Protein Quality of Wheat Desirable for Making Fresh White Salted Noodles and Its Influences on Processing and Texture of Noodles

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ABSTRACT

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Protein characteristics of wheat flours from various wheat classes, and of commercial flours for making noodles, were evaluated to determine the effects of protein content and quality on processing and textural properties of white salted noodles, as well as to identify protein quality required for making white salted noodles. SDS sedimentation volume based on constant protein weight, mixograph mixing time, and proportions of salt- and alcohol-soluble protein of three commercial flours for making noodles were more similar to those of hard wheat than to soft wheat flours. SDS sedimentation volume of commercial flours for making noodles based on constant protein weight ranged from 38.5 to 40.0 mL and was higher than those of most soft wheat flours. Mixograph mixing time and proportion of salt-soluble protein of hard and commercial flours for making noodles were >145 sec and mostly <13.8%, respectively, while those of club and soft wheat flours were < 95 sec and >15.0%. Both protein content and protein quality, as determined by SDS sedimentation volume based on constant protein weight, mixograph mixing time, proportion of salt-soluble protein, and score of HMW-GS compositions correlated with optimum water absorption of noodle dough and hardness of cooked white salted noodles.

Protein content of wheat flours determines the uses of wheat for specific food products and has served as an index for the prediction and evaluation of flour quality for end products. Wheat flour with ≈10% protein content is acceptable for making white salted noodles (Nagao et al 1977; Hou 2001). Although protein quality as related to breadbaking has been extensively studied and well established, little information regarding the protein quality requirements of wheat for production of Asian noodles is available, nor has a testing method been established. Therefore, it is necessary to evaluate the protein characteristics related to noodle making quality to determine the suitability of wheat flour for making noodles and to develop objective methods for screening wheat in breeding programs.

Because of the simple formula, noodle quality depends largely on flour characteristics and on conditions used during noodle preparation (Oh et al 1985a,c). Many researchers agree that protein content of wheat has a negative relationship with noodle color and a positive relationship with textural properties, especially hardness of cooked noodles (Miskelly 1984; Miskelly and Moss 1985; Oh et al 1985b; Toyokawa et al 1989; Baik et al 1994b; Kruger et al 1994; Yun et al 1996; Ross et al 1997; Hatcher et al 1999; Morris et al 2000). 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 flour for making bread. Sedimentation volume and mixograph mixing time exhibits a positive relationship with the texture of cooked noodles (Huang and Morrison 1988; Baik et al 1994b; Yun et al 1996).

Soft white spring, soft white winter and hard white wheat have good potential for making Asian noodles. Especially, hard white wheat has enjoyed growing attention from both domestic and international wheat industries for its uses in making bread and noodles. Challenges are that 1) generally, soft and hard wheat have quite different quality of protein and are used for different purposes; 2) quantity and quality together control the protein characteristics of wheat flour and influence processing and end product quality; 3) the quantity of protein depends mainly on growing conditions, while the quality of protein is controlled by the genetic background of the wheat. Therefore, establishing a protein quality standard of wheat for making Asian noodles and developing an efficient methodology for measuring protein quality of wheat is critical for identifying wheat cultivars possessing the required protein characteristics for making noodles and for screening breeding lines for noodle wheat.

Currently, there are intensive breeding efforts to develop wheat cultivars suitable for making noodles. However, little information is available for selecting wheat based on protein quality. Therefore, the objectives of this study were to determine the influences of protein content and quality on processing characteristics of flour and textural properties of noodles, and to elucidate protein quality of wheat suitable for or required for making white salted noodles through comparison with commercial noodle flours.

MATERIALS AND METHODS

Sixteen wheat flours, including three club, three soft white spring (SWS), three soft white winter (SWW), four hard white (HW), and three hard red spring (HRS) wheat, were obtained from the Western Wheat Quality Laboratory (Pullman, WA). Wheat grains of five different protein contents of three HW wheat cultivars ID377S, ML455, and Nuwest were provided by Pro-Mar Select (Spokane, WA). Wheat was milled using Bühler experimental mill, and flour of ≈60% extraction was prepared by blending millstreams. Two commercial wheat flours suitable for making udon noodles were obtained from Nissin Flour Milling (Tokyo, Japan) and are herein referred to as Com1 and Com2. One commercial wheat flour for making Korean dry noodles (Com3) was provided by W. J. Park, U.S. Wheat Associates in Seoul, South Korea, through the Wheat Marketing Center (Portland, OR).

Analytical Methods

Moisture, protein, and ash content of wheat flour were determined according to Approved Methods 44-15A, 46-30, and 08-01 (AACC 2000). The SDS sedimentation test was performed according to the procedure of Baik et al (1994a). 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. Flour mixing characteristics were determined using a 10-g mixograph (National Mfg. Co., Lincoln, NE), according to AACC Approved Method 54-40A (AACC 2000). The proportion of salt or 50% 1-propanol-soluble proteins of wheat flours were determined according to the procedures of Fu and Sapirstein (1996) with modifications. Salt-soluble protein was extracted from 5.0 g (db) of flour at room temperature with 25 mL of 0.5*M* NaCl for 1 hr with brief vortexing every 15 min. After centrifugation (3,000 × *g*) for 10 min,

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the residue was washed two times with 15.0 and 10.0 mL of deionized and distilled water for 2 min to remove residual salt. After centrifugation, three supernatants were pooled and freeze-dried. The remaining residue was then extracted three times with 25.0, 15.0, and 10.0 mL of 50% (v/v) 1-propanol for 1, 0.5, and 0.5 hr, respectively, with brief vortexing every 15 min. The three 50% 1-propanol supernatants were pooled and freeze-dried. The proportions of salt-soluble or 50% 1-propanol-soluble proteins were calculated based on protein quantity of wheat flours. Wet gluten of wheat flours was isolated according Approved Method 38-10 (AACC 2000). After being lyophilized, the protein quantity of dry gluten was determined and multiplied by the weight of the gluten. Gluten yield was calculated by dividing the protein quantity of the isolated gluten by flour weight. To determine the composition of high molecular weight glutenin subunits (HMW-GS), protein was extracted from 40 mg of flour with 500 µL of extraction buffer [0.125*M* Tris-HCl, pH 6.8, 1% (w/v) SDS, 6.7% (v/v) glycerol, 0.003% (w/v) bromophenol blue, and 5% (v/v) β-mercaptoethanol] by shaking for 2 hr at room temperature. SDS-PAGE of HMW-GS was run according to Laemmli (1970). 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 20mA/gel, the gel was stained overnight with a commassie blue R-250 and destained in 10% trichloroacetic acid. The HMW-GS subunits were evaluated with the scoring system proposed by Payne et al (1987).

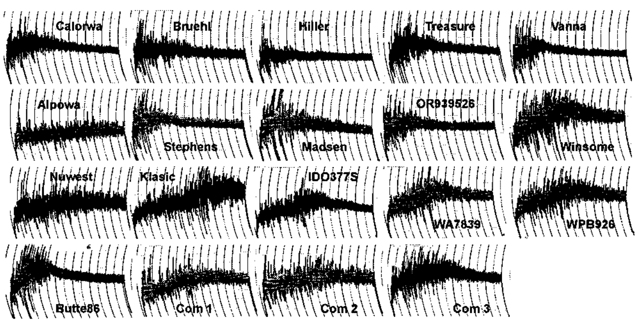

Fig. 1. Mixograms of 16 wheat flours of various wheat classes and of three commercial noodle flours (Com1 and 2, commercial noodle flours from Japan; Com3, commercial noodle flour from Korea).

Noodle Making and Texture of Cooked Noodles

White salted noodles were prepared from 16 wheat flours of various classes of wheat and three HW wheat flours with different protein contents with optimum water absorption of noodle dough. The optimum water absorption for making white salted noodles was determined based on appearance of the dough and dough sheet, and handling properties of the dough sheet during the noodle making process by experienced personnel, through trial and error. Commercial wheat flour, which required 35% absorption to make uniform, smooth and nonsticky dough, was used as a reference for comparison to other flours during the determination of optimum water absorption for making noodles.

Flour (100 g, 14% mb) was mixed with the predetermined amount of sodium chloride solution in a pin mixer (National) for 4 min, with a head speed of 86 rpm. The concentration of sodium chloride solution for making noodles with different absorption was adjusted to have 2.0% sodium chloride in the noodle dough. Dough was passed through the rollers of a noodle machine (Ohtake Noodle Machine, Tokyo, Japan) at 8 rpm and a 3-mm gap; dough was folded and put through the sheeting rollers. The folding and sheeting were repeated twice. The dough sheet was rested for 1 hr and then put through the sheeting rollers three times at progressively decreasing gaps of 2.40, 1.85, and 1.30 mm. Immediately after the last sheeting, thickness of the dough sheet was measured by a micrometer dial thickness gauge (Peacock Dial Thickness Gauge G, Ozaki Mfg. Co., Ozaki, Japan). The rest of the dough sheet was cut through no. 12 cutting rollers into noodle strands of about 30 cm in length, with a 0.3 × 0.2 cm cross-section.

Raw noodles (20 g) were cooked for 18 min in 500 mL of boiling distilled water and then rinsed with cold water. Two replicates of cooked noodles were evaluated by texture profile analysis (TPA) using a TA-XT2 texture analyser (Stable Micro Systems, Haslemeres, England) within 5 min after cooking. A set of five strands of cooked noodles was placed parallel on a flat metal plate and

TABLE I
Protein Characteristics of Club, Soft White Spring (SWS), Soft White Winter (SWW), Hard White (HW), Hard Red Spring Wheat (HRS) Flours, and Commercial Flours for Noodle Making

Class	Cultivar/Line	Protein (%)	SDSF[a] (mL)	SDSP[b] (mL)	Mixograph Time (sec)	Mixograph Abs[c] (%)	Salt-Soluble Protein (%)	Alcohol-Soluble Protein (%)	Gluten Yield (%)
Club	Calorwa	11.4	39.0	31.5	95	55.5	15.68	45.48	8.41
	Bruehl	8.9	25.5	27.0	60	53.0	18.92	48.67	5.94
	Hiller	8.2	18.5	22.0	48	52.5	19.18	49.69	5.56
SWS	Treasure	10.3	33.5	33.5	95	54.5	16.68	48.37	6.84
	Vanna	11.7	49.5	40.5	85	57.0	17.67	50.89	7.91
	Alpowa	8.9	40.0	44.5	60	54.0	16.74	44.25	6.35
SWW	Stephens	12.2	43.0	34.0	85	57.5	14.95	49.41	8.75
	Madsen	10.9	31.0	29.0	90	56.0	18.23	50.23	7.88
	OR939526	11.9	42.0	35.0	90	57.0	15.64	54.06	8.65
HW	Winsome	14.3	51.5	36.0	210	62.0	12.68	44.93	10.86
	Nuwest	10.9	41.0	35.5	205	57.5	15.81	46.30	8.23
	Klasic	14.9	57.0	40.0	330	62.0	10.86	44.10	11.66
	IDO377S	13.6	45.5	31.5	180	60.0	13.84	47.66	10.12
HRS	WA7839	16.9	75.0	44.0	195	65.0	12.55	46.57	12.93
	WPB926	17.5	79.5	46.0	200	65.5	12.51	45.85	12.91
	Butte86	16.2	—	—	145	60.0	13.03	47.11	11.56
Commercial[d]	Com1	10.1	29.0	39.0	210	60.0	13.33	44.62	7.38
	Com2	10.2	30.0	38.5	225	60.0	13.20	43.45	7.77
	Com3	10.8	36.5	40.0	198	60.0	13.81	45.16	7.78
LSD[e]		0.04	2.17	1.57	8.8	0.82	0.61	2.72	0.45

[a] SDS sedimentation test conducted on a constant flour weight (3 g).
[b] SDS sedimentation test conducted on a constant protein weight (300 mg).
[c] Water absorption of 10-g mixograph.
[d] Com1 and 2, commercial noodle flours from Japan; Com3, commercial noodle flour from Korea.
[e] Least significant difference ($P < 0.05$). Differences between two means exceeding this value are significant.

compressed crosswise twice to 70% of their original height, using the 3.175-mm metal blade at a speed of 1.0 mm/sec. From force-time curves of the TPA, the hardness (height of the peak) and adhesiveness (negative area between the first and second peak) were determined. Springiness was indicated by the ratio between the recovered height after first compression and the height of the first compression. Cohesiveness was indicated by the ratio between the area under the second peak and the area under the first peak.

Statistical Analysis

Statistical analysis of data was performed by SAS software (SAS Institute, Cary, NC) using Fisher's least significant difference procedure (LSD), analysis of variance (ANOVA), and Pearson's correlation coefficient. All data were determined at least in duplicate and all were averaged.

RESULTS AND DISCUSSION

Protein Characteristics of Wheat Flours

Protein characteristics of 16 wheat genotypes of various classes, including three club, three SWS, three SWW, four HW, and three HRS wheats, and three commercial flours for making noodles (Com1, 2 and 3) are summarized in Table I. Protein content of flour was generally higher in hard wheat than in club and soft wheat genotypes. While protein content of flour in club, SWS and SWW wheat was <12.2%, HW and HRS wheat genotypes were >13.6%, except in Nuwest (10.9%). Protein content of three commercial noodle flours was 10.1–10.8%. SDS sedimentation volume performed with constant flour weight (3 g), was 18.5–49.5 mL in club, SWS, and SWW wheat flours, and 41.0–79.5 mL in HW and HRS wheat flours. SDS sedimentation volume based on 3 g of flour of Com1, 2 and 3 was much lower than in hard wheat, but was in the range of SDS sedimentation volume of club and soft wheat flours. SDS sedimentation volume based on constant flour weight is influenced by protein content and quality. Therefore, it was necessary to run the SDS sedimentation test based on the constant content of protein to determine protein quality independent of protein content. Compared to sedimentation volume based on constant flour weight, differences in sedimentation volume between hard and soft wheat flours became smaller. Especially, SDS sedimentation volume based on constant protein weight of HW wheat flours ranged similarly to those of SWS and SWW wheat flours. Sedimentation volume of SWS wheat cvs. Alpowa and Vanna had exceptionally higher values, while SDS sedimentation volume of HW cv. IDO377S was only 31.5 mL, even lower than that of many soft wheat flours. HRS wheat flours exhibited the highest SDS sedimentation volume based on constant amount of protein, indicating that they have much stronger protein than soft and HW wheat flours. SDS sedimentation volume of Com1, 2 and 3 (38.5–40.0 mL) were much higher than in most club and soft wheat flours, except in SWS wheat cvs. Alpowa and Vanna, and similar to those of HW wheat flours other than IDO377S, but lower than in HRS wheat flours. It is believed that protein suitable for making white salted noodles has to be stronger than the protein of most club and soft wheat flours, but softer than the protein of HRS wheat flours.

Since dough mixing properties of flours are mainly controlled by quantity and quality of protein (Finney and Shogren 1972), mixograph parameters were used to compare wheat flours for their differences in protein quality. Figure 1 shows the mixograms of 16 wheat flours and three commercial flours for making noodles. There were clear differences in mixogram patterns of wheat flours between soft and hard wheat. Hard wheat flours generally exhibited longer mixing time, greater mixing tolerance and higher resistance to mixing than club and soft wheat flours. Mixogram patterns of Com1, 2, and 3 resembled those of hard wheat flours more than those of club and soft wheat flours. Mixograph mixing time of club, SWS and SWW wheat flours were much shorter (<95 sec) than HW, HRS, Com1, 2, and 3, which required >145 sec (Table I). Even though SWS wheat cvs. Vanna and Alpowa exhibited relatively higher SDS sedimentation volumes, mixing times were <85 sec. On the other hand, Com1, 2, and 3 had similar or lower protein content and SDS sedimentation volumes compared to Vanna and Alpowa, but required >198 sec of mixing time. Mixograph absorption of club, SWS and SWW wheat flours was <57%, while those of HW, HRS, Com1, 2, and 3 were >60%. Mixograph absorption of Com1, 2, and 3 was 60%, much higher than for wheat flours with similar protein content or protein quality. Compared to wheat

TABLE II
High Molecular Weight Glutenin Subunit (HMW-GS) Composition of Club, Soft White Spring (SWS), Soft White Winter (SWW), Hard White (HW), Hard Red Spring (HRS) Wheat and Commercial Flours for Noodle Making

		HMW-GS Composition[a]			
Class	Cultivar /Line	*Glu-A1*	*Glu-B1*	*Glu-D1*	Score[b]
Club	Calorwa	Null[c]	7+8	2+12	6
	Bruehl	1	6+8	2+12[d]	6
	Hiller	Null	6	2+12	4
SWS	Treasure	2*	6+8	2+12	6
	Vanna	1	17+18	2+12	8
	Alpowa	Null	7+9	5+10	7
SWW	Stephens	2*	7+9	2+12	7
	Madsen	2*	7+9	2+12	7
	OR939526	2*	7+9	2+12	7
HWS	Winsome	2*	17+18	5+10	10
	Nuwest	2*	7+9	5+10	9
	Klasic	1	17+18	5+10	10
	IDO377S	2*	17+18[e]	5+10	10
HRS	WA7839	2*	17+18	5+10	10
	WPB926	2*	17+18	5+10	10
	Butte86	2*	7+9	5+10	9
Commercial[f]	Coml	1	17+18	2+12	8
	Com2	1 & 2*	7+8 & 17+18	2+12 & 5+10	8–9
	Com3	1 & 2*	7+8 & 17+18	2+12 & 5+10	8–9

[a] Nomenclature according to Payne and Lawrence (1983).
[b] Scoring according to Payne et al (1987).
[c] Null allele.
[d] Multiline, major components listed, 5+10 subunits are minor components.
[e] Multiline, major components listed, 7+8 subunits are minor components.
[f] Com1 and 2, commercial noodle flours from Japan; Com3, commercial noodle flour from Korea.

flours with similar protein content and SDS sedimentation volumes, these commercial noodle flours had smaller particle size of flours, higher damaged starch content and water retention capacity (Park and Baik 2002), which contributed to the relatively high mixograph absorption.

Salt-soluble protein includes albumin and globulin, while 50% 1-propanol-soluble protein includes albumin, globulin and gliadin, and soluble glutenin (Sapirstein and Fu 1998). Proportion of salt and 50% 1-propanol-soluble protein also showed large contrast between soft and hard wheat cultivars. While the proportion of salt-soluble protein was 15.0–19.2% in club, SWS and SWW wheat flours, it was <13.8% in hard wheat flours, except in HW wheat cv. Nuwest. The proportion of salt-soluble protein of Com1, 2 and 3 was 13.2–13.8%. Proportion of 50% 1-propanol-soluble protein was 45.5–54.1% in club and soft wheat flours, 44.1–47.1% in hard wheat flours and 43.5–45.2% in Com1, 2, and 3. Sapirstein and Fu (1998) reported that 50% 1-propanol-soluble protein negatively correlated with mixograph mixing time. Mixograph mixing time negatively correlated with proportion of salt and 50% 1-propanol-soluble protein in 16 wheat flours. Com1, 2, and 3 showed a lower proportion of salt and 50% 1-propanol-soluble protein than club and soft wheat flours, but similar to values of many hard wheat flours.

Gluten yield of flours was 5.6–8.8% in club, SWS and SWW wheat flours, while HW and HRS wheat had >10.1% of gluten yield, except in HW wheat cv. Nuwest, which had 8.2% of gluten yield. Gluten yield of Com1, 2, and 3 was 7.4–7.8%, and was similar to the range of gluten yield in club and soft wheat flours. Lower gluten yields of Com1, 2, and 3, even though protein quality was comparable to hard wheat flours, as shown by SDS sedimentation volumes based on constant protein weight, mixograph parameters and proportion of salt- and alcohol-soluble protein, could be due to low protein content. Low protein content of flours might adversely affect the development of gluten during dough mixing.

Table II lists the HMW-GS composition of the 16 wheat flours and three commercial flours for making noodles. A high frequency

TABLE III
Protein Characteristics of Three Hard White Wheat Flours with Different Protein Contents

Cultivar	Protein (%)	SDSF[a] (mL)	SDSP[b] (mL)	Mixograph Time (sec)	Mixograph Abs[c] (%)	Salt-Soluble Protein (%)	Alcohol-Soluble Protein (%)	Gluten Yield(%)
IDO377S	11.0d[d]	45.0e	39.5a	180a	57.0b	14.62a	47.37a	8.15e
	11.8cd	50.0d	40.0a	184a	57.0b	13.72b	47.58a	8.92d
	12.7c	53.5c	38.0a	195a	62.0a	13.36b	48.20a	9.73c
	13.6b	55.5b	36.5ab	195a	63.0a	13.41b	46.84a	10.38b
	14.9a	62.0a	36.5ab	195a	64.0a	12.48c	47.34a	11.12a
ML455	9.4e	47.0d	50.0a	222a	57.0d	—	—	—
	11.2d	58.7c	49.0a	187b	59.0c	13.20ab	45.41a	8.46c
	12.8c	66.7c	48.0ab	210a	61.0b	13.49a	46.24a	9.61b
	13.1b	70.0b	50.0a	195a	62.0b	13.04b	45.88a	10.08b
	15.3a	78.2a	49.0a	200a	63.0a	11.81c	47.50a	11.87a
Nuwest	11.6e	58.0e	44.0a	152c	59.0d	13.16a	47.37a	8.77b
	12.4d	63.5d	42.7ab	222a	60.0c	12.38b	47.57a	—
	12.7c	65.0c	43.2a	180b	62.0bc	13.41a	46.10a	—
	14.0b	68.0b	43.7a	230a	63.0ab	11.72c	46.08a	10.52a
	14.3a	70.5a	40.0b	230a	64.0a	12.21b	47.27a	10.72a

[a] SDS sedimentation test was conducted on a constant flour weight (3 g).
[b] SDS sedimentation test was conducted on a constant protein weight (300 mg).
[c] Water absorption of 10-g mixograph.
[d] Values followed by the same letters within each cultivar are not significantly different at $P < 0.05$.

TABLE IV
Characteristics of Noodle Dough Sheet and Texture Profile Analysis Parameters of Cooked Noodles Prepared from Club, Soft White Spring (SWS), Soft White Winter (SWW), Hard White (HW), Hard Red Spring Wheat (HRS) and Commercial Flours for Making Noodles

		Noodle Dough		TPA Parameters[b]			
Class	Cultivar /Line	Abs[a] (%)	Thickness (mm)	HD (N)	AD (N × mm)	SP (ratio)	CO (ratio)
Club	Calorwa	35	1.66	5.37	−0.08	0.91	0.59
	Bruehl	37	1.64	4.01	−0.05	0.88	0.61
	Hiller	37	1.55	3.17	−0.04	0.88	0.60
SWS	Treasure	35	1.67	4.64	−0.06	0.92	0.61
	Vanna	34	1.67	4.94	−0.06	0.91	0.62
	Alpowa	36	1.64	4.46	−0.06	0.89	0.62
SWW	Stephens	34	1.66	4.75	−0.04	0.92	0.62
	Madsen	35	1.65	5.32	−0.06	0.93	0.59
	OR939526	35	1.71	5.22	−0.06	0.92	0.64
HW	Winsome	34	1.87	5.29	−0.06	0.92	0.65
	Nuwest	35	1.70	4.94	−0.08	0.91	0.61
	Klasic	31	2.01	5.42	−0.05	0.91	0.67
	IDO377S	33	1.82	5.22	−0.06	0.91	0.64
HRS	WA7839	32	1.89	6.28	−0.07	0.91	0.61
	WPB926	32	1.93	6.73	−0.09	0.91	0.60
	Butte86	32	1.84	5.85	−0.05	0.92	0.61
Commercial[c]	Com1	35	1.67	3.79	−0.03	0.92	0.65
	Com2	35	1.73	4.17	−0.03	0.92	0.64
	Com3	35	1.73	3.95	−0.03	0.93	0.66
LSD[d]			0.02	0.08	0.02	0.01	0.02

[a] Water absorption of noodle sheet.
[b] HD, hardness; AD, adhesiveness; SP, springiness; CO, cohesiveness.
[c] Com1 and 2, commercial noodle flours from Japan; Com3, commercial noodle flour from Korea.
[d] Least significant difference ($P < 0.05$). Differences between two means exceeding this value are significant.

of subunit 2* on *Glu-A1* loci was found among wheat cultivars. In *Glu-B1* loci, hard wheat had a high frequency of the subunits 17+18, while club and soft wheat showed a higher frequency of the subunits 7+9. In *Glu-D1* loci, all of the hard wheat cultivars had the subunits 5+10, but club and soft wheats had a high frequency of the subunits of 2+12, except Alpowa. Shewry et al (1992) proposed that wheat cultivars with good breadbaking quality might require allelic subunits 1 or 2* on the *Glu-A1* locus, 17+18 or 7+8 on the *Glu-B1* locus and 5+10 on the *Glu-D1* locus. Payne et al (1987) established the scoring system of HMW-GS composition for predicting the potential of breadmaking quality in wheat breeding programs based on the significant relationship between the specific HMW-GS composition and breadmaking quality. According to this system, the score of HMW-GS composition of hard wheat cultivars was >9 points, while club and soft wheat cultivars showed <8 points. In Com1, 2, and 3, two alleles were identified at *Glu-A1* loci (1 and 2*), two at *Glu-B1* loci (7+8 and 17+18), and two at *Glu-D1* loci (2+12 and 5+10). The subunits 7+9, which were high frequency in soft wheat flours, were not found in Com1, 2, and 3. The score of HMW-GS of Com1, 2, and 3 was higher than club and soft wheat cultivars, but lower than hard wheat cultivars. Among commercial noodle flours, Com2 and 3 could be mixtures of soft and hard wheat flours, because their composition of HMW-GS contained both 2+12 and 5+10 at *Glu-D1* loci, and 7+8 and 17+18 at *Glu-B1*, and their score of HMW-GS was higher than club and soft wheat cultivars.

Protein characteristics of three HW wheat cultivars with different protein content are summarized in Table III. SDS sedimentation volume based on constant flour weight significantly increased as protein content increased in three HW wheat cultivars. However, SDS sedimentation volume with constant protein basis was stable and little affected by protein content. Mixograph absorption increased as protein content increased, whereas there were no consistent differences in mixing time among flours with different protein content. Although there were decreasing trends in the proportion of salt-soluble protein as protein content increased, there were no differences in proportion of alcohol-soluble protein as protein content of flours increased. Gluten yield also increased as protein content increased. SDS sedimentation volume based on constant flour weight, mixograph absorption and gluten yield were affected by protein content. On the other hand, SDS sedimentation volume based on constant protein weight, mixograph mixing time and proportion of salt and alcohol-soluble protein of flour were relatively independent of protein content and suitable for effective evaluation of protein quality of flour.

Optimum Water Absorption and Thickness of Noodle Dough Sheets

Table IV shows the optimum water absorption and thickness of noodle dough sheets in 16 wheat flours of various wheat classes and three commercial flours. Optimum water absorption of noodle dough was 34–37% in club, SWS, and SWW wheat flours. Optimum water absorption was <34% in HW and HRS wheat flours, except in cv. Nuwest, which was lowest in protein content among hard wheat flours. Thickness of noodle dough sheets prepared with optimum water absorption was 1.55–1.71 mm in club, SWS, and

TABLE V
Characteristics of Noodle Dough Sheet and Texture Profile Analysis Parameters of Cooked Noodles Prepared from Three Hard White Wheat Flours with Different Protein Contents

Cultivar	Protein (%)	Noodle Dough		TPA Parameters[b]			
		Abs[a] (%)	Thickness (mm)	HD (N)	AD (N × mm)	SP (ratio)	CO (ratio)
IDO377S	11.0	37	1.80c[c]	4.17e	–0.05a	0.90b	0.63ab
	11.8	36	1.84bc	4.46d	–0.05a	0.89b	0.63b
	12.7	35	1.85b	5.02c	–0.05a	0.91ab	0.64ab
	13.6	34	1.90a	5.25b	–0.05a	0.92a	0.64a
	14.9	33	1.92a	5.68a	–0.05a	0.90b	0.63b
ML455	9.4	37	1.74d	4.16d	–0.06ab	0.87b	0.58d
	11.2	36	1.81c	4.90b	–0.06ab	0.90ab	0.60c
	12.8	36	1.84c	4.51c	–0.04a	0.92a	0.64a
	13.1	35	1.87b	4.96b	–0.06ab	0.91a	0.63b
	15.3	33	1.96a	5.89a	–0.07b	0.91a	0.64b
Nuwest	11.6	36	1.76b	4.72c	–0.06ab	0.91a	0.62a
	12.4	36	1.81a	5.10b	–0.06ab	0.91a	0.63a
	12.7	35	1.77b	5.10b	–0.05a	0.93a	0.63a
	14.3	34	1.82a	6.07a	–0.07b	0.91a	0.61b

[a] Abs, water absorption of noodle sheet.
[b] HD, hardness; AD, adhesiveness; SP, springiness; CO, cohesiveness.
[c] Values followed by the same letters within each cultivar are not significantly different at $P < 0.05$.

TABLE VI
Coefficients of Correlation Between Protein Characteristics and Noodle Processing Parameters, Including Optimum Water Absorption of Noodle Dough and Thickness of Noodle Sheets

Parameters[a,b]	Optimum Water Absorption		Thickness of Dough Sheets	
	Club, Soft and Hard Wheats (n = 16)	Three HW Wheats (n = 14)	Club, Soft, and Hard Wheats (n = 16)	Three HW Wheats (n =14)
Protein	–0.930***[c]	–0.939***	0.900***	0.819***
SDSF	–0.865***	–0.652***	0.821***	0.487
SDSP	–0.565*	0.292	0.519*	–0.189
Mixograph mixing time	–0.787***	–0.129	0.896***	0.110
Mixograph absorption	–0.889***	–0.899***	0.920***	0.630
Salt-soluble protein	0.898***	0.713**	–0.926***	–0.462
Alcohol-soluble protein	0.354	–0.151	–0.473	0.178
Gluten yield	–0.929***	–0.957***	0.929***	0.841***
Score of HMW-GS composition	–0.835***	—	0.886***	—

[a] SDS sedimentation test was conducted on a constant flour weight (3 g).
[b] SDS sedimentation test was conducted on a constant protein weight (300 mg).
[c] *,**,***, significant at $P < 0.05$, 0.01, and 0.001 level.

SWW wheat flours, and was >1.82 mm in HW and HRS wheat flours, except in cv. Nuwest. Com1, 2, and 3 had 35% water absorption of noodle dough, and thickness of dough sheets was 1.67–1.73 mm. Accordingly, Com1, 2, and 3 exhibited similar or lower water absorption than soft wheat flours, but higher water absorption than most hard wheat flours. Noodle dough sheets of Com1, 2, and 3 were generally thinner than those of hard wheat flours, but similar to or thicker than soft wheat flours.

In three HW wheat flours with different protein content, optimum water absorption of noodle dough was 33–37% in IDO377S and ML455 and 34–36% in Nuwest (Table V). Thickness of the noodle dough sheet was 1.80–1.92 mm in IDO377S, 1.74–1.96 mm in ML455, and 1.76–1.82 mm in Nuwest. Optimum water absorption of noodle dough decreased as protein content increased because flours with low protein content require more water for forming a uniform protein matrix and making a continuous noodle sheet with good handling properties. Thickness of the noodle dough sheet generally increased as flour protein content increased, except in Nuwest.

Table VI shows the correlation coefficients between protein characteristics and noodle processing parameters, including optimum water absorption of noodle dough and thickness of noodle dough sheet, in 16 wheat flours of various wheat classes. Protein content, SDS sedimentation volume with constant flour or protein bases, mixograph parameters, gluten yield, and score of HMW-GS composition correlated negatively with optimum water absorption of noodle dough, and positively with thickness of noodle dough sheets. Proportion of salt-soluble protein correlated positively with optimum water absorption of noodle dough and negatively with thickness of noodle dough sheets. In three HW wheat cultivars with different protein content, protein content, SDS sedimentation

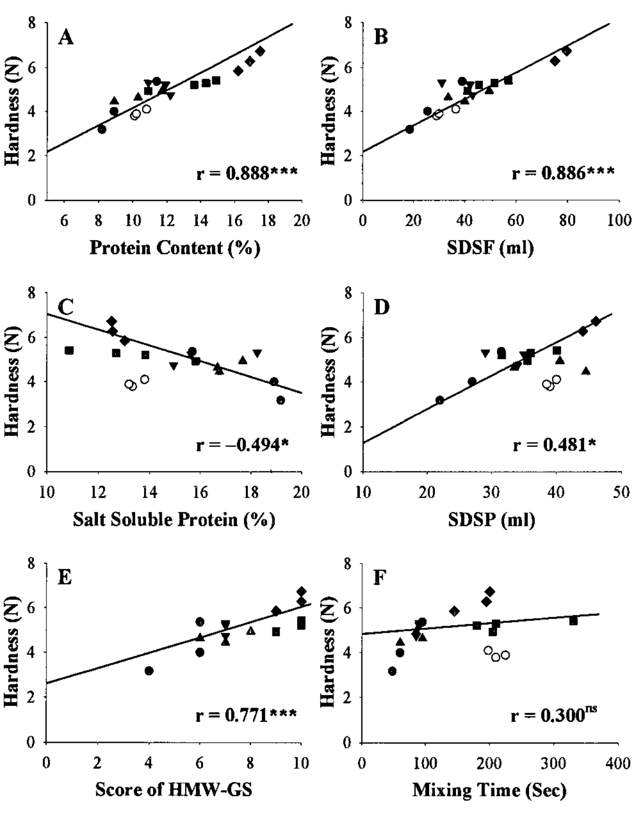

Fig. 2. Relationships between protein content (**A**), SDS sedimentation volume based on constant flour weight (**B**), proportion of salt-soluble protein (**C**), SDS sedimentation volume based on constant protein weight (**D**), score of HMW-GS composition (**E**) and mixograph mixing time (**F**) and hardness of cooked noodles. Club wheat (●), soft white spring wheat (▲), soft white winter wheat (▼), hard white wheat (■), hard red spring wheat (◆), and three commercial noodle flours (○).

volume with constant flour basis, mixograph absorption, proportion of salt-soluble protein, and gluten yield showed significant negative relationships with optimum water absorption. Only protein content and gluten yield positively correlated with thickness of noodle sheets.

Oh et al (1986) also reported a negative relationship between protein content and optimum water absorption of noodle dough. The relationship between thickness of Cantonese noodle sheets and protein content of flour was reported by Kruger et al (1994). In addition to protein content, protein quality determined by SDS sedimentation volume with constant protein basis, mixograph mixing time, proportion of salt-soluble protein, and HMW-GS composition influence water absorption of noodle dough and thickness of the noodle dough sheet in white salted noodles.

Texture Profile Analysis (TPA) of Cooked Noodles

TPA parameters of cooked noodles prepared from club, soft, and hard wheat flours and commercial flours for making noodles are summarized in Table IV. Hardness of cooked white salted noodles was highest in HRS wheat flours, followed by HW, SWW, and SWS wheat flours. While two club wheat cvs. Bruehl and Hiller produced the softest cooked noodles, hardness of cooked noodles prepared from club wheat cv. Calorwa was comparable to that of noodles prepared from HW wheat flours. Com1, 2, and 3 produced much softer texture of white salted noodles than HRS, HW, SWW, and SWS wheat flours. There was no consistent difference in adhesiveness and cohesiveness of cooked noodles between different types of 16 wheat flours. Still, adhesiveness of cooked noodles was much lower in Com1, 2, and 3 than in other wheat flours. Cohesiveness of cooked noodles was 0.64–0.67 in Com1, 2 and 3, three HW wheat flours and one SWW line OR939526, while it was <0.62 in HRS and most soft wheat flours.

Commercial flours for making noodles are null in the *Wx-1B* allele of granule bound starch synthase, which is probably responsible for the soft texture of cooked noodles, along with low protein content (Ross et al 1997). HW wheat cvs. IDO377S and Klasic are also null in *Wx-1B* allele of granule bound starch synthase. However, they are much higher in protein content and consequently produced harder texture of noodles than Com1, 2, and 3 (Table I). High cohesiveness of cooked noodles could also be attributed to starch characteristics.

TPA parameters of cooked noodles prepared from three HW wheat flours with different protein contents are summarized in Table V. Hardness of cooked noodles increased significantly as protein content increased. A higher cutting stress of noodles prepared from high protein content flours than those from low protein content flours was also reported by Oh et al (1985b). No significant differences in adhesiveness, springiness, and cohesiveness were found between flours of different protein content within the same cultivars.

Protein content and quality parameters of wheat flours significantly correlated with hardness of cooked noodles (Fig. 2). Protein content, as well as SDS sedimentation volumes based on constant flour weight as a measurement of protein content and quality, correlated positively with hardness of cooked noodles, but exhibited no relationship with other TPA parameters of cooked noodles. Noodles prepared from wheat flours with low protein content are more fragile than those with high protein content because the protein network in the low protein noodles is weaker than in the high protein noodles. Relationships between protein content as well as SDS sedimentation volume based on constant flour weight and hardness of cooked noodles were also reported by Baik et al (1994a), Kruger et al (1994), Huang and Morrison (1988), Oh et al (1985b), Ross et al (1997), and Yun et al (1996). The SDS sedimentation volume based on constant protein, mixograph mixing time and score of HMW-GS correlated positively with hardness of cooked noodles, while the proportion of salt-soluble protein showed a negative relationship with hardness of cooked noodles. Yun et al (1996) also reported that mixograph mixing time correlated positively with elasticity, eating quality and total noodle score.

Compared to hard wheat flours, Com1, 2, and 3 had similar protein quality as determined by SDS sedimentation volume based on constant protein weight, mixograph mixing time, and proportion of salt- and alcohol-soluble protein, whereas they were generally lower in protein content (Table I). Low protein content of Com1, 2, and 3, along with the null characteristics in the *Wx-1B* allele of granule bound starch synthase, probably resulted in lower hardness of cooked noodles, despite strong protein. Consequently, Com1, 2, and 3 were aberrant from 16 other wheat flours in the plots of relationships between protein quality parameters and hardness of cooked noodles. Accordingly, correlation coefficients between protein quality parameters and hardness of cooked noodles increased from $r = -0.494$ ($P < 0.05$) to $r = -0.755$ ($P < 0.01$) in the proportion of salt-soluble protein, from $r = 0.481$ ($P < 0.05$) to $r = 0.694$ ($P < 0.05$) in SDS sedimentation volume based on protein weight and from $r = 0.300$ ($P > 0.05$) to $r = 0.586$ ($P < 0.05$) in mixograph mixing time by omitting commercial noodle flours.

CONCLUSIONS

SDS sedimentation volume based on constant protein weight, mixograph mixing time and proportions of salt- and alcohol-soluble protein of commercial flours for making noodles were more comparable to those of hard wheat flours than those of soft wheat flours. In addition to protein content, quality parameters of flour protein, including SDS sedimentation volume with constant protein weight, mixograph mixing time, proportion of salt-soluble protein, and score of HMW-GS have significant relationships with processing and textural properties of white salted noodles. Therefore, in addition to protein content, protein quality of flour protein should be considered in the evaluation and selection of wheat flour for making white salted noodles.

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