	17.8	3.95	-0.03	0.92	0.66
LSD[5)]		-	0.02	1.25	0.16	1.07	0.14	0.02	0.02	0.01

[1)]SWS=Soft white spring, SWW=Soft white winter, HWS=Hard white spring, HRS=Hard red spring, COM=Commercial flours.
[2)]Abs=Water absorption of noodle sheet.
[3)]L=lightness; a=redness-greenness; b=yellowness-blueness.
[4)]Com1 and Com2=Commercial noodle flour from Japan and Korea, respectively.
[5)]Least significant difference ($p<0.05$). Differences between two means exceeding this value are significant.

Table 4. Correlation coefficients between characteristics of noodle dough and flour characteristics

Parameters[1)]	Optimum water absorption percent			Thickness of dough sheet		
	All (n=22)	Korean (n=8)	US (n=14)	All (n=22)	Korean (n=8)	US (n=14)
Ash	0.154	0.230	0.156	-0.151	0.061	-0.160
Amylose	0.497*[2)]	0.433	0.573*	-0.474*	-0.281	-0.568*
Protein	-0.905***	-0.932***	-0.921***	0.878***	0.798	0.903***
SDSSF	-0.635**	-0.714*	-0.804***	0.714***	0.668	0.805***
SDSSP	-0.372	0.293	0.643*	0.461	-0.270	0.592*
NIRS	-0.622**	-0.825*	-0.583*	0.637***	0.930***	0.679**
Gluten	-0.928***	-0.952***	-0.922***	0.896***	0.841**	0.916***
Mabs	-0.801***	-0.923*	-0.903***	0.763***	0.726*	0.907***
Mtime	-0.643***	-0.003	-0.820***	0.837***	0.229	0.925***

[1)]SDSSF=SDS sedimentation volume based on constant flour weight (3.0 g), SDSSP=SDS sedimentation volume based on constant protein weight (300 mg), NIRS=NIRS hardness, Gluten=gluten yield, Mabs=mixograph water absorption, Mtime=mixograph mixing time.
[2)] * indicates significance at the 0.05 level, ** at the 0.01 level, and *** at the 0.001 level.

water absorption percent was 73.5～79.6, a value of noodle dough was 0.7～1.4, and b value was 15.4～18.1. Noodle sheet prepared from club and soft wheat flours showed higher L values than that of hard wheat flours. HRS wheat flours produced higher a value of noodle sheets than club and soft wheat flours. There was no significant difference between soft and hard wheat flours in b value of noodle sheets. Compared to Com1 and 2, noodle sheets from Korean wheats showed lower L values (>81.2), higher a value (<0.3) and similar b value (17.8～18.5). Protein content positively correlated with the value of noodle sheets from Korean wheats (r=0.830, p<0.05), but no significant relationships between protein content and other values of noodle dough sheets were found. Protein content correlated with L and a value of noodle sheets prepared from US wheat flours (r=-0.715, p<0.01, and r=0.826, p<0.001, respectively). Significant relationships between protein content and color characteristics of noodle sheets were reported by several previous studies in white salted noodles (17,22,23).

Hardness of cooked white salted noodles prepared from Korean wheat flours was 4.15~5.88 N. Hardness of cooked noodles was highest in HRS wheat flours (> 6.28 N), followed by HWS, SWW, SWS and club wheats, except in Calowa which was comparable to that of noodles prepared from HWS wheat flours. Com1 and 2 produced much softer textured white salted noodles (3.95 N) than hard and soft wheat flours. Compared to similar protein content of Com1 and 2, hardness of cooked noodles from Korean wheats were lower than that of soft and hard wheat flours. Adhesiveness and springiness of cooked noodles from Korean wheats were similar to US wheat flours, with no consistent differences in adhesiveness and springiness of cooked noodles among the 14 different wheat flours. Adhesiveness of cooked noodles from Com1 and 2 was higher than other wheat flours. Cohesiveness of cooked noodles from Korean wheat flours was 0.60~0.63, which was similar to that of club, soft and HRS wheat flours. Cohesiveness of cooked noodles from IDO377S and Klasic in HWS wheat flours was similar to that of Com1 and 2. Commercial flours for making noodles are null in the *Wx-1B* allele of granule bound starch synthase, which is probably responsible for the soft texture of cooked noodles, along with low protein content (24). However, cooked noodles from HWS wheat flours are much higher in protein content and consequently produced harder textured noodles than Com1 and 2. Olgeurumil and Urimil showed similar texture profiles of cooked noodles to Com1 and 2, in spite of the high amylose content of the flours. They showed similar protein content and quality to Com1 and 2 (Table 2).

Hardness of cooked noodles from Korean and US wheat flours positively correlated with protein content of wheat flours (Fig 2-A). Hardness of cooked noodles positively correlated with SDS sedimentation volume based on constant protein weight as a measurement of protein content and quality in US wheat flours, but no significant relationship was found among Korean wheat flours (Fig 2-B). Hardness of cooked noodles prepared from Korean and US wheat flours correlated positively with NIRS hardness (Fig 2-C), mixograph water absorption and gluten yield, parameters all of which were mainly influenced by protein content. Noodles prepared from wheat flours with low protein content are more fragile than those with high protein content, since the protein network in the low protein noodles is weaker than in high protein noodles. The relationship between protein content as well as SDS sedimentation volume and hardness of cooked white salted noodles was reported by many previous researchers (14,23-25). Adhesiveness of cooked noodles from US wheat negatively correlated with SDS sedimentation volume, and springiness of cooked noodles from Korean wheat positively correlated with SDS sedimentation volume based on constant protein weight. However, there was no significant relationship between protein content and quality and other texture profiles of cooked noodles.

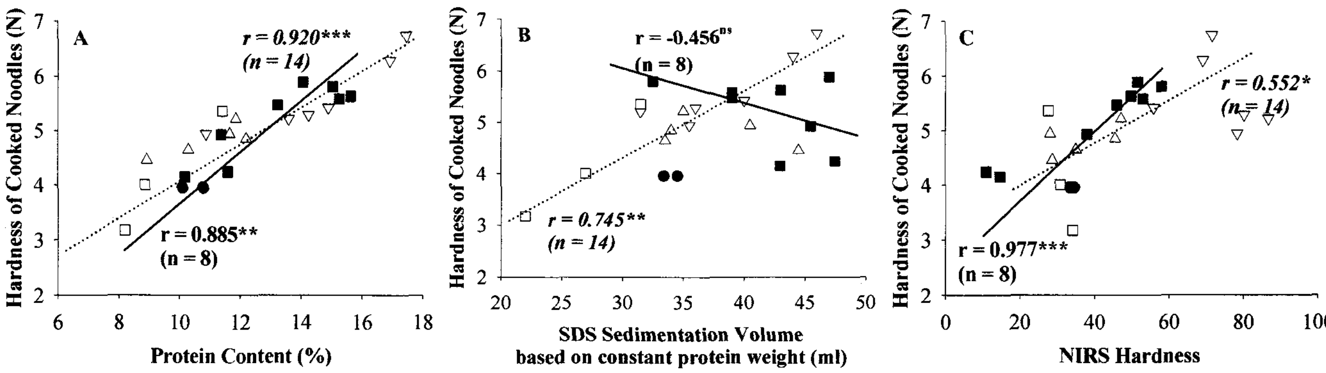

Fig. 2. The relationships between protein content (A), SDS sedimentation volume based on constant protein weight (B), NIRS hardness (C) and hardness of cooked white salted noodles prepared from Korean wheat flours with 1Dx2.2+1Dy12 subunits in HMW-GS, US wheat flours and commercial noodle flours.
Solid and dotted lines indicate Korean and US wheat flours, respectively. ■: Korean wheat, □: club wheat, △: soft wheat, ▽: hard wheat and ●: commercial flours for making noodles. r=correlation coefficients, n=8: Korean wheat flours, n=14: US wheat flours with different classes. **, *** and ns mean p=0.01, p=0.001 and not significant, respectively.

Characteristics of pan bread

Characteristics of pan bread baked from Korean wheats, US hard wheat flours and Com3 are shown Table 5. Crumb structure of pan bread baked from Korean wheat flours with 1Dx2.2+1Dy12 subunits in HMW-GS, US hard wheat flours and Com3 are shown in Fig. 3. Mixing time of Korean wheats with 1Dx2.2+1Dy12 subunits in HMW-GS was shorter than 176.5 sec, except in Olgeurumil, Urimil and Suwon 278. Urimil and Suwon 278 showed longer mixing time than other Korean wheat flours, which were similar to mixing times of HWS wheat flours. Mixing times of HRS wheat flours were shorter than Com3, which was similar to that of HWS wheat flours. Proof height of Korean wheat was 7.4~8.0 cm, which was lower than that of hard wheat flours, but similar to that of Com3. Loaf volume of pan bread baked from Korean wheat was lower than 870.0 mL, which was lower than that of hard wheat flours and (885.0~1,112.5 mL) and Com3 (1,017.5 mL). Crumb firmness of pan bread baked from Korean wheats was 2.1~6.2 N, which was much harder than hard wheat flours (<1.4 N), except in Winsome (2.6 N) and Com3 (1.8 N). Compared to US hard wheat flours, Eunpamil, Joeunmil, Suwon278 and 280, which these wheat flours showed similar protein and quality to US hard wheat flours (Table 2), and showed comparable loaf volume and crumb firmness to Winsome. However, those wheat flours showed lower loaf volume and harder crumb firmness than HRS wheat flours and Com3. That indicates that Korean wheat flours with 1Dx2.2+1Dy12 subunits in HMW-GS are not suitable for making pan bread, although the influence of low molecular glutenin and gliadin compositions of Korean wheats with 1Dx2.2+1Dy12 subunits in HMW-GS on pan bread quality should be investigated.

Table 5. Characteristics of bread baking parameters of Korean wheats with 1Dx2.2+1Dy12 subunits in HMW-GS, US hard wheat flours and commercial bread wheat flours

Class[1]	Cultivar & line	Mixing time (sec)	Proof height (cm)	Loaf volume (mL)	Crumb firmness (N)
Korea	Eunpamil	167.5	7.5	870.0	2.5
	Geurumil	159.0	7.6	810.0	3.0
	Jinpoommil	176.5	7.4	755.0	3.4
	Joeunmil	149.0	7.7	820.0	2.6
	Olgeurumil	189.5	7.8	840.0	2.5
	Urimil	268.0	7.3	640.0	6.2
	Suwon278	230.5	8.0	855.0	2.7
	Suwon280	144.0	7.5	815.0	2.1
HWS	Winsome	232.0	8.1	885.0	2.6
	Klasic	262.5	8.5	985.0	1.3
HRS	WA7839	182.0	8.3	1112.5	1.4
	WPB926	187.0	8.4	1085.0	1.3
COM[2]	Com3	226.5	7.6	1017.5	1.8
LSD[3]		12.87	0.28	57.86	0.31

[1]SWS=Soft white spring, SWW=Soft white winter, HWS=Hard white spring, HRS=Hard red spring, COM=Commercial flours.
[2]Com3=Commercial bread baking flours from Western Wheat Quality Lab.
[3]Least significant difference ($p<0.05$). Differences between two means exceeding this value are significant.

A. Commercial bread wheat and HRS wheats B. Commercial bread wheat and Korean wheats

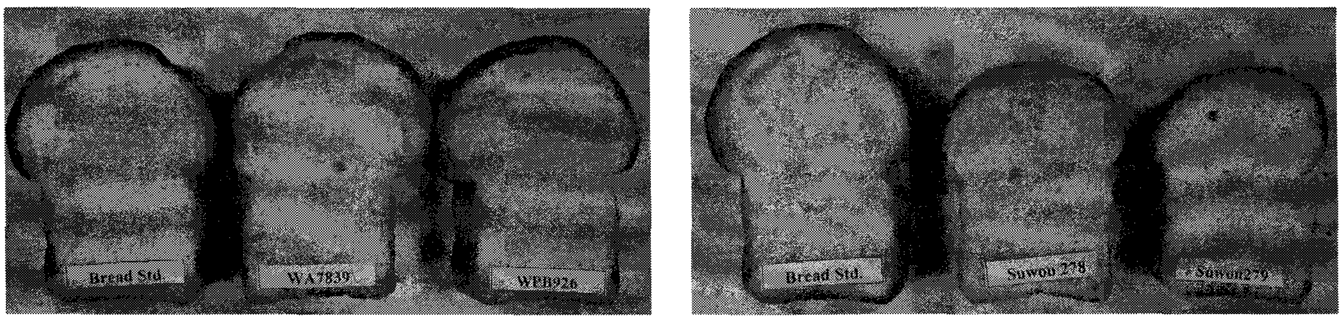

Fig. 3. Crumb structure of pan bread baked from Korean wheat flours with 1Dx2.2+1Dy12 subunits in HMW-GS, US hard wheat flours and commercial bread wheat flour.
A. Commercial bread wheat flours and US HRS wheat flours.
B. Commercial bread wheat flours and Korean wheat flours.

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