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Environmental Impacts of Korean and CIMMYT Wheat Lines on Protein Characteristics and Bread Making Quality

Chul-Soo Park*, Hong-Sik Kim**, Dae-Ho Kim***, Jong-Nae Hyun**, and Chon-Sik Kang*[†]

**Department of Crop Science and Biotechnology, Chonbuk National University, Jeonju 561-756, Korea*
***National Institute of Crop Science, Rural Development Administration, Suwon 441-857, Korea*
****Gyeongsangnam-do Agricultural Research & Extension Services, Jinju 660-985*

ABSTRACT This study was conducted to compare the protein characteristics, dough rheology and bread loaf volume of Korean wheat cultivars and CIMMYT lines produced in diverse environments and to determine the genetic and environmental effects on bread making quality. Protein characteristics, including protein content and SDS-sedimentation volume, mixing properties during dough development and bread loaf volume were primarily influenced by the environment. Wheat cultivated in Jinju exhibited higher SDS-sedimentation volume based on constant protein weight and bread loaf volume than those in Suwon and Iksan. SDS-sedimentation volume based on constant protein weight, mixing time of mixograph and mixing tolerance of mixograph were positively correlated with bread volume. Korean wheat cultivars showed different allelic variations of *Glu-1* and *Glu-3* compared to CIMMYT wheat lines. Alchanmil, Keumkangmil and Tapdongmil could be suitable for bread making because these cultivars exhibited a 10 point *Glu-1* score. However, Korean wheat cultivars should be introduced specific alleles in *Glu-3* loci, including *Glu-A3b* or *d* and *Glu-B3b*, *d*, *f* or *g*, to improve gluten strength related to increase bread loaf volume.

Keywords : environment, flour, rheology, bread

Wheat grain protein is known as a primary factor for bread making because protein content and composition influence dough rheology and baking properties including high water absorption of dough, good dough extensibility, tolerance to mixing, and high loaf volume (Finney *et al*., 1987; Bruckner *et al*., 2001; Campbell *et al*., 2001). Good bread loaf volume is invariably accompanied by more satisfactory crumb grain and somewhat whiter or less creamy crumb color (Finney *et al*., 1987). Bread loaf volume is generally increased with increasing protein content and also is significantly influenced by both protein content and composition in wheat grains (Weegels *et al*., 1996; Lafiandra *et al*., 1999; Branlard *et al*., 2001). In many previous studies, physicochemical properties of flour and dough rheology properties related to bread making quality were usually influenced by wheat genotypes and interactions of genotypes and environment, although grain protein composition depended primarily on genotype (Busch *et al*., 1969; McGuire and McNeal 1974; Baenziger *et al*., 1985; Lukow and McVetty 1991; Gupta *et al*., 1992; Peterson *et al*., 1992, 1998; Blumenthal *et al*., 1995; Ciaffi *et al*., 1995; Graybosch *et al*., 1995, 1996; Huebner *et al*., 1997; Triboï *et al*., 2000; Zhu and Khan 2001).

Quality improvement associated with bread making is recently attracting much attention by wheat breeders in Korea, although high grain yield and early maturation are the major consideration in Korean wheat breeding program since the 1970s. Currently, there have been attempts to identify biochemical markers, especially both high molecular weight and low molecular weight glutenin subunits (HMW-GS and LMW-GS, respectively) compositions related to bread making quality and to characterize and select breeding lines in wheat breeding programs of Korea. Superior advanced wheat lines of International Maize and Wheat Improvement Center (CIMMYT) were recently tested in international multi-location trials to provide wheat lines carrying high quality in end-use purpose within each wheat-growing region as well as to evaluate the degree of yield stability in international environments (van Beem *et al*., 2005).

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[†]Corresponding author: (Phone) 82-63-840-2156 (E-mail) kcs1209@korea.kr

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Crop Science (NICS), Rural Development Administration (RDA) and CIMMYT was conducted to evaluate the effects of genetic and environmental factors on the gluten properties of Korean wheat cultivars and CIMMYT elite advanced lines carrying high quality in bread making. The purposes of this study were to determine the genetic and environmental effects on bread making quality in Korean wheat cultivars and CIMMYT lines with different glutenin compositions and to provide the information for improving bread making quality in Korean wheat breeding programs.

MATERIALS AND METHODS

Materials

Ten Korean wheat cultivars and ten CIMMYT lines were grown in the upland conditions at Iksan, Jinju and Suwon in 2006/2007 and 2007/2008. The seed was sawn on October 25 and cultivated with the standard method of wheat in the National Institute of Crop Science. Mean temperature (9.3℃) of two years were higher than that of average year (8.8℃) and average precipitation (434 mm) was similar to that of average year (438 mm).

Glutenin subunit compositions

To determine the composition of HMW-GS, grain protein was extracted from 40 mg of wheat 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. 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. HMW-GS compositions were classified using the nomenclature of Payne and Lawrence (1983).

Five seed of each line were grown in a temperature-controlled greenhouse to analyze the allelic variations of *Glu-3* alleles. Two weeks after germination, single leaves from individuals within cultivars were collected, bulked and snap-frozen in liquid nitrogen and stored at -80℃ until needed. All plants were kept in the greenhouse for analysis of glutenin compositions. Genomic DNA was extracted from 100 mg of young leaf tissue using the Genomic DNA prep kit (Solgent Co., Korea) according to the manufacturer's instructions. The allelic variations of *Glu-A3*, *Glu-B3* and *Glu-D3* were determined by the procedure described by Zhang *et al*. (2004), Wang *et al*. (2009) and Appelbee *et al*. (2009), respectively.

Analytical methods

Wheat grain samples were milled using Bühler experimental mill, and flour of about 60% extraction was prepared by blending millstreams. Moisture and protein content of wheat flour were determined according to Approved Methods 44-15A and 46-30, respectively (AACC 2000). The SDS sedimentation test was performed according to the procedure of Baik *et al*. (1994). 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. Optimum water absorption, mixing time and mixing tolerance of wheat flour were determined using a 10g mixograph (National Mfg. Co., USA) according to approved method 54-40A (AACC 2000).

Bread making quality

The bread baking procedures followed according to the straight-dough methods described by Finney (1984) and AACC approved method 10-10A (AACC 2000) with some modifications. The ingredients of baking formula were consisted of 100 g (14% moisture basis) of flour, 6 g of sugar, 3 g of shortening, 1.5 g of salt, 5.0 g of fresh yeast, 50 mg of ascorbic acid, and 0.25 g of barley malt (about 50 DU/g, 20℃). 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℃ and 85% relative humidity for 70 minutes with two punches and a proof period of 60 minutes, and then baked at 210℃ for 18 minutes.

After the bread was taken out from an oven, the loaf volume was measured immediately by rapeseed displacement and weighted. After cooling for two hours at room temperature, bread was mechanically sliced about 12.50 mm thick and put into a plastic bag for a day. Crumb firmness of bread was measured with a Texture Analyser (TA-XT2*i*, Version 1.17, Stable Micro Systems, England) according to the procedures described by Baker *et al*. (1988). Sliced bread was placed between SMS P/35 probe (Ø35 mm /stainless steel) and flatten metal plate. The test was performed with a load cell pressure of 5 kg, at a test speed of 0.8 mm/sec., and a test distance of 25% strain of sample height.

Statistical analysis

At least two independent measurements per sample were collected for each quality parameter tested, and values were averaged for statistical analyses using the SAS computer software package (SAS Institute, Cary, NC). Analysis of variance was conducted using the general linear model procedure, and the genotype×year×location component was used as the error term. Sources of variation in the model were considered to be fixed effects. Pearson's correlation coefficients were also determined and statistical significance levels were P<0.05 unless otherwise specified.

RESULTS AND DISCUSSION

Protein characteristics, dough rheology and bread loaf volume

Year, genotype, location, and their interactions significantly influenced grain protein content, SDS-sedimentation volume, mixing dough properties and bread loaf volume of Korean wheat cultivars and CIMMY wheat lines (Table 1). Protein characteristics, rheological properties and bread loaf volume were significantly influenced by cultural environment of Korea. These results were agreed with previous studies (Miezan *et al*., 1977; Baenziger *et al*., 1985; Bassett *et al*., 1989; Lukow and McVetty 1991). SDS sedimentation volume based on constant flour weight is influenced by protein content and quality, whereas SDS volumes based on constant protein reflect differences in protein quality among wheat genotypes. Environment accounted for the largest proportion of the variation among SDS volumes based on constant flour weight, mixing time and mixing tolerance of mixograph in CIMMYT wheat lines (62, 37

Table 1. Effects of year, location, genotype and their interactions on protein characteristics and bread volume of 10 Korean wheat cultivars and 10 CIMMYT lines

Source of Variation	df	Protein (%)	F-values^{a}					Bread Volume (cc)
			SDS-Sedimentation		Mixograph			
			Flour Weight (mL)	Protein Weight (mL)	Absorption (%)	Mixing Time (min)	Mixing Tolerance (mm)	
Korean wheat cultivar								
Year (Y)	1	2204.8^{***a}	3049.1^{***}	1656.0^{***}	7.5^{**}	3136.4^{***}	310.5^{***}	52.3^{***}
Location (L)	2	4216.1^{***}	3620.8^{***}	3790.4^{***}	920.7^{***}	367.7^{***}	204.2^{***}	11.5^{***}
Genotypes (G)	9	5737.5^{***}	2359.0^{***}	7382.1^{***}	1109.3^{***}	1686.3^{***}	190.8^{***}	247.8^{***}
Y × L	2	3859.0^{***}	469.7^{***}	3976.8^{***}	78.1^{***}	289.3^{***}	266.7^{***}	0.8
Y × G	9	230.9^{***}	665.3^{***}	858.8^{***}	1126.5^{***}	87.0^{***}	117.8^{***}	3.7^{***}
L × G	18	176.3^{***}	299.5^{***}	596.2^{***}	51.2^{***}	116.0^{***}	50.5^{***}	6.2^{***}
CIMMYT line								
Y	1	49.4^{***}	197.8^{***}	40.45^{***}	6.2^{*}	1608.9^{***}	50.9^{***}	44.5^{***}
L	2	235.4^{***}	11187.4^{***}	2158.8^{***}	4.9^{**}	2414.7^{***}	375.8^{***}	9.4^{***}
G	9	94.3^{***}	4235.4^{***}	2457.7^{***}	4.6^{***}	774.4^{***}	220.6^{***}	95.9^{***}
Y × L	2	1989.8^{***}	1312.2^{***}	2751.5^{***}	2.5	1423.1^{***}	265.1^{***}	1.8
Y × G	9	16.8^{***}	638.3^{***}	188.7^{***}	3.1^{*}	78.0^{***}	45.8^{***}	33.8^{***}
L × G	18	46.0^{***}	631.3^{***}	446.1^{***}	2.8^{**}	202.4^{***}	94.7^{***}	18.9^{***}

^{a*}, ** and *** are significant at P=0.05, P=0.01 and P=0.001, respectively.

and 36%, respectively). These results indicated that protein content and quality of CIMMYT wheat lines changed significantly under different cultural environments. Water absorption of mixograph in CIMMYT wheat lines were significantly affected by all sources of variation except for the interaction between year and location. Bread loaf volume was also significantly affected by all sources of variation except for the interactions between year and location in both Korean wheat cultivars and CIMMYT wheat lines. Bread loaf volume of both Korean wheat cultivars and CIMMYT wheat lines were significantly influenced by genotype rather than production environment. The protein quality and bread loaf volume of Korean wheat cultivars appeared to be more stable across diverse production environments than those of CIMMYT wheat lines.

Mean values for protein content, quality parameters and bread loaf volume of Korean wheat cultivars and CIMMYT wheat lines are summarized by grouping on the environmental basis in Table 2. Protein content and SDS-sedimentation volume based on constant flour weight in Suwon were significantly higher for both Korean wheat cultivars and CIMMYT wheat lines than those in Iksan and Jinju. Optimum water absorption of mixograph was lower in Suwon than in other locations despite the high protein content. Mixing time and tolerance of mixograph were highest in Iksan for Korean wheat cultivars and in Suwon for CIMMYT wheat lines. SDS-sedimentation volume based on constant protein weight and bread loaf volume was significantly higher in Jinju for both Korean wheat cultivars and CIMMYT wheat lines than those in Suwon and Iksan.

Protein content and sedimentation volume of wheat cultivars cultivated in northern part of Korea, including Suwon, Chuncheon, Cheongju and Jechen, were higher than those of southern part of Korea, including Gwangju, Jinju and Chilgog in previous studies (Ryu *et al*., 1977; Chang *et al*., 1986; Ha *et al*., 1990; Song and Lee 1993). Ryu *et al*. (1977) proposed the temperature during ripening period of wheat cultivated in northern part of Korea was higher than that of southern part because of the late heading date in northern part. Heading date of wheats cultivated in Suwon (May 4 in Korean wheat cultivars and May 14 in CIMMYT wheat lines, respectively) was later than that of Iksan (April 29 in Korean wheat cultivars and May 9 in CIMMYT wheat lines, respectively) and Jinju (April 26 in Korean wheat cultivars and May 7 in CIMMYT wheat lines, respectively). High temperature during ripening period of wheat cultivated in Suwon could be influenced on increasing

Table 2. Flour chemical composition, rheological properties and bread loaf volume for 10 Korean wheat cultivars and 10 CIMMYT wheat lines grown in two years and three locations

Source of Variation	Protein (%)	SDS-Sedimentation		Mixograph			Bread Volume (cc)
		Flour weight (mL)	Protein weight (mL)	Absorption (%)	Mixing Time (min)	Mixing Tolerance (mm)	
Korean wheat cultivar[a]							
Suwon	11.51a[b]	50.80a	45.20b	60.93b	3.67c	18.95c	727.42c
Iksan	10.75b	44.70b	44.30c	61.89a	4.08a	22.63a	738.29b
Jinju	10.09c	41.18c	52.48a	59.66c	4.01b	20.85b	749.96a
CIMMYT line[c]							
Suwon	10.13a	50.10a	59.45b	58.53b	6.66a	28.85a	865.06b
Iksan	9.49c	41.83c	47.05c	60.09a	4.95c	24.38b	870.44b
Jinju	9.88b	42.75b	60.53a	60.41a	5.97b	29.00a	883.33a

[a] Average of values for 10 Korean wheat cultivars.

[b] Least significant difference ($P<0.05$).

[c] Average of values for 10 CIMMYT wheat lines.

protein content and SDS-sedimentation volume based on constant flour weight. However, SDS-sedimentation volume based on protein content protein content was higher in wheat cultivated in Jinju than that of Suwon and Iksan. Protein content of Korean wheat cultivars in Iksan and Jinju was lower than that of Suwon, which may have contributed to the extended mixing times required for flours from Iksan and Jinu. But, CIMMYT wheat lines cultivated in Suwon showed higher protein content and longer mixing time than those in Iksan and Jinju. Wheats cultivated in Jinju contrarily showed higher bread loaf volume than that of other locations although wheat in Suwon had higher protein content than others.

Pomeranz (1988) proposed high protein contents could be usually desirable for bread wheats because increased protein content is typically associated with higher loaf volumes and increased water absorption is desirable for hard wheat because loaf volume increase. Temperature during grain development had generally significant influence on end-use quality. However, there are contrary results between grain filling conditions and protein content. Positive correlation between increased temperatures during the early stages of grain filling and protein content existed, while higher average temperatures in grain filling showed no effect on protein content (Johnson *et al*., 1972). However, Rao *et al* (1993) indicated that protein content of soft white winter wheats was positively associated with maximum temperatures during grain filling but the relationships varied among locations. Dupont and Altenbach (2003) also proposed that effects of temperature on storage protein composition might not be clear, and might vary with genotype. They concluded that most studies on the effect of temperature on protein composition and flour quality related to bread making could not explain the effects of temperature on protein content. Peterson *et al*. (1992) proposed variation in total protein content alone could not adequately account for established differences in varietal end-use quality characteristics.

High temperature during grain filling caused the decrease of glutenin to gliadin ratio because gliadin synthesis continued while there was a greatly decreased synthesis of glutenin proteins at high temperature during grain filling (Blumental *et al*., 1990a, b; 1994). During grain filling period, high temperature reduced the size of glutenin polymers and as a result weakened the dough because glutenin polymers were strongly correlated with bread making quality (Blumental *et al*., 1995; Ciaffi *et al*., 1995). Environment affected not only protein content but also the proportion of glutenin polymers and the proportion of glutenin polymers was more strongly correlated with dough strength properties and bread making quality than total protein content (Singh *et al*., 1990; Gupta *et al*., 1993; Weegels *et al*., 1996; Zhu *et al*., 2001). Therefore, the proportion of glutenin polymers of Korean wheat cultivars during grain filling period should be considered to improve bread making quality by increasing dough strength as well as protein content of Korean wheat cultivars.

Protein contents were 8.53~12.19% and 9.30~10.20% for Korean cultivars and CIMMYT wheat lines, respectively (Table 3). Ranges of SDS sedimentation volume based on constant flour weight were 23.25~62.50 mL for Korean wheat cultivars and 30.67~60.67 mL for CIMMYT wheat lines. SDS sedimentation volume based on constant protein weight for Korean wheat cultivars was 36.83~56.42 mL and 38.92~68.92 mL for Korean cultivars and CIMMYT wheat lines, respectively. Korean wheat cultivars showed higher average protein content and SDS sedimentation volume based on constant flour weight (10.78% and 45.56 mL, respectively) than CIMMYT wheat lines (9.83% and 44.95 mL, respectively). But, average SDS sedimentation volume based on constant protein content of CIMMYT wheat flours was higher (55.68 mL) than that of Korean wheat flours (47.33 mL). Conducting SDS sedimentation tests on a constant protein basis neutralized the effect of protein content on sedimentation volume, allowing a more accurate comparison among cultivars (Mikhaylenko *et al*., 2000).

Mixing time and tolerance of mixograph and bread loaf volume are generally determined by glutenin and gliadin seed storage protein composition, as well as protein content (Pomeranz 1988). Low SDS sedimentation volumes usually indicate weaker gluten (Mosleth and Uhlen 1991), which is desirable for a majority of products made from soft wheat flour. Soft wheat flour with strong gluten is not suitable for end-use quality, such as cookies with small diameter, sponge cakes with low volumes, and noodle of poor texture compared with soft wheat flour with weak gluten (Gaines

Table 3. Protein content, SDS-sedimentation volume, mixograph properties and bread loaf volume of 10 Korean wheat cultivars and 10 CIMMYT lines cultivated in three locations for two years

Genotypes	Protein (%)	SDS-Sedimentation (mL)		Mixograph			Bread Volume (cc)
		Flour weight	Protein weight	Absorption (%)	Mixing Time (min)	Mixing Tolerance (mm)	
Korean wheat cultivar							
Alchanmil	9.46g[a]	42.42f	56.42a	59.71e	5.32a	26.08a	817.78c
Eunpamil	11.00d	46.67e	44.83f	61.08d	3.68f	15.83i	759.17d
Gobunmil	10.83e	48.33d	53.17b	61.50c	4.38c	24.75b	676.94g
Joeunmil	13.35a	51.33c	36.83h	63.29b	2.92i	20.75e	701.67f
Jopoommil	12.19b	62.50a	53.42b	63.21b	3.25h	18.75g	738.06e
Keumkangmil	12.15b	61.83b	52.08c	63.75a	4.23d	21.50d	840.14b
Olgeurumil	9.21h	29.67h	40.42g	58.33g	3.37g	17.25h	676.11g
Seodunmil	9.98f	40.92g	47.67e	58.96f	2.91i	19.67f	636.25h
Tapdongmil	11.12c	48.67d	48.25d	61.21d	5.14b	20.00f	917.50a
Urimil	8.53i	23.25i	40.17g	57.21h	4.00e	23.50c	621.94h
CIMMYT line							
14SAWYT-MXI-01	9.93b	47.42d	57.58d	59.33a	5.58e	25.25f	897.36b
14SAWYT-MXI-02	10.20a	55.08b	62.67b	55.25b	6.35c	28.75c	958.39a
14SAWYT-MXI-03	9.32d	38.08i	51.67f	59.42a	6.13d	30.08b	849.69d
14SAWYT-MXI-04	9.53c	40.42g	55.17e	60.88a	6.13d	27.58d	881.53c
14SAWYT-MXI-05	10.18a	50.83c	58.25c	61.46a	4.77g	21.33h	858.61d
14SAWYT-MXI-06	10.14a	60.67a	68.92a	59.71a	7.24a	33.33a	859.58d
14SAWYT-MXI-07	10.17a	41.92f	49.83h	59.33a	6.38bc	28.75c	944.14a
14SAWYT-MXI-08	9.30d	44.42e	62.83b	59.42a	6.45b	30.25b	861.53c
14SAWYT-MXI-09	10.02b	30.67j	38.92i	61.33a	4.23h	22.42g	760.28e
14SAWYT-MXI-10	9.52c	39.42h	50.92g	60.63a	5.34f	26.33e	858.33d

[a] Values followed by same letters within Korean wheat cultivars or CIMMYT lines are not significantly different at $P<0.05$.

1990; Baik *et al*., 1994). Regardless of environments, CIMMYT wheat lines showed higher average of mixing time and tolerance of mixograph and bread loaf volume (5.86 min, 27.41 mm and 872.94 cc, respectively) than Korean wheat cultivars (3.92 min, 20.81 mm and 738.56 cc, respectively). These results indicated CIMMYT wheat lines contained more suitable glutenin compositions for bread making rather than Korean wheat cultivars. Most Korean wheat cultivars could be suitable for making noodles, cookies and sponge cakes. Among the Korean wheat cultivars, Keumkangmil and Tapdongmil showed similar level of the average of bread loaf volume of CIMMYT wheat lines.

Bread volume has positively correlated with SDS-sedimentation volume based on constant protein weight, mixing time of mixograph and mixing tolerance of mixograph (Fig. 1). SDS sedimentation volume and mixing properties during dough formation are mainly influenced by protein quality and these properties are highly correlated with bread loaf volume (Graybosch *et al*., 1996; Peterson *et al*., 1998; Mikhaylenko *et al*., 2000; Bruckner *et al*., 2001). Protein content was found to be the primary factor contributing to the variation in bread loaf volume in hard wheats (Graybosch *et al*., 1993). But there was no significant relationship between protein content and bread loaf volume due to the narrow variation of protein content in this study. SDS sedimentation volume based on constant protein weight,

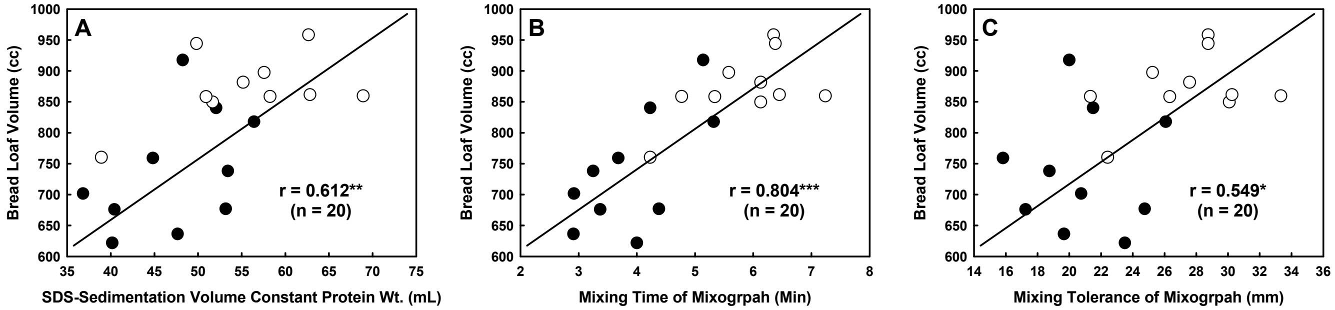

Fig. 1. Relationship between bread loaf volume and SDS-sedimentaion volume based on constant protein weight (A), mixing time of mixograph (B) and mixing tolerance of mixograph (C) in 10 Korean wheat cultivars (●) and 10 CIMMYT wheat lines (○).

mixing time and tolerance of mixograph could be considered in the evaluation of suitability of flours related to bread making quality in Korean wheat breeding program.

Allelic variations of glutenin

Allelic composition of *Glu-1* and *Glu-3* in 10 Korean wheat cultivars and 10 CIMMYT wheat lines is shown in Table 4 and Fig. 2. Pedigree of Korean wheat cultivars indicates that germplasms from Japan and CIMMYT have been introduced mainly to improve early maturation and increase grain yield in Korean wheats (Park *et al*., 2011). Shewry *et al*. (1992) proposed that *Glu-A1a/b*, *Glu-B1b/i* and *Glu-D1d* were required for bread because these alleles have stronger influences on gluten strength than other alleles at the *Glu-1* loci. Eight out of ten CIMMYT wheat lines contained those compositions of HMW-GS, but only three cultivars of Korean wheat, including Alchanmil, Keumkangmil and Tapdongmil, did for good bread making. These cultivars exhibited a 10 point *Glu-1* score as the sum of the assigned scores of the identified *Glu-1* alleles (Payne 1987).

At the *Glu-3* locus, Korean wheat cultivars predominantly carried *Glu-A3d*, *Glu-B3d* and *Glu-D3ab* alleles and CIMMYT wheat lines mainly had *Glu-A3c*, *Glu-B3fg* and *Glu-D3ab* alleles. Australian researchers proposed that *Glu-A3b* and *Glu-A3d* alleles showed stronger dough strength than other alleles (Gupta *et al*., 1989, 1991; Metakovsky *et al*., 1990; Vawser *et al*., 2002). The rankings of *Glu-A3* alleles to dough strength were $a=d=f\geq e$ in French wheat cultivars and $d>c=e$ alleles in New Zealand wheat cultivars (Branlard *et al*., 2001; Luo *et al*., 2001). Peña *et al*. (2004) reported that wheat lines with *Glu-D1d* and *Glu-B3d* showed the strongest gluten strength followed by groups possessing *Glu-D1d* combined with *Glu-B3b*, *Glu-B3f* and *Glu-B3g*. *Glu-D3b* allele showed stronger dough strength than *Glu-D3a* and *Glu-D3c* in Australian and New Zealand cultivars (Gupta *et al*., 1989, 1991; Metakovsky *et al*., 1990; Luo *et al*., 2001). However, Branlard *et al*. (2001) reported that *Glu-D3a* positively affected dough strength in French wheat and Vawser *et al*. (2002) reported that no difference was found in dough strength at *Glu-D3* locus. Park *et al*. (2011) proposed that various glutenin subunits, such as *Glu-B1i* and *Glu-B3g/f* alleles, should be introduced into Korean wheat cultivars and also frequencies of specific glutenin compositions, including *Glu-A1a*, *Glu-D1d*, *Glu-A3d* and *Glu-B3b/d* should be also included because Korean wheat cultivars have a narrow genetic background in glutenin composition.

To improve bread making quality of Korean wheats, specific glutenin alleles closely related to increase gluten strength should be introduced in breeding programs because bread loaf volume were significantly influenced by genotype rather than wheat production environment in Korea. Protein quality parameters, including SDS sedimentation volume based on constant protein weight, mixing time and tolerance of mixograph, could be also considered in the evaluation of suitability of flours related to bread making quality in Korean wheat breeding program. The environmental effects on the proportion of glutenin polymers during grain filling period should be considered to improve bread loaf volume because wheats cultivated in Jinju showed higher

Table 4. Allelic compositions of high-molecular-weight glutenin subunits (HMW-GS) and low-molecular-weight glutenin subunits (LMW-GS) in 10 Korean wheat cultivars and 10 CIMMYT lines.

Cultivar / Line	Pedigree	HMW-GS[a]			LMW-GS[b]		
		Glu-A1	*Glu-B1*	*Glu-D1*	*Glu-A3*	*Glu-B3*	*Glu-D3*
Korean wheat cultivar							
Alchanmil	Suwon210/Tapdongmil	*b*	*b*	*d*	*d*	*d*	*ab*
Eunpamil	Chukoku81/Tob-CNO//Yuksung3/3/Suwon185	*c*	*c*	*f*	*d*	*d*	*ab*
Gobunmil	Eunpamil/Tapdongmil//Eunpamil/Shannung6521	*c*	*c*	*a*	*d*	*d*	*ab*
Joeunmil	Eunpamil/Suwon242	*c*	*f*	*f*	*e*	*h*	*ab*
Jopoommil	SW88416-B-0/SW89277	*c*	*f*	*f*	*d*	*i*	*ab*
Keumkangmil	Geuru'S'/Kanto75//Eunpamil	*b*	*b*	*d*	*c*	*h*	*ab*
Olgeurumil	Geuru'S'/Chokwang//Seohae143	*b*	*b*	*f*	*d*	*d*	*ab*
Seodunmil	Geurumil/Genaro81	*b*	*b*	*f*	*d*	*d*	*c*
Tapdongmil	Chukoku81//Shinkwang/Toropi	*b*	*b*	*d*	*d*	*d*	*ab*
Urimil	Geurumil/Olmil	*c*	*b*	*f*	*d*	*d*	*c*
CIMMYT line							
14SAWYT-MXI-01	FRTL/CMH83.2517	*b*	*i*	*d*	*d*	*h*	*ab*
14SAWYT-MXI-02	Cham6/Attila//Pastor	*a*	*i*	*d*	*c*	*fg*	*ab*
14SAWYT-MXI-03	Attila/Pastor//Pastor	*a*	*i*	*d*	*c*	*fg*	*ab*
14SAWYT-MXI-04	SLV*2/Pastor	*a*	*i*	*d*	*c*	*fg*	*ab*
14SAWYT-MXI-05	Croci/Ae.squarrosa(224)//Opata/3/Pastor/4/Jaru	*b*	*i*	*d*	*c*	*h*	*ab*
14SAWYT-MXI-06	Chen/Ae.squarrosa(224)//Opata/3/Pastor	*a*	*b*	*d*	*c*	*d*	*ab*
14SAWYT-MXI-07	Attila/Babax//Pastor	*b*	*a*	*d*	*c*	*fg*	*ab*
14SAWYT-MXI-08	Altar84/Taus//OCI/3/VEE/MJI//2*TUI	*b*	*i*	*d*	*b*	*d*	*ab*
14SAWYT-MXI-09	Milan/Kauz//Prina/3/Babax	*b*	*c*	*d*	*c*	*h*	*ab*
14SAWYT-MXI-10	Pastor/3/PRL/Sara//TSI/VEE#5	*a*	*i*	*d*	*c*	*i*	*ab*

[a] Nomenclature of *Glu-1* according to Payne and Lawrence (1983) as shown in Fig 2-A.

[b] Nomenclature of *Glu-A3*, *Glu-B3* and *Glu-D3* according to Zhang *et al.* (2004), Wang *et al.* (2009) and Appelbee *et al.* (2009), respectively, as shown in Fig 2-B.

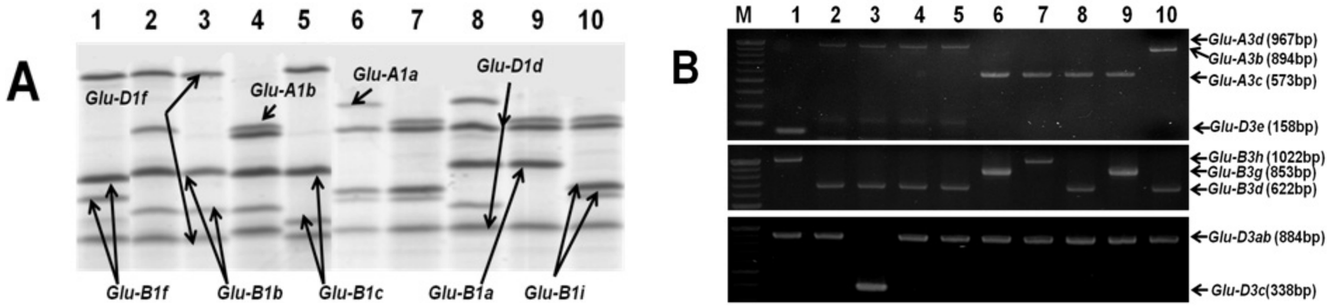

Fig. 2. SDS-PAGE patterns of *Glu-1* alleles (A) and agarose gel electrophoresis of *Glu-3* alleles (B) of Korean wheat cultivars and CIMMYT wheat lines. M indicates molecular size marker. 1, Joeunmil; 2, Olgeurumil; 3, Urimil; 4, Tapdongmil; 5, Eunpamil; 6, 14SAWYT-MXI-04; 7, 14SAWYT-MXI-05; 8, 14SAWYT-MXI-06; 9, 14SAWYT-MXI-07; 10, 14SAWYT-MXI-08.

bread loaf volume than that of other locations although wheat in Suwon had higher protein content than others.

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