Korean J. Crop Sci. 47(1): 1~12(2002)

Genotypic and Environmental Effects on Flour Properties in Korean Winter Wheat

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ABSTRACT : Flour characteristics of Korean winter wheat grown in Suwon in 1997 and 1998, and in Suwon and Deokso in 1998 were evaluated. Korean winter wheat cultivars were significantly influenced by years and locations in flour properties such as ash content, protein content, damaged starch content, starch swelling volume and power. Protein content was highly correlated with starch damage and alkaline water retention capacity. There were highly significant correlations between mixing time of mixograph and SDS sedimentation volume. Swelling properties of flour and starch were highly correlated with pasting properties of flour and starch, respectively. Compared to commercial flours for baking, Alchanmil, Gobunmil, Keumkangmil and Tapdongmil showed similar protein content, SDS sedimentation volume and mixograph mixing time. Eunpamil, Geurumil, Olgeurumil, Suwon 258, Suwon 261, Suwon 265, Suwon 275, Suwon 276, Suwon 277, Suwon 278 and Urimil had similar values to commercial noodle flours in SDS sedimentation volume. Alchanmil, Olgeurumil, Suwon 274, Suwon 275, Suwon 276 and Urimil showed higher swelling and pasting properties than the others. Chokwang, Olgeurumil, Suwon 277 and Urimil were similar to commercial cookie flours. Friabilin-absence lines showed higher protein content and starch damage than those of friabilin-presence lines. Absence lines of 1Dx2.2 + 1Dy12 subunit in high molecular weight glutenin subunits showed higher SDS sedimentation volume and mixing time of mixograph than those of presence lines.

Keywords: SDS-sedimentation volume, alkaline water retention capacity, damaged starch content, swelling and pasting properties

Diversity of end-use quality of wheat depends on the type of wheat produced and conventional uses. The identification of wheat flour characteristics should be seriously considered for production of desirable end-use quality. These characteristics are usually subject to the effects wheat genotype and growing environment. Therefore, an accurate evaluation and identification of wheat and flour properties is required for prediction of the end-use quality of wheat. Suitable screening tools including developed and improved test methods are also very important for the characterization of end-use quality of wheat breeding programs.

Many tests have been developed and used in the past to improve wheat quality. These include simple chemical, physical and physicochemical tests, physical dough testing equipment and techniques and baking methods and techniques (Finney *et al.*, 1987). Most physochemical and rheological methods for evaluation of wheat quality include moisture, protein, ash, amylose, damaged starch content and NIR hardness; SDS sdeimentation test and alkaline water retention capacity (AWRC); mixograph, alveograph and farinograph test; swelling and pasting test of starch and flour; and bread and cookie baking and noodle making.

The content and quality of flour protein have been used as indices for the evaluation of bread-making because proteins have an effect on mixing time, mixing tolerance, mixing and baking water absorption, loaf volume potential, and crumb grain and color of bread, which are highly correlated with the mixing properties and bread properties (Finney *et al.*, 1987). Protein content and quality of flours also influences the strength of raw noodles and the chewiness of cooked noodles and contributes to the textural quality of oriental noodles (Baik *et al.*, 1994a, 1994b). Cookie diameter has negative correlation to protein content of flour, and cookie quality is more affected by the content of the flour protein than the quality (Souza *et al.*, 1993).

The mixograph has been succesfully used in evaluation of hard wheat bread-making properties because mixograph can objectively determine the effects of quality and quantity of flour proteins (Finney and Shorgen, 1972). The sedimentation test has been used for estimating potential protein quality and quantity in wheat breeding programs. Sedimentation test also has been used for screening gluten strength of durum wheat and for prediction of noodle firmness and chewiness of Chinese style noodles (Baik *et al.*, 1994b). AWRC has been used as a powerful method for the evaluation of cookie baking quality in soft winter wheat and highly significant correlations have been obtained between AWRC and cookie diameter (Yamazaki, 1953). Bassett *et al.* (1989)

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<Received May 23, 2001>

reported that AWRC showed significant correlations with cookie diameter.

Swelling volume and power test (SSV and SSP), as a simple, fast and small-scale method to determine the swelling properties of flour and starch, were recently introduced for prediction of noodle quality (Crosbie, 1991; Konik *et al.*, 1993). Crosbie and Lambe (1993) introduced the flour swelling volume (FSV) test as method for prediction of noodle quality of sprouted wheat breeding lines. They also showed that FSV was highly correlated with the eating quality of cooked noodles. The rapid visco-analyser (RVA), which was developed for the detection of sprout damage, has been recently applied for measuring pasting properties as a screening method for noodle texture in wheat breeding programs. Panozzo and McCormick (1993) also reported that peak paste viscosity, measured by RVA, was highly correlated with eating quality of noodles.

Genotype, environment and their interactions on end-use qualities of wheat should be considered for the cultivar toward enhancing quality. In soft winter wheats, highly significant differences were detected among environments and genotypes for quality variables, and their interactions were highly significant (Baenzinger *et al.*, 1985; Bassett *et al.*, 1989; Schuler *et al.*, 1995). Milling properties and cookie and noodle making properties of soft wheats can be distinguished by genotypes, but the environment has been shown to have strong influence on grain condition, which had the most influence on milling characteristics and baking characteristics; a softer kernel produces better end-use properties (Gaines *et al.*, 1996). Growing conditions have strong influence on wheat starch characteristics (Lin and Czuchajowska, 1996; Mathewson and Pomeranz, 1978; Meredith and Pomeranz, 1982; Morris *et al.*, 1997a; Shi *et al.*, 1994).

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 Korean wheat breeders than ever. Wheat breeders have mostly used screening methods suitable for prediction of flour characteristics because flour characteristics play an important role in end-use quality. Although the understanding of flour characteristics is very important to improve end-use quality of wheat, there is little information about flour characteristics related to end-use quality in Korean wheat. This study is aimed at the evaluation of flour characteristics of Korean wheat cultivars and experimental lines and the determination of year and location influence on flour characteristics for potential use in quality improvement in Korean wheat breeding programs.

MATERIALS AND METHODS

Materials

A set of Korean winter wheat cultivars and lines was 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. The seed was sown on October 5, 1996 and October 15, 1997 at Suwon and on October 16, 1997 at Deokso. Compared with annual climate conditions, the mean temperature of 1996 was similar to that of normal years but 1997 was higher than average. Average precipitation of 1996 was lower in the overwintering period, but higher in the grain filling stage. Average precipitation of 1997 was higher in the seedling and overwintering stages, but lower in the grain filling stage than average.

The two sets of wheat samples were milled with a Bühler experimental mill with 65% flour extraction. Five samples of flours and starches from ID377S, Klasic, Penawawa, Tres and Rely, and three standard wheat flours and starches, Japanese and Chinese noodle flours and hard red spring wheat flour for baking 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. In these flours, ID377S, Klasic and Penawawa have been used as udon flours due to good protein and starch quality. Tres and Rely have good cookie quality. Water-washed prime starch of Korean winter wheat cultivars and Korean commercial flours was isolated by AACC approved methods 38-10 (AACC, 1983).

Analytical methods

Protein content (N×5.7) was determined by boric acid modification of the micro-Kjeldahal method. Ash content was determined by AACC approved methods 08-01 (AACC, 1983). The SDS-sedimentation test was performed according to the procedure of Axford *et al.* (1979). AWRC was performed according to the procedure of Kitterman and Rubenthaler (1971). The determination of damaged starch content was followed according to the procedure described by Gibson *et al.* (1992) using an enzymatic assay kit (Mega-Zyme Pty., Ltd., North Rocks, Australia). Flour mixing characteristics were determined by 10-g mixograph (National Mfg., Lincoln, NE, U.S.A.), using AACC approved methods 54-40A (AACC, 1983).

Amylose content was determined as described by Morrison and Bernard (1983) with a primary starch. The primary starch was prepared as described by South and Morrison (1990). Swelling properties of starch and flour were followed as described by Crosbie (1991).

Data from electrophoresis patterns of high molecular weight-glutenin subunits (HMW-GS) and friabilin using single kernel were performed and adapted from our previous paper (Park *et al.*, 2001).

Pasting properties of starch and flour

Pasting properties of flour and starch were measured by RVA-3 using 4.0 g of flour and 3.0 g of starch suspended in 25.0 ml of water. The temperature profile of RVA was followed using the procedure described by Battey *et al.* (1997) with some modifications. The temperature profile is as follows: hold at 60°C for 2 min, heat to 95°C at 5.83°C/min over 6 min, hold at 95°C for 4 min, cool to 50°C at 11.25°C/min over 4 min, and hold at 50°C for 6 min for flour and 7 min for starch. Therefore, total analysis took 22 min for the flour sample and 23 min for the starch sample. The measured parameters of RVA were peak viscosity and breakdown. The viscosities of RVA were expressed in Rapid-Visco Analyser units (RVU).

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.

Table 1. Physicochemical properties of flour over years and locations from Korean winter wheat cultivars and lines[†].

	Ash (%)	Protein (%)	Amylose (%)	Damaged Starch (%)	AWRC (%)	SDSS (ml)	Mixograph	
							WA (%)	TM (sec)
Year 1997	0.46	10.17	29.45	3.52	70.26	69.45	59.45	212.68
1998	0.50	10.28	28.91	3.30	70.24	68.74	59.54	206.79
LSD[‡]	0.01	0.08	0.67	0.04	0.46	0.24	0.00	3.71
Location Suwon	0.49	10.37	28.91	3.65	71.44	67.44	59.74	193.82
Deokso	0.48	10.17	29.82	3.69	71.94	67.47	59.45	191.45
LSD	0.01	0.08	0.47	0.02	0.34	0.27	0.00	3.94
Cultivar/Line								
Alchanmil	0.48ed[§]	9.57gf	29.82ab	4.43bcd	73.77ed	87.42a	58.90fg	270a
Chokwang	0.53abc	9.72ef	29.50abcde	2.72ef	65.85k	44.92m	59.05ef	90h
Eunpamil	0.48ed	10.99bc	29.43abcde	4.69b	76.28bc	71.84e	60.20bc	197cd
Geurumil	0.50cd	10.68cd	29.59abcd	4.27bcd	73.37def	63.25i	60.03cd	139g
Gobunmil	0.47ed	11.54ab	30.05a	3.94d	74.07d	78.84b	60.73ab	240b
Keumkangmil	0.44ef	11.73a	29.51abcde	4.16bcd	69.95h	79.17b	60.85a	206cd
Olgeurumil	0.42f	10.15def	29.82ab	2.45efg	65.39k	72.67ed	59.40ef	195d
Tapdongmil	0.54ab	11.40ab	28.93cde	3.92d	72.52fg	76.42c	60.60ab	283a
Urimil	0.49cd	8.68h	28.90de	2.09g	67.11j	62.67i	58.10h	270a
Suwon258	0.47ed	10.35de	29.34abcde	2.84ef	72.75efg	61.00j	59.55de	169e
Suwon261	0.50bcd	10.20def	28.99cde	4.31bcd	75.58c	71.17ef	60.60ab	169e
Suwon265	0.46ed	9.92ef	28.81e	4.09cd	72.64fg	73.67d	59.23ef	180e
Suwon274	0.47ed	9.74ef	29.23bcde	2.91e	67.86ij	55.84k	59.00efg	150fg
Suwon275	0.55a	9.06gh	28.15f	2.32fg	68.45i	60.84j	58.48gh	210c
Suwon276	0.47ed	10.19def	29.66abc	2.62efg	70.68h	65.50h	59.40ef	139g
Suwon277	0.48ed	9.59gf	29.08cde	2.45efg	65.18k	67.75g	58.88fg	236b
Suwon278	0.50bcd	10.00ef	29.46abcde	4.34bcd	72.20g	69.92f	59.20ef	242b
Suwon279	0.48ed	11.85a	29.11bcde	4.63bc	80.54a	54.17l	60.95a	154f
Suwon280	0.49cd	10.25def	28.98cde	5.73a	76.92b	66.83gh	59.45ef	150fg

[†] AWRC= alkaline water retention capacity; SDSS = SDS sedimentation volume; WA = water absorption; TM = mixing time.

[‡] Least significant difference ($P = 0.05$).

[§] Values followed by same letters are not significantly different at $P < 0.05$.

RESULTS AND DISCUSSION

Physicochemical properties

Physicochemical properties of Korean winter wheat cultivars and lines were measured for the flour grown at Suwon for two years, 1997 and 1998, and the samples harvested at two locations, Suwon and Deokso, grown in 1998, and are summarized in Table 1. Means of the flour characteristics of eight flours obtained from Western Wheat Quality Laboratory (WWQL) and three Korean commercial flours are summarized in Table 2. Ash content for cultivars and lines over years and locations ranged from 0.42% to 0.55%. Protein content for cultivars and lines over years and locations varied greatly from 8.68% to 11.85%. The flours harvested in 1998 showed significantly higher ash and protein content than those of 1997, and wheats harvested at Suwon significantly higher than those from Deokso. Compared to flours obtained from WWQL and Korean commercial flours, protein content of Korean winter wheat cultivars and lines showed similar content to that of Korean commercial flours for noodles (COM2) and Japanese noodle flours (JPN). Eunpamil, Gobunmil, Keumkangmil, Suwon 279 and Tapdongmil showed higher protein content than other Korean flours. Ash content of wheat flours is related to the amount of barn in wheat and small or shriveled kernels have more bran on percentage basis in flour yield. Protein content of wheat flour depends in part on variety and class and on environmental conditions during wheat development (Halverson and Zeleny, 1988). Growing conditions, including years and locations, had influence on ash and protein content in this study.

Amylose content ranged from 28.15% to 30.05%. The flours harvested at Deokso showed significantly higher amylose content than those from Suwon, but there were no significant differences between cultivars and lines over years. Korean winter wheats showed higher amylose content compared with JPN. In our previous study, amylose content showed no significant differences among cultivars and lines and Korean winter wheats contained all three granule-bound starch synthase (GBSS) encoded by *Wx* loci, except for Suwon 252 (Park *et al.*, 2001). Growing conditions had not nfluence on amylose content because of narrow genetic variation in GBSS.

Damaged starch content over years and locations ranged from 2.09% to 5.73%. Damaged starch content of flour produced in 1997 and at Deokso showed significantly higher values than those of 1998 and Suwon. Evers and Stevens (1985) stated that starch damge is produced during milling process and it is consequence of miiling and the level of damaged starch content directly affects water absorption and hydrolytic enzymes activity of flours. Both rheological properties of flour dough and end-use quality are greatly influenced by the amount of damaged starch in flour. Damaged starch content is consistently lower in soft wheat flour than in hard wheat flour. High starch damage is detrimental to soft wheat products, especially in cookies and cakes (Evera and Stevens, 1985). Alchanmil, Eunpamil, Geurumil, Gobunmil, Keumkangmil, Suwon 265, Suwon 278, Suwon 279, Suwon 280 and Tapdongmil had higher damaged starch content than other Korean wheat flours. These flours also had no friabilin (Park *et al.*, 2001) and showed

Table 2. Physicochemical properties of flour obtained from Western Wheat Quality Lab and Korean commercial flours[†].

Sample	Ash (%)	Protein (%)	Amylose (%)	Damaged Starch (%)	AWRC (%)	SDSS (ml)	Mixograph	
							WA (%)	TM (sec)
JPN[‡]	0.46	10.17	26.49	5.00	71.00	64.00	59.40	210
CHN	0.40	13.12	-	7.06	88.89	72.00	62.20	240
HRS	0.46	12.50	-	4.61	81.40	81.00	61.60	240
Penawawa	0.52	10.70	23.36	1.71	68.82	80.67	59.90	270
ID377S	0.49	13.10	27.46	6.08	77.44	70.67	62.20	210
Tres	0.46	10.73	27.37	3.50	69.23	51.67	59.90	75
Rely	0.46	9.73	29.34	3.43	66.33	45.67	59.00	90
Klasic	0.43	14.08	19.23	4.46	80.89	86.67	63.10	390
COM1	0.43	13.08	28.19	6.08	81.15	78.00	62.20	240
COM2	0.43	9.82	28.19	5.54	74.24	65.33	59.10	210
COM3	0.43	7.73	27.13	3.23	65.69	52.33	57.10	100
LSD[§]	0.04	0.41	2.37	0.18	1.36	0.70	0.01	0.01

[†] AWRC=alkaline water retention capacity; SDSS=SDS sedimentation volume; WA=water absorption; TM=mixing time.

[‡] 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.

[§] Least significant difference ($P = 0.05$).

higher protein content than other flours. These flours with high protein content and damaged starch content and harder texture cannot be suitable for baking cookie or cakes.

AWRC over years and locations ranged from 65.18% to 80.54%. SDS-sedimentation volume ranged from 44.92 ml to 87.42 ml. Although both years and locations had influenced on protein content, AWRC and SDS sedimentation were influenced by locations or years. AWRC and SDS sedimentation volume are influenced by both protein content and quality. The means for AWRC obtained from WWQL and Korean commercial flours ranged from 65.69% for COM3 to 88.89% for CHN. SDS-sedimentation volume of Rely was significantly lower than other flours and Klasic showed significantly higher volume than others. Alchanmil, Gobunmil, Keumkangmil and Tapdongmil showed higher SDS-sedimentation volume than other Korean wheat flours and had similar values compared with HRS and COM1. Eunpamil, Geurumil, Olgeurumil, Suwon 258, Suwon 261, Suwon 265, Suwon 275, Suwon 276, Suwon 277, Suwon 278 and Urimil had similar values to commercial noodle flours (JPN, CHN and COM2) in SDS-sedimentation volume. The AWRC of Chokwang, Olgeurumil, Suwon 277 and Urimil was similar to commercial cookie flours (COM3).

Flours produced in 1998 and at Suwon showed higher water absorption of mixograph than those from 1997 and Deokso, respectively because the amount of water in mixograph is usually determined by protein content. The mean ranges of cultivars and lines over years and locations were 57.95%~61.05%. Chokwang (90 sec) and Tapdongmil (283 sec) showed lowest and highest mixing time over years and locations. Mixogram data is usually used to differentiate flour quality for bread making, which is desirable if it is higher in water absorption, medium and medium-long mix-

Table 3. Swelling and pasting properties of starch and flour over years and locations of Korean winter wheat cultivars and lines.

	Swelling Properties			Pasting Properties			
	FSV (ml)	SSV (ml)	SSP (%)	FPV (RVU)	FBD (RVU)	SPV (RVU)	SBD (RVU)
Year 1997	15.70	23.18	12.65	281.36	119.29	195.89	68.32
1998	14.90	23.48	12.95	261.82	135.43	183.46	66.00
LSD[‡]	0.12	0.19	0.09	3.20	2.40	2.43	1.94
Location Suwon	14.86	23.48	12.90	267.24	136.26	185.29	67.45
Deokso	14.80	23.80	13.00	271.11	136.84	192.66	60.42
LSD	0.11	0.14	0.08	2.76	1.90	2.52	3.35
Cultivar/Line							
Alchanmil	15.27bcde[§]	23.40efg	12.54fg	281.25bcd	133.13cdef	185.88c	66.00abcd
Chokwang	15.64abcd	23.11fgh	12.95ef	248.13def	92.63h	194.88c	60.63cde
Eunpamil	14.42defg	24.30abc	14.35b	273.88cde	139.25bcd	218.13ab	74.63abc
Geurumil	13.39gh	22.63hi	13.42de	234.75fg	115.63efg	187.75c	77.38ab
Gobunmil	14.34efg	22.92ghi	12.93ef	274.00cde	136.38bcde	182.25c	68.25abcd
Keumkangmil	13.96fgh	22.86ghi	13.81cd	266.50cdef	122.63def	180.50c	66.38abcd
Olgeurumil	15.55bcde	24.33abc	15.50a	294.63bc	144.50bc	201.88bc	73.88abc
Tapdongmil	13.91fgh	24.78ab	14.01bc	236.88efg	138.88bcd	185.13c	61.13cde
Urimil	16.87a	23.46efg	11.25h	316.50ab	144.75bc	195.00c	60.63cde
Suwon258	16.01abc	24.23bcd	13.00ef	297.00bc	146.75bc	201.50bc	62.75bcd
Suwon261	14.87cdef	23.53defg	12.65fg	242.75ef	138.00bcd	185.75c	59.25cde
Suwon265	16.10abc	24.04cde	12.33g	298.00bc	142.13bcd	185.38c	60.00cde
Suwon274	16.36ab	24.04cde	11.67h	285.25bcd	136.13bcde	183.25c	60.75cde
Suwon275	16.19ab	23.37efg	10.67i	293.63bc	155.88ab	187.63c	60.38cde
Suwon276	16.24ab	25.00a	15.34a	345.75a	167.25a	224.75a	78.50a
Suwon277	15.67abc	23.82cdef	13.02ef	255.13def	133.13cdef	200.25bc	75.00abc
Suwon278	13.65fgh	22.28i	12.29g	205.25g	112.88fg	157.13d	60.00cde
Suwon279	12.93h	23.21fgh	10.63i	266.75cdef	129.00cdef	191.75c	46.50e
Suwon280	13.39gh	21.22j	12.25g	236.75efg	100.75gh	152.25d	58.00de

[†] FSV=flour swelling volume; SSV=starch swelling volume; SSP=starch swelling power; FPV=peak viscosity of flour; FBD=breakdown of flour; SPV=peak viscosity of starch; SBD=breakdown of starch.

[‡] Least significant difference (*P*=0.05).

[§] Values followed by same letters are not significantly different at $P < 0.05$.

ing time and satisfactory mixing tolerance (Finney *et al.*, 1987). Alchanmil, Gobunmil, Suwon 277, Suwon 278, Tapdongmil and Urimil showed similar values of mixing time compared with HRS and COM1. Considering protein content and SDS-sedimentation volume, Alchanmil, Gobunmil, Keumkangmil and Tapdongmil could be used for baking bread with good quality among Korean winter wheat cultivars and lines tested.

Swelling and pasting properties

Swelling and pasting properties of starch and flour of Korean winter wheat cultivars and lines are summarized in Table 3. Means of flours obtained from WWQL and three Korean commercial wheat flours are summarized in Table 4. Starch swelling volume (SSV) over years and locations ranged from 21.22 ml to 25.00 ml. Starch swelling power (SSP) ranged from 10.63% to 15.50%. Flour swelling volume (FSV) ranged from 12.93 ml to 16.87 ml. Uniquely, Korean winter wheat cultivars and lines in this study showed lower swelling properties than those of WWQL and commercial flours and starches due to high amylose content and narrow genetic variation of GBSS. Starch from wheats harvested in 1998 and at Deokso showed significantly higher SSV and SSP than those from 1997 and Suwon. Flours harvested in 1997 showed significantly higher FSV than those from 1998. No significant difference over locations was found. This result is consistent with the report by Morris *et al.* (1997a). They reported that FSV was highly and primarily influenced by cultivar and secondly by environment; especially, crop year has more effect than location within a crop year.

Pasting properties have long been measured by using the Brabender viscoamylograph, which requires about 40 g flour or starch and takes over two hours to obtain a completed pasting curve. The pasting properties of RVA have shown highly significant correlation with starch peak viscosity obtained by using the viscoamylograph (Panozzo and McCormick, 1993). Starch peak viscosity over years and locations ranged from 152.25 RVU to 224.75 RVU. Flour peak viscosity ranged from 205.25 RVU to 345.75 RVU. Penawawa and Rely showed higher and lower peak viscosity of starch and flour than others. Starches and flours from wheats harvested in 1997 showed significantly higher peak viscosity than those from 1998, and Deokso had significantly higher peak viscosity of starch and flour than that from Suwon. Breakdown of starch and flour are determined by the difference between peak viscosity and holding strength. Suwon 276 had higher breakdown of starch and flour (167.25 RVU and 78.50 RVU) than others. Flours from wheats harvested at Suwon and in 1997 showed significantly higher flour breakdown than that of Deokso and 1998, respectively. Meredith and Pomeranz (1982) reported that varietal and seasonal, but not locational affect on pasting of wheat flours and starches. But, pasting properties of starch and flour are influenced by both years in this study. Location effects in protein content and damaged starch content can influence on pasting properties of starch and flours.

Swelling and pasting properties of flours are generally related to qualities of cooked noodles. Flours with high

Table 4. Swelling and pasting properties of flour and starch obtained from Western Wheat Quality Lab and Korean commercial flours[†].

Sample	Swelling Properties			Pasting Properties			
	FSV (ml)	SSV (ml)	SSP (%)	FPV (RVU)	FBD (RVU)	SPV (RVU)	SBD (RVU)
JPN[‡]	19.71	27.42	16.23	301.00	160.00	221.50	62.00
CHN	16.61	-	-	293.00	131.00	-	-
HRS	16.13	-	-	236.00	107.50	-	-
Penawawa	25.09	28.76	15.49	335.50	156.50	246.50	63.50
ID377S	20.67	27.02	15.27	292.50	153.00	206.50	40.00
Tres	17.80	23.39	13.12	256.00	91.50	182.00	28.50
Rely	20.31	25.81	13.25	210.50	87.50	169.50	36.00
Klasic	20.19	24.86	15.92	325.00	167.50	211.50	56.00
COM1	16.13	22.04	11.43	218.50	83.00	181.00	51.00
COM2	18.52	23.52	15.64	271.00	130.00	200.50	53.00
COM3	21.86	26.34	17.63	215.50	81.50	169.50	47.00
LSD[§]	0.62	0.78	0.77	3.79	3.73	5.33	4.85

[†] FSV=flour swelling volume; SSV=starch swelling volume; SSP=starch swelling power; FPV=peak viscosity of flour; FBD=breakdown of flour; SPV=peak viscosity of starch; SBD=breakdown of starch.

[‡] 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.

[§] Least significant difference (P=0.05).

swelling volume, high peak viscosity and high breakdown have shown good texture qualities of cooked noodles. While starch properties generally have an effect on flour pasting properties and end-use qualities and play an important role in end-use properties, starch swelling and pasting properties have a disadvantage in the direct utilization in screening procedures for quality because starch preparations are laborious and time-consuming and starch pasting properties alone do not explain the variation of flour pasting properties. Alchanmil, Olgeurumil, Suwon 274, Suwon 275, Suwon 276 and Urimil showed the higher swelling and pasting properties than the others. Compared to commercial noodle flours (JPN, CHN and COM2), flour peak viscosity of Alchanmil, Olgeurumil, Suwon 259, Suwon 265, Suwon 274, Suwon 276 and Urimil was similar to JPN. Flour breakdown of these flours, except for Suwon 275, Suwon 276 and Urimil, showed similar values to CHN and COM2. These flours also showed similar starch peak viscosity compared to JPN and COM2. Eunpamil and Suwon 277 were also similar to these flours, but did not show high flour peak viscosity.

Environmental conditions and differences in starch properties influenced the α-amylase susceptibility of starches and consequently the values of peak viscosity (Mathewson and Pomeranz, 1978). Peak viscosity has been shown to be significantly correlated with amylose content obtained from several individual Australian cultivars (Moss, 1980). Pasting properties of flour have been influenced by flour components as well as starch components. However, starch pasting properties explain less than 40% of the total variation of flour pasting properties (Meredith and Pomeranz, 1982). SSV and SSP were influenced by environmental factors (Crosbie, 1991). SSP depends on the cultivars and growing conditions of wheat (Konik *et al.*, 1993). With high temperature during grain filling, starch lipid levels increased markedly, amylose level incereased slightly, gelatinazation temperature of the starch increased and swelling of starch in hot water decreased (Shi *et al.*, 1994). Prime starch is the primary determinant of flour paste viscosity, but tailing starch, water solubility and gluten fractions all exert an effect (Morris *et al.*, 1997b). The effects of tailings starch and gluten are positive either due directly to the pasting capacity of starch in tailings or through competition for water, as in the case of gluten, and has been deduced to be the case with pentosan (Morris *et al.*, 1997b).

Relationships among flour characteristics

Fig. 1 shows the relationship between cultivar means over years and locations of protein content, damaged starch content, AWRC, SDS-sedimentation volume and mixograph mixing time. Protein content of the nineteen Korean winter

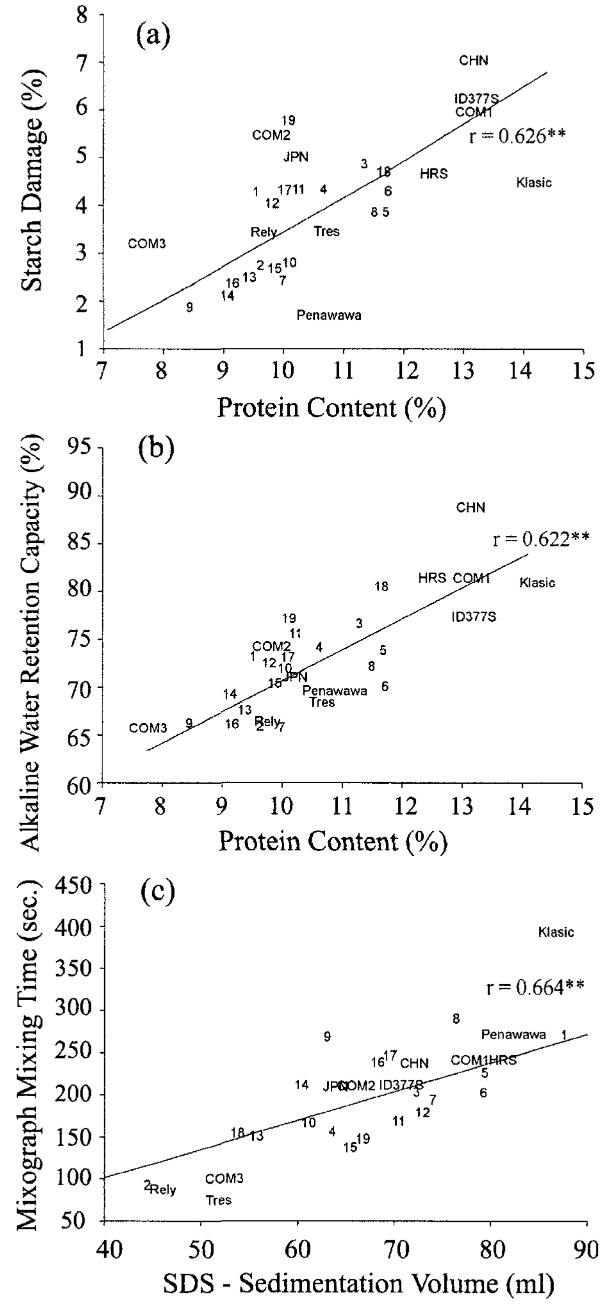

Fig. 1. The relationships between cultivar means of protein content, starch damage, alkaline water retention capacity, SDS-sedimentation and mixograph mixing time of Korean wheats. 1; Alchanmil, 2; Chokwang, 3; Eunpamil, 4; Geurumil, 5; Gobunmil, 6; Keumkangmil, 7; Olgeurumil, 8; Tapdongmil, 9; Urimil, 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 Wheats 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).

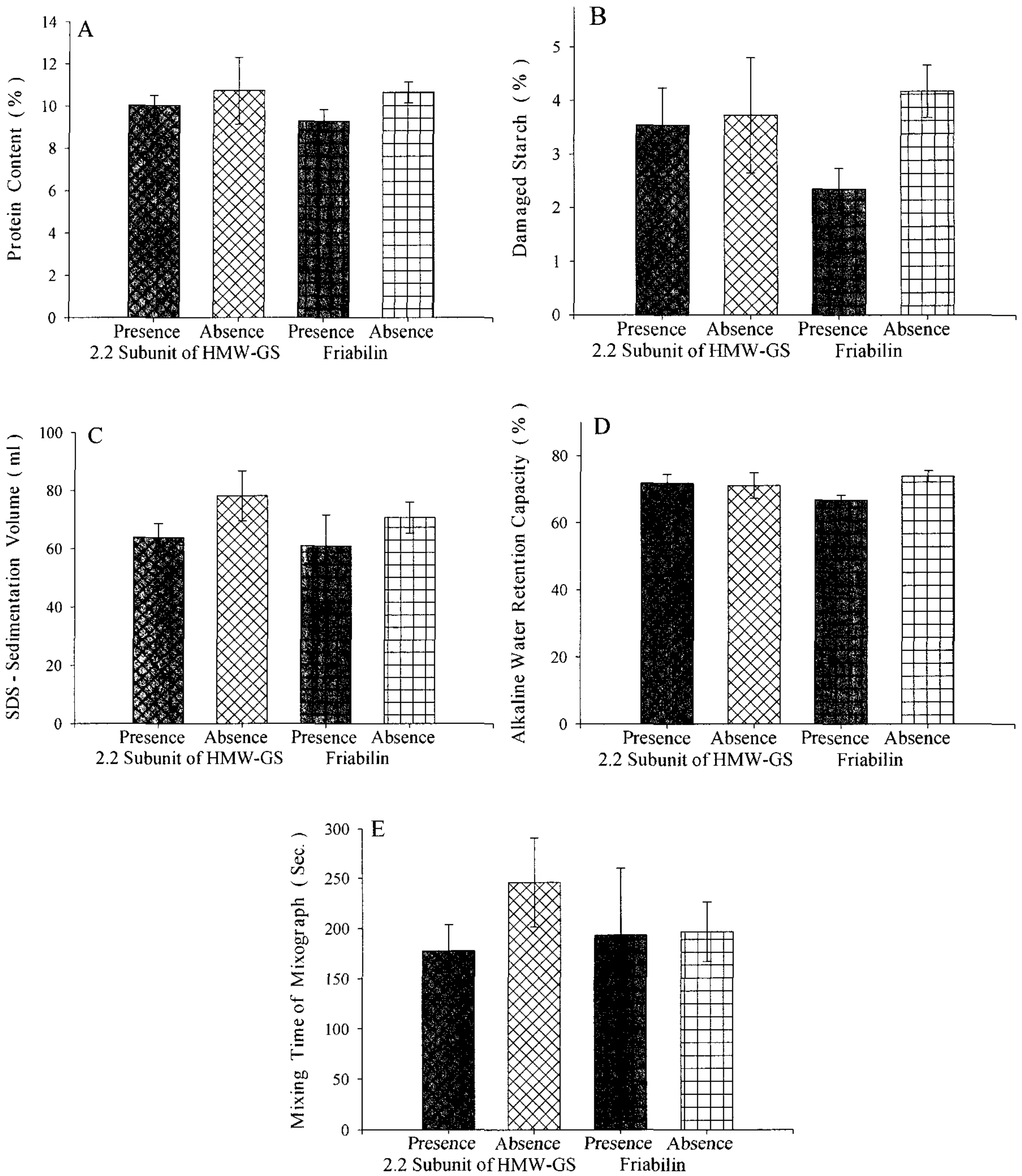

Fig. 2. The difference of protein content (A), damaged starch content (B), SDS-sedimentation volume (C), alkaline water retention capacity (D) and mixing time of mixograph (E) according to the presence or absence of 1Dx2.2 + 1Dy12 subunit of high molecular weight glutenin subunit (2.2 subunit of HMW-GS) and friabilin in Korean winter wheat cultivars and lines.

wheat cultivars and lines was correlated with starch damage and AWRC ($r = 0.626$, $P<0.01$ and $r = 0.622$, $P<0.01$, respectively). There were significant correlation coefficients between mixograph mixing time and SDS-sedimentation volume ($r = 0.664$, $P<0.01$). Sedimentation volume and mixograph parameters, as a measurement of protein content and quality of flour have been used as indices for the evaluation and prediction of bread baking quality. The effects of quality and quantity of flour proteins on mixing properties could be objectively determined by mixograph and these properties are good indices of handling properties (Finney and Shorgen, 1972). Therefore, the mixograph test has been used in many laboratories to determine the dough rheological properties that are mainly governed by the protein content and quality. Positive correlation between AWRC and protein content was considered to be a result from an increase in either trait that reflects a lessening of flour quality on cookie baking quality in soft wheats (Schuler *et al.*, 1995). SDS-sedimentation test and mixograph parameters could be used as a potential predictor for flour qualities related to bread and noodle making in Korean wheat breeding programs.

Fig. 2 shows the differences of protein content, damaged starch content, SDS-sedimentation volume and mixing time of mixograph presence and absence of 1Dx2.2+1Dy12 subunits of HMW-GS and friabilin. There was no difference in the protein content and damaged starch content between the presence and absence of 1Dx2.2+1Dy12 subunits of HMW-GS (2.2-presence and absence), and friabilin-absence lines showed higher protein content and damaged starch content (10.64% and 4.17%) than friabilin-presence lines (9.29% and 2.33%). In SDS-sedimentation volume, 2.2-absence lines showed higher volumes (78.19 ml) than those of 2.2-presence lines (63.86 ml), but there was no difference between friabilin-presence and absence lines. Friabilin-absence lines showed higher AWRC (73.90%) than friabilin-presence lines (66.71%), but there was no difference between 2.2-presence and absence lines. There was no difference in the mixing time of mixograph between friabilin-presence and absence lines, and 2.2-absence lines (245.81 sec) showed higher mixing time of mixograph than 2.2-presence lines (177.43 sec).

The relationships between presence of 1Dx2.2+1Dy12 subunits and flour texture of Japanese cultivars has been reported (Nakamura *et al.*, 1990; Oda *et al.*, 1992). Although the relationship between friabilin and kernel hardness is not known, the relationship between friabilin and kernel hardness remains unbroken (Jolly *et al.*, 1993). In this study, flours with 1Dx2.2+1Dy12 subunits of HMW-GS showed lower SDS sedimentation volume and shorter mixograph mixing time. Friabilin-presence lines showed lower protein content, SDS sedimentation volume and AWRC. Therefore, the relationships between these proteins and flour properties should be further elucidated for the improvement of Korean winter wheats. However, these biochemical markers obtained from single kernels will provide useful information in evaluation of flour properties and could be used for samples of early-generation in wheat breeding programs.

Fig. 3 shows the relationship between cultivar means over years and locations of swelling and pasting properties of starch and flour. SSV of the nineteen Korean winter wheat cultivars and lines were correlated with SSP and starch peak viscosity (r = 0.540, P<0.05 and r = 0.720, P<0.01, respectively). FSV was also significantly correlated with flour

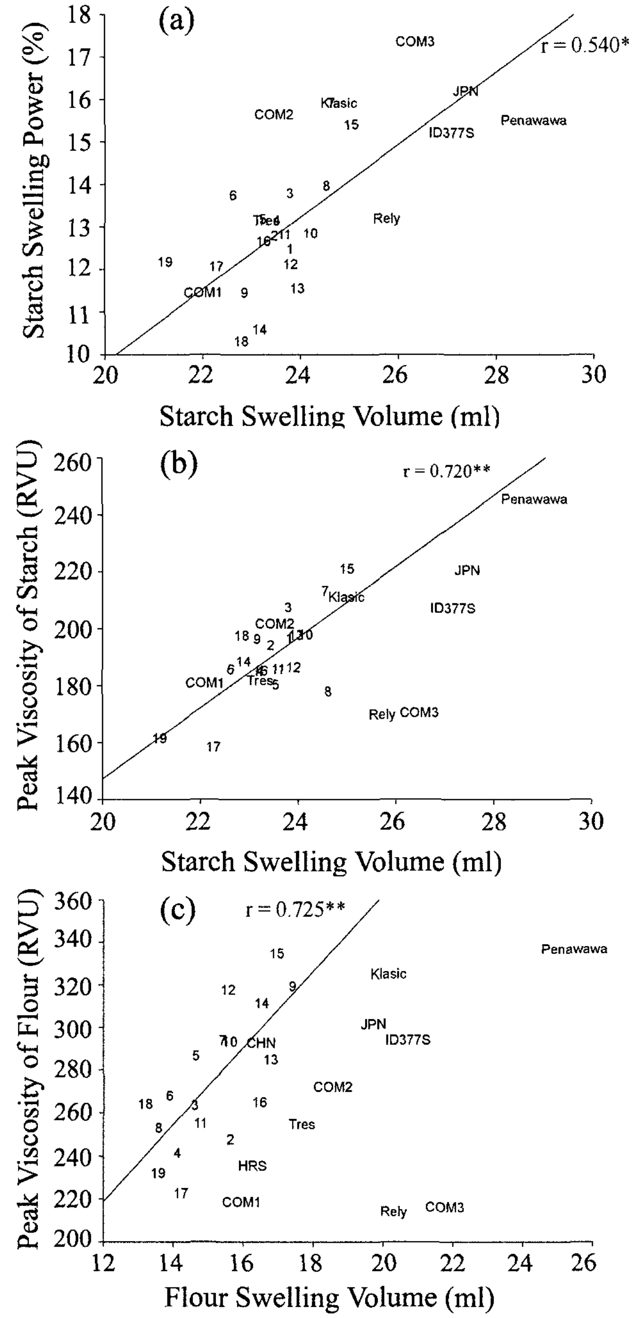

Fig. 3. The relationships between cultivar means of swelling and pasting properties of starch and flour of Korean wheats. 1; Alchanmil, 2; Chokwang, 3; Eunpamil, 4; Geurumil, 5; Gobunmil, 6; Keumkangmil, 7; Olgeurumil, 8; Tapdongmil, 9; Urimil, 10; Suwon 258, 11; Suwon 261, 12; Suwon 265, 13; Suwon 274, 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 Flour 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).

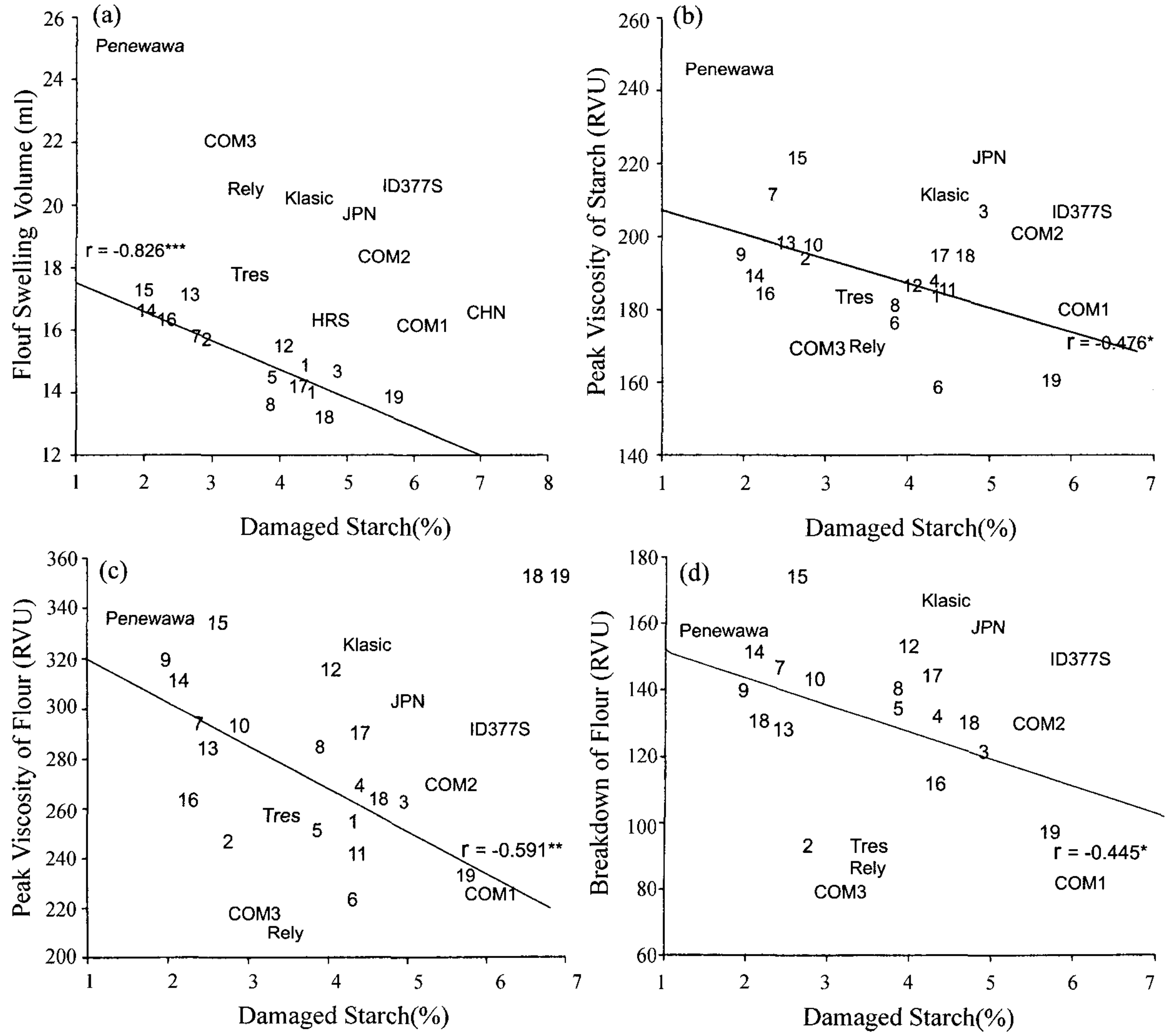

Fig. 4. The relationships between cultivar means of damaged starch content and swelling and pasting properties of starch and flour. 1; Alchanmil, 2; Chokwang, 3; Eunpamil, 4; Geurumil, 5; Gobunmil, 6; Keumkangmil, 7; Olgeurumil, 8; Tapdongmil, 9; Urimil, 10; Suwon 258, 11; Suwon 261, 12; Suwon 265, 13; 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 Flour 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).

peak viscosity (r = 0.725, P<0.01). Fig. 4 shows the relationships between cultivar means over years and locations of swelling and pasting properties of starch and flour and damaged starch content. Damaged starch content was correlated with FSV (r = -0.826, P<0.01). Starch damage was also correlated with peak viscosity of starch and flour and flour breakdown (r = -0.476, P<0.05, r = -0.591, P<0.01, and r = -0.445, P<0.05, respectively). The levels of starch damage should be considered as one criterion of flour characteristics in Korean winter wheat cultivars and lines.

Significant correlation coefficients were present between SSP and SSV, and these also gave high correlation with starch peak viscosity (Crosbie, 1991). Konik *et al.* (1992) suggested that some variation in white salted noodle quality could be assigned to kernel hardness. SSP is useful especially for noodle parameters such as elasticity and eating quality (Konik *et al.*, 1993). Crosbie and Lambe (1993) showed that FSV was highly correlated with the eating quality of cooked noodles. Most starch swelling properties were highly correlated with noodle eating qualities, but no significant correlation between SSP and peak viscosity was found (Konik *et al.*, 1994). Changes of RVA pasting profile and salt additions had an influence on the correlation with eating quality of noodle (Yun *et al.*, 1996). FSV is highly heritable and cultivar development programs could easily identify and track down the desirable FSV types (Morris *et al.*, 1997a). There were highly correlated relationships between pasting temperature and kernel hardness and starch damage (Zeng *et al.*, 1997). FSV and pasting parameters of flour using RVA should be applied to wheat breeding programs, because these tests have the advantages of using small samples and requiring a short period of time to test compared to starch swelling and pasting tests.

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. (97-04-02-01-01-3) from the basic research program of the Korea Science & Engineering Foundation.

REFERENCES

AACC. (American Association of Cereal Chemists). 1983. Method 38-10, approved April 1961, reviewed October 1982; Method 54-40A, approved April 1961. 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 Pelschenke 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.

Baik, B. -K., Z. Czuchajowska, and Y. Pomeranz. 1994a. An SDS-FY test to evaluate quality of wheat for oriental noodles. *J. Cereal Sci.* 19 : 191-201.

Baik, B. -K., Z. Czuchajowska, and Y. Pomeranz. 1994b. Role and contribution of starch and protein contents and quality to texture profile analysis of oriental noodles. *Cereal Chem.* 71 : 315-320.

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

Battey, I. L., B. M. Curtin, and S. A. Moore. 1997. Optimize of Rapid-Visco Analyser test conditions for predicting Asian noodle quality. *Cereal Chem.* 74 : 497-501.

Crosbie G. B. 1991. The relationship between starch swelling properties, paste viscosity and boiled noodle quality in wheat flours. *J. Cereal Sci.* 13 : 145-150.

Crosbie G. B. and W. J. Lambe. 1993. The application of the flour swelling volume test for potential noodle quality to wheat breeding lines. *J. Cereal Sci.* 18 : 267-276.

Evers, A. D. and D. J. Stevens. 1985. Starch damage. Pages 321-349 in Advances in Cereal Science and Technology, Vol. II, 3rd ed. Y. Pomeranz, ed. Am. Assoc. Cereal Chem.: St. Paul, MN.

Finney, K. F., and M. D. Shorgen. 1972. A ten-gram mixograph for determining and predicting functional properties of wheat flours. *Bakers Dig.* 46 : 32-35, 38, 42, 77.

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.

Gaines, C. S., P. L. Finney, and G. Rubenthaler. 1996. Milling and baking qualities of some wheats developed for eastern or northeastern regions of the United States and grown at the both locations. *Cereal Chem.* 73 : 521-525.

Gibson T. S., H. A. Qalla, and B. V. McCleary. 1992. An improved method for the measurement of starch damage in wheat flour.. *J. Cereal Sci.* 15 : 15-27.

Halverson, J., and L. Zeleny. 1988. Criteria of wheat quality. Page 15-45 in: Wheat Chemistry and Technology Vol. I, 3rd edition. Y. Pomeranz, ed. Am. Assoc. Cereal Chem., St. Paul, MN.

Jolly, C. J., S. Rahman, A. A. Kortt, and T. J. V. Higgins. 1993. Characterization of the wheat Mr 15000 "grain-softness protein" and analysis of the relationship between its accumulation in the whole seed and grain softness. *Theor. Appl. Genet.* 86 : 589-597.

Kitterman, J. S., and G. L. Rubenthaler. 1971. Assessing the quality of early generation wheat selections with the micro AWRC test. *Cereal Sci. Today* 16 : 313-314, 316, 328.

Konik, C. M., D. M. Miskelly, and P. W. Gras. 1993. Starch swelling power, grain hardness and protein: Relationship to sensory properties of Japanese noodles. *Starch/Strake* 45 : 139-144.

Konik, C. M., D. M., Miskelly, and P. W. Gras. 1992. Contribution of starch and non-starch parameters to the eating quality of Japanese white salted noodles. *J. Sci. Food Agric.* 58 : 403-406.

Konik, C. M., L. M. Miskelsen, L. M. Moss, and P. J. Gore. 1994. Relationships between physical starch properties and yellow alkaline noodle quality. *Starch/Strake* 46 : 292-299.

Lin, P.-Y., and Czuchajowska, Z. 1996. Starch damage in soft wheats of the Pacific Northwest. *Cereal Chem.* 73 : 551-555.

Mathewson, P. R., and Pomeranz, Y. 1978. Hot paste viscosity and alpha-amylase susceptibility of hard red winter wheat flour. *J. Food Sci.* 43 : 60-64.

Meredith, P., and Y. Pomeranz. 1982. Inherent amylograph pasting ability of U.S. wheat flours and starches. *Cereal Chem.* 59 : 355-360.

Morris, C. F., B. J. Shackeley, G. E. King, and K. K. Kidwell. 1997a. Genotypic and environmental variation for flour swelling volume in wheat. *Cereal Chem.* 74 : 16-21.

Morris, C. F., G. E. King, and G. L. Rubenthaler. 1997b. Contribution of wheat flour fractions to peak hot paste viscosity. *Cereal Chem.* 74 : 147-153.

Morrison W. R. and L. Bernard. 1983. An improved colorimetric procedure for determining apparent and total amylose in cereal and other starches. *J. Cereal Sci.* 1 : 9-20.

Moss, H. J. 1980. The pasting properties of some wheat starches free of sprout damage. *Cereal Res. Commun.* 8 : 297-302.

Nakamura, H., H. Sakaki, H. Hirano, and A. Yamashita. 1990. A high molecular weight subunit of wheat glutenin seed storage protein correlates with its flour quality. *Jpn. J. Breed.* 40 : 485-494.

Oda, S., K. Komae and T. Yasui. 1992. Relation between starch granule protein and endosperm softness in Japanese wheat (*Triticum aestivum* L.) Cultivars. *Jpn. J. Breed.* 4 2: 161-165.

Panozzo, J. F. and K. M. McCormick. 1993. The Rapid Viscoanalyser as a method of testing for noodle quality in a wheat breeding program. *J. Cereal Sci.* 17 : 25-32. Park *et al.*, 2001.

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

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

Schuler, S. F., R. K. Bacon, P. L. Finney, and E. E. Gbur. 1995. Relationship of test weight and kernel properties to milling and baking quality in soft red winter wheat. *Crop Sci.* 35 : 949-953.

Shi, Y.-C., Seib, P. A., and Benmadin, J. E. 1994. Effects of temperature during grain-filling on starches from six wheat cultivars. *Cereal Chem.* 71 : 369-371.

South, J. B. and W. R. Morrison. 1990. Isolation and analysis of starch from single kernels of wheat and barley. *J. Cereal Sci.* 12 : 43-51.

Souza, R., J. M. Tyler, K. D. Kephart, and M. Kruk. 1993. Genetic improvement in milling and baking quality of hard red spring wheat varieties. *Cereal Chem.* 70 : 280-285.

Yamazaki, W. L. 1953. An alkaline water retention capacity test for the evaluation of cookie baking potentialities of soft winter wheat flours. *Cereal Chem.* 30 : 242-246.

Yun, S. H., K. Quail, and R. Moss. 1996. Physicochemical properties of Australian wheat flours for white salted noodles. *J. Cereal Sci.* 23 : 181-189.

Zeng, M., C. F. Moriss, I. L. Battey, and C. W. Wigley. 1997. Source of variation for starch gelatinization, pasting, and gelation properties in wheat. *Cereal Chem.* 74 : 63-71.