Korean J. Crop Sci. 47(1): 13~20(2002)

Evaluation of Bread Baking Quality of Korean Winter Wheat over Years and Locations

Chul Soo Park*, Byung-Kee Baik, and Byung Hee Hong*†**

*Dept. of Agronomy, College of Natural Resources, Korea Univ., Seoul, 136-701, Korea
**Dept. of Food Science & Human Nutrition and IMPACT, Washington State Univ., WA, 99164, USA.

ABSTRACT : Bread baking parameters and relationships between bread baking properties and flour characteristics were evaluated for two years, 1997 and 1998, and at two locations, Suwon and Deokso, with Korean winter wheat cultivars and lines. Among the bread baking parameters, lightness of crumb grain showed differences between years. No significant differences were found in dough mixing time, bread loaf volume, crumb grain score or firmness. Keumkangmil, Suwon 278 and Tapdongmil showed higher bread loaf volume, good structure of crumb grain and softer crumb firmness. However, compared to commercial flours for baking, cultivar means averaged over years and locations of nineteen Korean winter wheats showed poor bread baking quality because of low protein content and unsuitable protein quality. Protein content and flour swelling volume showed better relationships with the bread baking parameters than other flour characteristics. Friabilin-absence lines showed softer crumb firmness than those of friabilin-presence lines.

Keywords : wheat, flour, bread baking, bread loaf volume, crumb firmness

The evaluation of bread baking quality is very important for determination of proper utilization of wheat flours. Accurate evaluation of bread baking quality in breeding programs is based on the relationship among wheat flour properties. An optimized, straight-dough, bread baking method was summarized by Finney (1984). Good flour quality for bread baking should have high water absorption, a medium to medium-long mixing time, satisfactory mixing tolerance, good loaf volume, and good internal crumb grain and color (Finney *et al.*, 1987).

Proteins enable the leavened bread dough to rise by forming a structure of minute cells during fermentation and are used as indices for the evaluation of bread baking. Proteins have been known as a primary factor for bread baking because of protein content and quality effects on mixing properties, such as mixing water absorption, mixing time and tolerance, and baking properties, such as baking water absorption, bread loaf volume and crumb grain and color.

Bread loaf volume generally increases with increasing protein content and also is influenced by both the content and quality of protein (Finney and Barmore, 1948). Good bread loaf volume has been invariably accompanied by more satisfactory crumb grain and somewhat whiter or less creamy crumb color than poor loaf volume of bread (Finney *et al.*, 1987). The sedimentation test is used for estimating potential evaluation of protein quality and quantity with a small sample of wheat. The sodium dodecyl sulfate (SDS) sedimentation test is a simple, rapid and practical test developed by Axford *et al.* (1979). The SDS sedimentation test is more convenient to use and gives a better correlation with loaf volume of bread than the Pelshenke and Zeleny-sedimentation test (Axford *et al.*, 1979).

Crumb firmness is influenced by interactions among swollen starch granules, partial solubilization of starch molecules and protein during the baking (Maleki *et al.*, 1980). He and Hoseney (1991) reported that poor loaf volume of bread had harder crumb firmness than good loaf volume because poor loaf volume of bread had more hydrophilic properties and more interaction with starch granules in the dough, and then these interactions were also stronger during and after baking. Martin *et al.* (1991) proposed that bread firming resulted in the interactions between glutens (continuous phase) and remnants of starch granules (discontinuous phase) during baking.

Johnson *et al.* (1972) found that environmental effects influenced baking parameters except for mixing time. Miezan *et al.* (1977) reported that some wheat lines with high protein were more influenced by genotype than by environment or by interactions of genotype and environment. The magnitude of genotype environment interactions was found to be of similar magnitude to genotypic effects for mixing tolerance and kernel hardness, but smaller for flour protein content, mixing time and SDS-sedimentation value (Peterson *et al.*, 1992). Protein content and the gliadin and nongluten fractions of protein were more influenced by environment than by genotype, but the glutenin fraction of protein was found to be nearly totally genotype dependent and this fraction was found to be significantly related to loaf grain

†Corresponding author: (Phone) +82-2-3290-3001 (E-mail) byhong@korea.ac.kr <Received May 23, 2001>

properties (Graybosch *et al.*, 1996). Both genotype and environment effects were related to the qualitative protein distribution of loaf volume in hard red winter wheats (Heubner *et al.*, 1997).

High grain yield and early maturation are the major consideration in Korean wheat breeding programs. Recently, importance of end-use quality of wheat has become important and development of screening methods suitable to accurate prediction of flour quality has been received more attention by wheat breeders than ever. Although consumption of breads has consistently increased in Korea, there is little information about bread baking quality of Korean wheats. The purposes of this study were to understand relationships among flour characteristics and bread baking parameters of Korean winter wheats and to determine criteria for selection for high bread baking quality in Korean wheat breeding programs.

MATERIALS AND METHODS

Materials

A set of Korean winter wheat cultivars and lines were harvested at Suwon (Upland Crop Experimental Farm of National Crop Experiment Station) in 1997 and another set of materials was produced at Suwon (Upland Crop Experimental Farm of National Crop Experimental Station) and Deokso (Korea University Research Farm) in 1998.

Those two sets of wheat samples were milled with a Bühler experimental mill with 65% flour extraction. Two flours, cvs ID377S and Penawawa, and three standard wheat flours, Japanese and Chinese noodle flours and hard red spring wheat flour for baking (JPN, CHN and HRS, respectively) were obtained from Western Wheat Quality Laboratory (WWQL), Washington State University, Pullman, U.S.A. Three Korean commercial wheat flours (COM1 is suitable for bread in Korea and COM2 and 3 are used for noodles and cookies), obtained from Daehan Flour Mills Co. Ltd., Korea were also included in sample analyses as a reference. ID377S and Penawawa have been used as udon flours due to good protein and starch quality.

Bread baking

The bread baking procedures were followed according to the straight-dough methods described by Finney (1984) and AACC approved methods 10-10A (AACC 1983) with some modifications. The ingredients of the baking formula 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°C). After a check of diastatic activity with falling number, the barley malt was added only if the flour falling number was over 300 SN. The falling number was measured by the procedure described by Bason *et al.* (1995) using a Rapid Visco Analyser (RVA)-3 (Newport Scientific Pty. Ltd., Warriewood, Australia). The optimum water absorption and mixing time were determined by the feel and appearance of the dough during mixing. The dough was fermented in a cabinet at 30°C and 85% relative humidity for 70 min with two punches and a proof period of 60 min, and then baked at 210°C for 18 min.

After the bread was taken out of the oven, the loaf volume was measured immediately by rape seed displacement and weighted. After cooling for two hr at room temperature, the bread was mechanically sliced to about 12.5 mm thick and put into a plastic bag for 1 day. Crumb grain score was evaluated on a six-point scale of 0 to 5, in which 0 and 5 indicate unsatisfactory and outstanding crumb grain, respectively. Lightness of crumb grain was measured by the Minolta CR-300 Spectrophotometer (Minolta Camera Co. Ltd., Osaka, Japan). Crumb firmness of bread was measured with a Texture Analyzer (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 a SMS P/35 probe (Ø35 mm/stainless steel) and a flatt 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.

Analytical methods

Data of protein content, SDS sedimentation volume, mixograph mixing time, swelling and pasting properties of starch and flours, high molecular weight glutenin subunits compositions and friabilin of Korean winter wheat cultivars and lines were obtained from our previous reports (Park *et al.*, 2001a; 2001b).

Statistical analysis

Data analysis were performed by the SAS Package (SAS, 1995) using analysis of variance (ANOVA), Fishers least significant difference procedure (LSD), and Pearson correlation coefficient.

RESULTS AND DISCUSSION

Bread baking

Bread baking properties of Korean winter wheat cultivars were measured with the samples grown at Suwon over two

Table 1. Characteristics of bread baking parameters over years and locations of Korean winter wheat cultivars and lines.

	Dough mixing time (sec.)	Bread loaf volume (ml)	Crumb		
			Grain Score	Lightness	Firmness (N)
Year					
1997	295.54	890.12	2.17	67.93	2.93
1998	296.96	890.60	2.24	68.17	2.90
LSD[†]	1.49	10.08	0.16	0.22	0.06
Location					
Suwon	317.50	888.86	2.19	68.46	2.71
Deokso	318.68	891.23	2.14	68.41	2.66
LSD	1.35	8.48	0.14	0.26	0.05
Cultivar/Line					
Alchanmil	244j[‡]	865g	2.0efg	65.67jk	3.68b
Chokwang	180o	843i	1.0i	65.46kl	2.97c
Eunpamil	396c	912c	1.9fg	69.34d	2.70d
Geurumil	231l	882f	1.8fgh	66.59i	2.29e
Gobunmil	352e	900d	2.6cd	69.37d	2.48e
Keumkangmil	388d	943b	3.0b	69.37d	2.07f
Olgeurumil	236k	897de	2.1efg	69.50d	2.96c
Tapdongmil	451b	942b	3.0b	68.81ef	2.30e
Urimil	192n	789j	1.5h	65.17l	4.53a
Suwon258	299g	887ef	2.0efg	72.05a	1.86g
Suwon261	333f	878f	2.0efg	68.52f	2.43e
Suwon265	329f	880f	2.3de	69.18de	2.37e
Suwon274	291h	899d	1.8gh	67.96g	3.61b
Suwon275	219m	853hi	2.0efg	68.60f	2.96c
Suwon276	273i	903cd	2.7bc	66.13ij	1.78g
Suwon277	191n	856gh	2.0efg	67.07h	3.15c
Suwon278	454b	1014a	3.6a	71.54b	2.38e
Suwon279	489a	902cd	2.2ef	68.71ef	1.78g
Suwon280	489a	857gh	2.0efg	70.48c	3.08c

[†]Least significant difference ($P = 0.05$).
[‡]Values followed by same letters are not significantly different at $P<0.05$.

years, 1997 and 1998; the samples harvested at two locations, Suwon and Deokso, in 1998 are summarized in Table 1. Dough mixing time ranged from 180 sec for Chokwang to 489 sec for Suwon 278 and Suwon 280. Bread loaf volume varied from 789 ml for Urimil to 1014 ml for Suwon 278. Crumb grain score ranged from 1.0 for Chokwang to 3.6 for Suwon 278. Lightness of crumb grain ranged from 65.17 for Urimil to 72.05 for Suwon 258. Crumb firmness ranged from 1.78 N for Suwon 276 and Suwon 279 to 4.53 N for Urimil. The flours from 1998 showed significantly higher lightness values than those of 1997. No significant differences were found among cultivars over locations. No significant differences between cultivars over years and locations for dough mixing time, bread loaf volume, crumb grain score or crumb firmness were found.

Environment had very significant effects on baking parameters (Johnson *et al.*, 1972). Many studies have shown that environment, genotype and their interactions influenced protein content in soft and hard wheats, and these results also might affect baking parameters and end-use properties (Baenzinger *et al.*, 1985; Pomeranz and Mattern 1988; Basset *et al.*, 1989; Peterson *et al.*, 1998). Peterson *et al.* (1992) reported that genotype, environment and interaction effects were found to significantly influence variation in all quality parameters. Some bread baking parameters of Korean winter wheat cultivars and lines showed differences between locations and years. Dough mixing time, bread loaf volume, crumb grain score and crumb firmness showed no differences between locations and years.

Means of the baking parameters of flour samples obtained from WWQL and Korean commercial wheat flours are summarized in Table 2. Dough mixing time ranged from

Table 2. Characteristics of bread baking parameters of flour obtained from Western Wheat Quality Lab and Korean commercial flours.

Sample†	Dough mixing time (sec.)	Bread loaf volume (ml)	Crumb		
			Grain Score	Lightness	Firmness (N)
JPN	215	853	3.6	66.24	4.39
CHN	485	865	3.3	70.71	2.55
HRS	517	1073	5.0	71.51	1.31
Penawawa	267	806	3.3	69.10	5.30
ID377S	252	790	3.3	65.39	2.93
COM1	510	1046	5.0	69.70	1.55
COM2	300	833	2.0	68.03	4.25
COM3	210	731	2.0	69.76	5.97
LSD‡	8.87	39.09	0.71	0.74	0.17

†JPN=Japanese Noodle Flour, CHN=Chinese Noodle Flour, HRS=Hard Red Spring Wheat standard Flours for Baking, COM1=Korean Commercial Flour for Bread, COM2=Korean Commercial Flour for Noodles, COM1=Korean Commercial Flour for Cookies.
‡Least significant difference (P=0.05). Differences between two means exceeding this value are significant.

210 sec for COM3 to 517 sec for HRS. Crumb grain score ranged from 2.0 to 5.0. Lightness of crumb grain ranged from 66.24 to 71.51. Crumb firmness ranged from 1.31 N for HRS to 5.97 N for COM3. Fig. 1 shows the appearance of bread and crumb. Commercial flours for bread, HRS and COM1, showed better appearance than other flours. Compared to HRS and COM1, Korean winter wheat cultivars showed lower bread loaf volume and unsuitable structure of crumb grain. Among Korean wheats, Keumkangmil, Suwon 278 and Tapdongmil showed higher bread loaf volume, good structure of crumb grain and softer crumb firmness than others. The low protein content and improper protein quality of Korean winter wheats might have resulted in the inadequate bread loaf volume and crumb grain score.

Relationships between bread baking parameter and flour characteristics

Fig. 2 shows the relationships between cultivar means over years and locations of bread baking parameters. Bread loaf volume of the nineteen Korean winter wheat cultivars and lines were highly correlated with crumb grain score ($r = 0.782$, $P<0.01$) and crumb firmness ($r = -0.580$, $P<0.01$). There were positively significant correlations between crumb grain score and dough proof height ($r = 0.599$, $P<0.01$). Lightness of crumb grain was negatively correlated with crumb firmness ($r = -0.579$, $P<0.01$). Finney *et al.* (1987) reviewed that good loaf volumes usually were accompanied by somewhat whiter or less creamy crumb colors than those that accompany poor loaf volumes, other factors being equal, because cell walls were less dense in loaves with good loaf volumes. With the increase of bread loaf volume, Korean winter wheat cultivar and lines had increased dough mixing time, crumb grain score and lightness, but decreased crumb firmness.

Martin *et al.* (1991) proposed a model in which bread firming resulted from cross-link (hydrogen bonds) between the continuous protein matrix and the discontinuous remnants of starch granules and suggested that the lesser degree of starch swelling during baking correlated with less firming granules of bread crumb. Inagaki and Sieb (1992) reported that prime wheat starch showed lower swelling power compared to starch of cross-linked waxy barley starches, and showed that the more highly swollen the starch in the bread crumb, the higher the rate of crumb firming. Korean winter wheat cultivars showed softer crumb firmness than WWQL flours and Korean commercial flours, except for HRS and COM1. The adequate crumb firmness could have been obtained from the decreased level of hydrogen bonding between starch granule remnants and gluten matrix.

Protein content showed significantly positive correlations with dough mixing time ($r = 0.635$, $P<0.01$), bread loaf volume ($r = 0.530$, $P<0.01$), crumb grain score ($r = 0.406$, $P<0.01$) and lightness of crumb grain ($r = 0.362$, $P<0.01$). Protein content exhibited negative correlations with crumb firmness ($r = -0.574$, $P<0.01$) (Fig. 3). SDS-sedimentation volume showed positive correlations with bread loaf volume ($r = 0.349$, $P<0.05$) and crumb grain score ($r = 0.446$, $P<0.01$). Protein content and quality could influence on crumb firmness and these results also had effects on the relationships between crumb firmness and lightness of crumb grain. Flour protein content and SDS sedimentation volume were more consistently correlated with quality variables than any of the protein fractions measured by SE-HPLC (Graybosch *et al.*, 1996). Flour protein content was found to be the primary factor contributing to variation in baking parameters in hard wheats (Graybosch *et al.*, 1993). Protein and bread loaf vol-

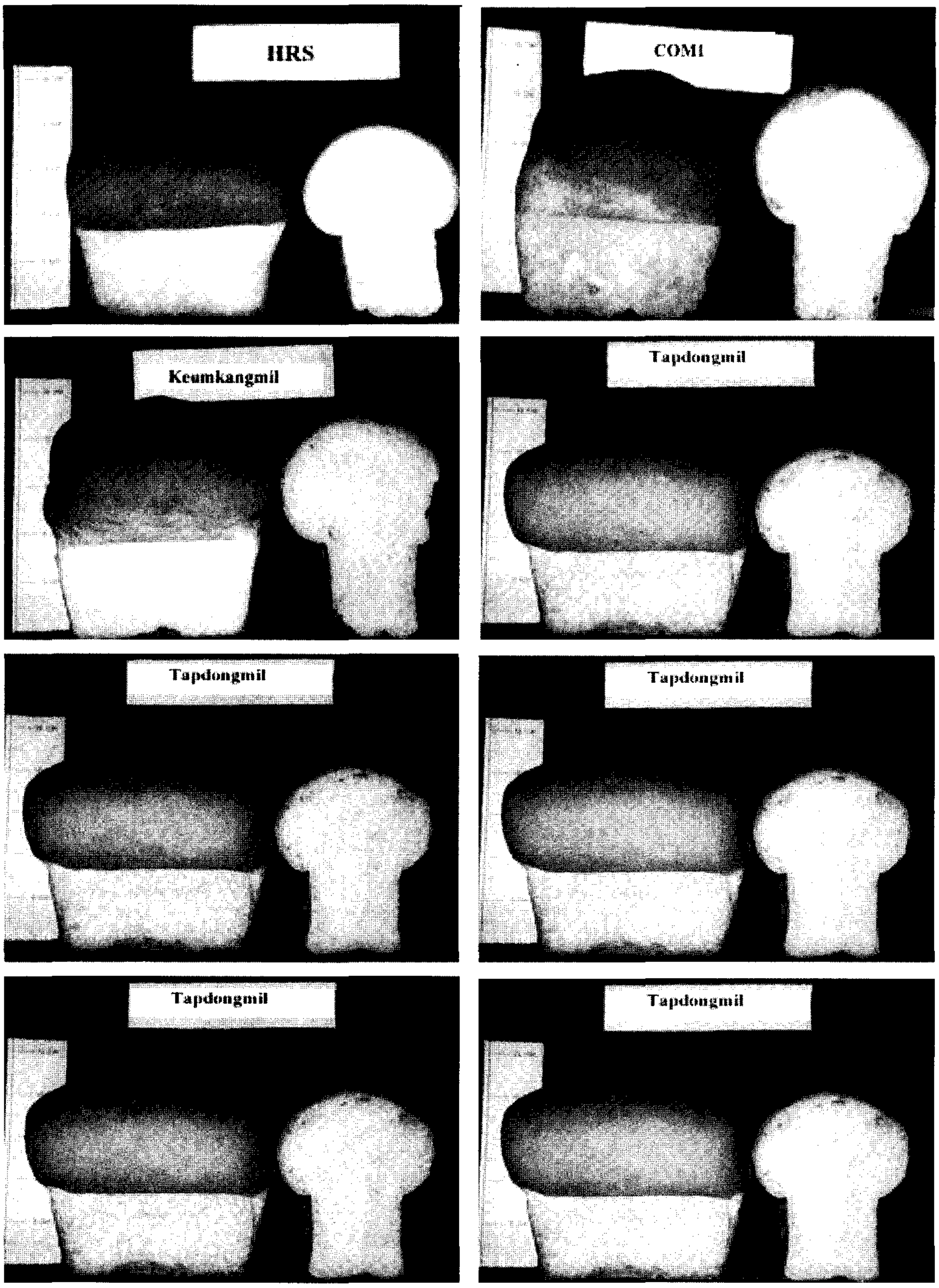

Fig. 1. The comparison of bread loaf volume and crumb grain of Korean winter wheat cultivars and lines. HRS. Hard Red Spring Wheat Standard Flours for Baking; COM1, Korean Commercial Flours for Bread.

ume were the most useful variables in small-scale procedures (Graybosch *et al.*, 1999). Flour protein content showed better and more correlated with a higher number of baking parameters than any other measurement. SDS sedimentation volume also correlated with baking parameters. Protein content and quality should be considered in the evaluation of suitability of flours related to bread baking quality in Korean wheat breeding programs.

Swelling and pasting properties of starch and flour showed negative correlations with baking parameters, except for crumb firmness. Flour swelling volume of the nineteen Korean winter wheat cultivars correlated with bread loaf volume ($r = -0.518$, $P<0.05$), crumb grain score ($r = 0.508$, $P<0.05$) and crumb firmness ($r = 0.532$, $P<0.05$) (Fig.

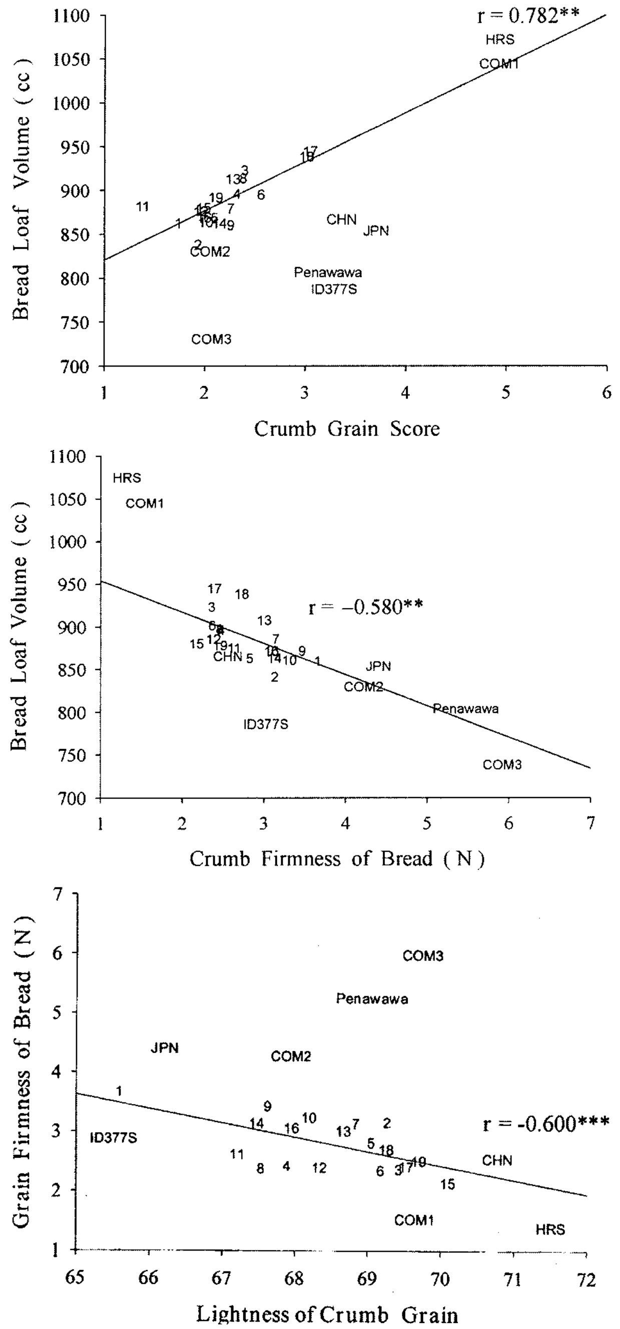

Fig. 2. The relationships between cultivar means of protein content, bread loaf volume, crumb grain score, dough proof height, and crumb firmness. 1; Alchanmil, 2; Chokwang, 3; Eunpamil, 4; Geurumil, 5; Gobunmil, 6; Keumkangmil, 7; Olgeurumil, 8; Tapdongmil, 9; Urimil, 10; Suwon 258, 11; Suwon 261, 12; Suwon 265, 13; Suwon 274, 14; Suwon 275, 15; Suwon 276, 16; Suwon 277, 17; Suwon 278, 18; Suwon 279, 19; Suwon 280, JPN; Japanese Noodle Flour, CHN; Chinese Noodle Flour, HRS; Hard Red Spring Wheat Standard Flours for Baking, COM1; Korean Commercial Flour for Bread, COM2; Korean Commercial Flour for Noodles, COM3; Korean Commercial Flour for Cookies. r = Correlation Coefficients (n=19).

3). Flour swelling volume should be employed as a useful tool to indirectly characterize bread loaf volume and crumb firmness in selection of breeding lines for the improvement of bread baking qualities in Korean wheat breeding programs.

Fig. 4 shows the difference of crumb firmness according to the presence and absence of 1Dx2.2 + 1Dy12 subunits of HMW-GS and friabilin. No difference in bread loaf volume, crumb grain score and dough proof height between the presence and absence of 1Dx2.2 + 1Dy12 subunits of HMW-GS (2.2-presence and absence) and presence and absence of friabilin (friabilin-presence and friabilin-absence) was found. However, friabilin absence lines (2.63 N) showed softer crumb firmness than that of friabilin-presence lines (3.16 N); friabilin-absence lines showed higher protein content and sedimentation volumes than friabilin-presence lines. Therefore, friabilin could be used as a biochemical marker for the improvement of crumb firmness in Korean wheat breeding programs.

Improvement of protein content and quality should be also considered for better bread baking qualities with Korean winter wheats because Korean winter wheats had lower bread loaf volume, unsuitable crumb grain and harder crumb firmness than those of HRS and COM1. Flour protein content and quality which influence bread baking parameters and gliadins, as well as HMW-GS, could strongly influence bread baking properties. 1Dx5 + 1Dy10 subunits of HMW-GS are positively correlated with good bread baking quality in different sets of wheat genotypes (Payne *et al.*, 1983; Lawrence *et al.*, 1988; Ng and Bushuk, 1988; Dong *et al.*, 1991, 1992). Flour protein content and glutenin (Glu-1) scores were closely related to loaf volume and flour protein was closely related to loaf volume (Preston *et al.*, 1992). He and Hoseney (1991) reported that dough from poor-quality flour produced low loaf volumes because dough released more carbon dioxide and the higher protein solubility of heated gluten during fermentation and the early stages of baking. They also reported that these poor quality glutens interacted strongly with starch granules in dough and were stronger in baking; consequently, poor quality gluten showed harder firmness than good quality gluten. Protein content and kernel hardness were best suited to be used as classification tools for differentiating hard red spring wheats and hard red winter wheat (Slaughter *et al.*, 1992). Both genetics and environment affect the relationship of quantitative protein distribution to loaf volume (Heubner *et al.*, 1997). Bushuk (1998) proposed that protein content was weakly heritable and strongly dependent on environmental factors, and that each end-use requires a specific quality in the protein. He also suggested that 1Dx5 + 1Dy10 subunits of HMW-GS are successful markers for bread baking qual-

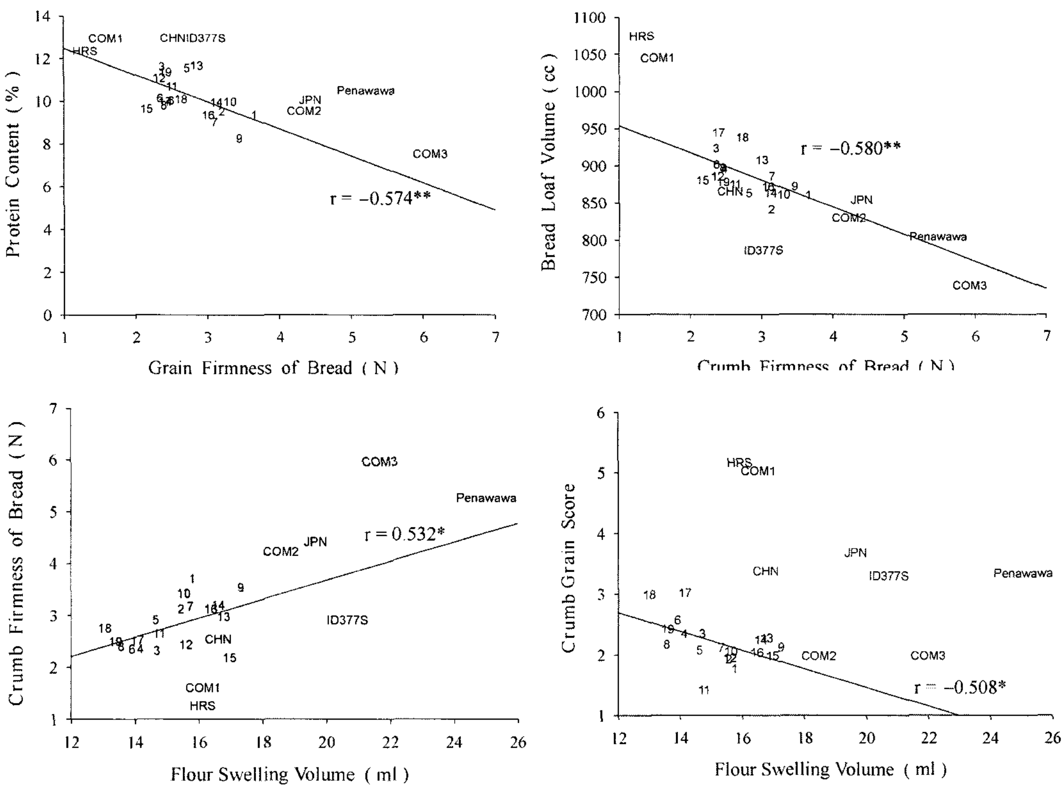

Fig. 3. The relationships between cultivar means of bread loaf volume, crumb grain score, crumb firmness of bread and flour swelling volume and pasting properties. 1; Alchanmil, 2; Chokwang, 3; Eunpamil, 4; Geurumil, 5; Gobunmil, 6; Keumkangmil, 7; Olgeurumil, 8; Tapdongmil, 9; Urimil, 10; Suwon 258, 11; Suwon 261, 12; Suwon 265, 13; Suwon 274, 14; Suwon 275, 15; Suwon 276, 16; Suwon 277, 17; Suwon 278, 18; Suwon 279, 19; Suwon 280, JPN; Japanese Noodle Flour, CHN; Chinese Noodle Flour, HRS; Hard Red Spring Wheat Standard Flours for Baking, COM1; Korean Commercial Flour for Bread, COM2; Korean Commercial Flour for Noodles, COM3; Korean Commercial Flour for Cookies. r=Correlation Coefficients (n=19).

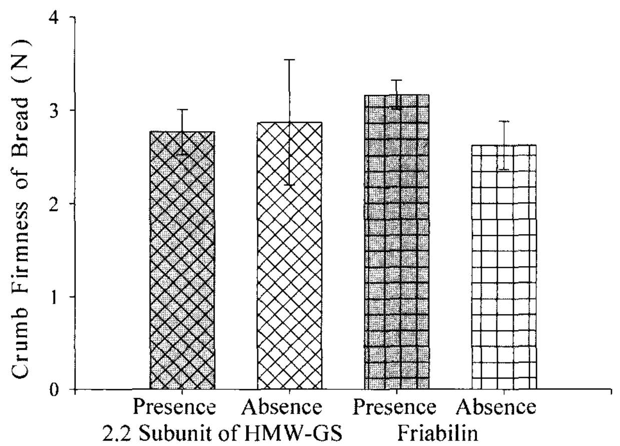

Fig. 4. The difference of crumb firmness of bread according to the presence or absence of 1Dx2.2 + 1Dy12 subunit of high molecular weight glutenin subunit (2.2 subunit of HMW-GS) and friabilin in Korean wheats.

ity of hard common wheats.

In this study, Korean winter wheats showed lower bread loaf volume and unsuitable crumb grain structure and harder crumb firmness than those of commercial flours for bread (HRS and COM1). There was significant correlation between baking parameters and protein content. Flour swelling volume had better relationship with bread loaf volume and crumb firmness than other starch swelling and pasting properties. Friabilin-absence lines showed softer crumb firmness than friabilin-presence lines, but crumb firmness of friabilin-absence lines had harder firmness values compared with HRS and COM1. The introduction of 1Dx5+1Dy10 subunits of HMW-GS and the increase of the flour protein content should be highly considered for the improvement of bread baking qualities in Korea.

ACKNOWLEDGMENTS

We sincerely thank our colleagues at the Wheat and Barley Division, National Crop Experiment Station for providing materials for experiments.

This work was supported by grant No. (97-0402-01-01-3) from the basic research program of the Korea Science & Engineering Foundation.

REFERENCES

AACC (American Association of Cereal Chemists). 1983. Method 10-10A, approved January 1983. The Association. : St. Paul MN.

Axford, D. W. E., E. E., McDermott, and D. G. Redman. 1979. Note on the sodium dodecyl sulfate test of breadmaking quality: Comparison with Pelshenke and Zeleny tests. *Cereal Chem.* 56 : 582-584.

Baenzinger, P. S., R. L. Clements, M. S. McIntosh, W. T. Yamazaki, T. M. Starling, D. J. Sammons, and J. W. Johnson. 1985. Effect of cultivar, environment, and their interaction and stability analyses on milling and baking quality of soft red winter wheat. *Crop Sci.* 25 : 5-8.

Baker, A. E., C. E. Walker, and K. Kemp. 1988. An optimum compression depth for measuring bread crumb firmness. *Cereal Chem.* 65 : 302-307.

Bason, M. L., W. Sing, and R. I. Booth. 1995. Comparison of stirring number and falling number tests for detecting sprout damage in wheat during harvest. Pages 357-361. Proc. 44th Cereal Chem. Conf. RACI, Melbourne, Australia.

Basset, L. M., R. E. Allan, G. L. Rubenthaler. 1989. Genotype environment interaction on soft wheat quality. *Agronomy J.* 81 : 955-960.

Bushuk, W. 1998. Wheat breeding for end-product use. *Euphytica.* 100 : 137-145.

Dong, H. S., T. S. Cox, R. G. Sears, and G. L. Lookhart. 1991. Effects of high molecular weight glutenin genes on quality in wheat. *Crop Sci.* 31 : 974-979.

Dong, H., R. G. Sears, T. S. Cox, R. C. Hoseney, G. L. Lookhart, and M. D. Shorgren. 1992. Relationships between protein composition and mixograph and loaf characteristics in wheat. *Cereal Chem.* 69 : 132-136.

Finney, K. F. 1984. An optimized, straight-dough, bread-making method after 44 years. *Cereal Chem.* 25 : 20-27.

Finney, K. F. and M. A. Barmore. 1948. Loaf volume and protein content of hard winter and spring wheats. *Cereal Chem.* 25 : 291-312.

Finney, K. F., W. T. Yamazaki, V. L. Moore, and G. L. Rubenthaler. 1987. Quality of hard, soft, and durum wheats. Pages 677-748: in E. G. Heyne ed. Wheat and wheat improvement. ASA, Inc., CSSA, Inc., SSSA, Inc.: Madison, WI.

Graybosch, R. A., C. J. Peterson, D. R. Shelton, and P. S. Baenzinger. 1996. Genotypic and environmental modification of wheat flour protein composition in relation to end-use quality. *Crop Sci.* 36 : 296-300.

Graybosch, R. A., C. J. Peterson, G. A. Hareland, D. R. Shelton, M. C. Olewnik, H. He, and M. M. Stearn. 1999. Relationships between small-scale wheat quality assays and commercial test bakes. *Cereal Chem.* 76 : 428-433.

Graybosch, R. A., C. J. Peterson, K. J. Moore, M. M. Stearn, and D. L. Grant. 1993. Comparative effects of wheat flour protein, lipid, and pentosan composition in relation to baking and milling quality. *Cereal Chem.* 70 : 95-101

He, H. and R. C. Hoseney. 1991. Difference in gas retention, protein solubility, and rheological properties between different baking quality flours. *Cereal Chem.* 68 : 526-530.

Heubner, F. R., T. C. Nelsen, O. K. Chung, and J. A. Bietz. 1997. Protein distribution among hard red winter wheat varieties as related to environment and baking quality. *Cereal Chem.* 74 : 123-128.

Inagaki, T. and P. A. Sieb. 1992. Firming of bread crumb with cross-linked waxy barley starch substituted for wheat starch. *Cereal Chem.* 69 : 321-325.

Johnson, J. A., M. N. A. Khan, and C. R. S. Sanchez. 1972. Wheat cultivars, environment and bread-making quality. *Cereal Science Today* 17 : 323-326.

Lawrence, G. J., F. Macritchie, and C. W. Wigley. 1988. Dough and baking quality of wheat lines deficient in glutenin subunits controlled by Glu-A1, Glu-B1 and Glu-D1 loci. *J. Cereal Sci.* 7 : 109-112.

Maleki, M., R. C. Hoseney, and P. J. Mattern. 1980. Effects of loaf volume, moisture content, and protein quality on the softness and staling rate of bread. *Cereal Chem.* 57 : 138-140.

Martin, M. L., K. J. Zelenak, and R. C. Hoseney. 1991. A mechanism of bread firming. I. Role of starch swelling. *Cereal Chem.* 68 : 498-503.

Miezan, K., E. G. Heyne, and K. F. Finney. 1977. Genetic and environmental effects on grain protein content in wheat. *Crop Sci.* 17 : 591-593.

Ng, P. K., and W. Bushuk. 1988. Statistical relationships between high molecular weight subunits of glutenin and breadmaking quality of Canadian-grown wheats. *Cereal Chem.* 65 : 408-413.

Park, C. S., B.-K. Baik, and B. H. Hong. 2001a. Evaluation of quality properties of Korean wheats with biochemical markers and quality parameters with small samples. *Korean J. Crop Sci. Accepted.*

Park, C. S., B.-K. Baik, and B. H. Hong. 2001b. Characteristics of flour related to end-use quality of Korean winter wheat over years and locations. Korean J. Crop Sci. *Accepted.*

Payne, P. I., L. M. Holt, R. D. Tompson, D. Bartels, N. P. Harbed, P. A. Haris, and C. N. Law. 1983. The high-molecular-weight subunits of glutenin: Classical genetics, molecular genetics and the relationship to bread-making quality. In: Proceedings of the 6th International Wheat Genetics Symposium. pp. 827-834.

Peterson, C. J., R. A. Graybosch, D. R. Shelton, and P. S. Baenzinger. 1998. Baking quality of hard winter wheat: Response of cultivars to environment in the Great Plains. *Euphytica.* 100 : 157-162.

Peterson, C. J., R. A. Graybosch, P. S. Baenzinger, and A. W. Grombacher. 1992. Genotype and environment effects on quality characteristics of hard red winter wheat. *Crop Sci.* 32 : 98-103.

Pomeranz, Y., and P. J. Mattern. 1988. Genotype and genotype environmental interaction effects on hardness estimates in winter wheats. *Cereal Foods World* 33 : 371-374.

Preston, K. R., O. M. Lukow, and B. Morgan. 1992. Analysis of relationships between flour quality properties and protein fractions in a world wheat collection. *Cereal Chem.* 69 : 560-567.

SAS. 1995. SAS Users Guide. The Institute: Cary, NC.

Slaughter, D. C., K. H., Norris, and W. R. Hruschka. 1992. Quality and classification of hard red wheat. *Cereal Chem.* 69 : 428-432.