Australian Salt-Noodle Flours and Their Starches Compared to U.S. Wheat Flours and Their Starches[1]

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ABSTRACT

The properties of flours and starches from three soft wheats segregated in Western Australia for noodlemaking were compared with those of 12 wheats from the United States representing six classes. Also included were seven Korean noodle flours and their starches. Wheat starches were isolated from the flours in ≈65% recovery by dough washing and in ≈90% yield by protease digestion. Compared to the Australian flours, three U.S. soft red wheat flours had ≈10% more total lipids and nonstarch lipids, whereas Western White wheat flour had less. Total lipids were low in the Australian flours, but nonstarch lipids were average. The swelling powers (SP) of the three Australian flours at 92.5°C ranged from 20.0 to 21.1 g/g, whereas those of the 12 U.S. flours ranged from 14.8 to 19.0 g/g. Multiple regression analysis showed that the SP of the 22 flours were positively correlated (r^2 = 0.93, P = 0.001) with the SP of the starches and negatively correlated with flour protein levels. The high SP (92.5) of an Australian noodle-segregate flour was attributed to its low protein level and to its starch's low amylose and lipid levels. Gels prepared at 6% from Gamenya starch, one of the high-swelling Australian wheat starches, gave a high storage modulus (G') in dynamic rheological tests when compared to the gels of low-swelling wheat starches. When the starch concentrations in gels were increased to 10.5%, the G' increased less for Gamenya than for the low-swelling starches, especially one from a soft wheat (Geneva). Low-swelling starch from the hard red winter wheat Karl gave gels at 8.0–10.5% solids with G' values that almost matched those of Gamenya. The size distributions of starch granules from Karl and Geneva wheats were the lowest and highest, respectively, among the starches tested.

Cereal Chem. 73(2):167-175

Many workers have provided evidence that high-swelling starch in wheat flour is beneficial to the quality of Japanese salt noodles (Nagao et al 1977; Moss 1980; Oda et al 1980; Rho et al 1988; Endo et al 1989; Crosbie 1989; Toyokawa et al 1989; McCormick et al 1991; Crosbie 1991; Crosbie et al 1992; Konik et al 1992, 1993; Takahashi et al 1993). High-swelling starch also may be desirable in alkaline noodles and instant fried noodles (Miskelly and Moss 1985, Kim and Seib 1993, Konik et al 1994).

Crosbie (1991) introduced the swelling volume test to monitor starch quality in new wheats. In that test, a slurry of white flour (3.6% dry solids) in a capped tube is heated rapidly with intermittent agitation to 92.5°C, and the mixture is held 30 min, then cooled and centrifuged to obtain gel height. Also, Crosbie et al (1992) found significant positive correlation with whole grain flour (4.0% dry solids) between meal swelling volume and total texture score of cooked salt noodles.

McCormick et al (1991) reported that peak paste viscosities of flours determined on the Rapid Visco-Analyzer (RVA) correlated significantly with salt noodle eating quality. Konik and Moss (1992) found that RVA peak viscosities for starches and flours from 49 wheats correlated positively with salt noodle eating quality, and that set-back and final viscosity (50°C) correlated negatively with eating quality. In contrast to an amylogram, an RVA curve was collected in one-half the time on approximately 1/10th the sample size.

Wheat Starch Pastes and Gels

Heating an aqueous wheat starch slurry above 50°C and below 100°C causes irreversible swelling of the granules and leaching of amylose (AM) from the swollen granules (Ellis et al 1989, Morris 1990, Tester and Morrison 1990, Shi et al 1991). When the concentration of wheat amylose with DP_n ≈1,000 is >0.8% in the continuous phase of the paste, gelation occurs upon cooling (Gidley and Bulpin 1989). The concentration of AM in the continuous phase is controlled by starch swelling, which in turn depends on starch concentration, temperature, and shear. Ultimately, it is the differences in gel properties of various wheat starches at high concentration that affect noodle texture.

Swelling of starch has been reported in terms of different parameters. In all methods, starch concentration, temperature, heating period, stirring, and centrifuging conditions are specified. The classical swelling power (SP) is defined as the wet weight of the sedimented gel divided by its dry weight (Leach et al 1959). Water holding capacity (WHC) or swelling capacity (Q) is the wet weight of the sedimented gel divided by the dry weight of starch (Bagley and Christianson 1982, Toyakawa et al 1989), while swelling volume (SV) is the volume divided by the dry weight of starch (Crosbie 1991). Swelling factor (SF) is the ratio of the volume of the sedimented gel particles divided by the volume of the granules with density of 1.40 g/ml (Tester and Morrison 1990). SF measures the increase in the volume of water inside the swollen granules and discounts the water trapped between granules. Above ≈85°C for wheat starch, SF is difficult to determine experimentally because of high swelling.

Previous investigators used the following procedure to isolate wheat starch from noodle flours and report swelling parameters, usually with a heating period of 30 min: SP on 2.5 g of starch (ds)/100 ml at 62–93°C with stirring (Endo et al 1989); WHC on 4–8 g of starch (ds)/100 ml at 75°C in tubes with shaking every 5 min (Toyakawa et al 1989); WHC on 4 g of starch/100 ml at 70°C in tubes for 10 min in a mechanically shaken water bath followed by vortex mixing and heating at 100°C for 10 min (McCormick et al 1991); SV on 2.8 g of starch (ds)/100 ml at 92.5°C in tubes with mixing by inverting the tubes (Crosbie 1991); and SP on 3.33 g of starch (ds)/100 ml at 92.5°C in tubes with mixing by inverting the tubes (Crosbie 1991).

The objectives of this research were to compare the swelling of 12 U.S. hard and soft wheat flours and their starches with three Western Australian and seven Asian noodle flours and starches

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Publication no. C-1996-0212-01R.

and to compare the storage moduli of gels prepared from high- and low-swelling starches.

MATERIALS AND METHODS

Materials

Twenty two wheat flours were obtained from several sources. Flours of ≈60% extraction were from three soft white wheat cultivars (Gamenya, Eradu, and Cadoux) grown in 1992 at several locations in Western Australia and were obtained from Graham Crosbie (Grain Products Laboratory, Department of Agriculture, South Perth, WA); four 1992 commercial noodle flours, reportedly milled from Australian Standard White (ASW) wheat of unknown extraction rate, were obtained from Dongah, Cheil, Daehan, and Daesun Flour Mills of South Korea; two 1992 commercial noodle flours of unknown extraction rate, which were 1:1 blends of hard red winter and Western white (HRW:WW) or dark northern spring and HRW (DNS:HRW) wheats, respectively, came from Dongae and Daesun Flour Mills; one Australian hard wheat flour of unknown extraction rate came from Daesun Flour Mill; two 1993 soft white wheat flours from the cultivars Geneva and Harus and three 1993 soft red wheat flours of unknown extraction rate came from Madison, FFR-555W, and Coker 9803, all five obtained from the Soft Wheat Quality Lab, Wooster, OH; two hard white spring (HWS) flours milled to ≈63% extraction rate at Kansas State University (KSU) from 1992 Klasic wheat grown in California and received from the Wheat Marketing Center, Portland; three HRW wheat flours, Eagle (1991), Karl (1991), and Larned (1992), milled to 62–64% extraction at KSU, and one hard white winter (HWW) wheat flour, Rio Blanco (1992), grown in Kansas and milled to 61% extraction, all from the U.S. Grain Marketing Research Laboratory, Manhattan, KS; and one 1992 flour, Western White (soft white and club, 9:1), milled to 56% extraction at KSU from wheat sent by the USDA-ARS, Western Wheat Quality Lab, Pullman, WA.

All chemicals were reagent grade unless otherwise specified.

General Methods

Flour moisture, protein, ash, Agtron color, falling number, and damaged starch were determined by standard methods (AACC 1983). The α-amylase in flour was determined by the method of McCleary and Sheehan (1987) using an assay kit from Mega-Zyme Pty. Ltd. Sydney, NSW. One unit of activity, termed a Ceralpha Unit, is defined as the amount of enzyme, in the presence of excess α-glucosidase and glucoamylase, required to release one micromole of *p*-nitrophenol from terminally blocked *p*-nitrophenyl maltoheptoside (BPNPG7) in 1 min under the defined assay conditions. All assays were run at least twice.

Particle size distributions of flour (100 g) were determined with the Alpine Air Jet Sieve (model A 200 LS, Alpine Ag., Augsburg, Germany) on sieves with openings of 15, 20, 38, 53, 75, and 106 μm. The percentages of fractions were determined from the weights of the overs on the sieves (Oh et al 1985).

Starch granule size distributions were determined on a Coulter Counter model TAII (Coulter Corp., Hialeah, FL). Wheat starch (≈100 mg) was added and mixed with 10 ml of isotonic saline solution containing 8.6 g/L of sodium chloride, 0.38 g/L of potassium chloride, 0.4 g/L of ethylenediaminetetraacetic acid, and 0.2 g/L of 2-phenoxyethanol in deionized water. The suspension was allowed to stand 30 min and shaken vigorously; then one to two drops of the slurry were removed and added to the isotonic solution (≈80 ml) in the sample reservoir of the instrument. Measurements were made on the channel numbers with particle diameters (μm) as follows: 1, 1.59–2.00; 2, 2.00–2.52; 3, 2.52–3.17; 4, 3.17–4.00; 5, 4.00–5.04; 6, 5.04–6.35; 7, 6.35–8.00; 8, 8.00–10.08; 9, 10.08–12.7; 10, 12.7–16.0; 11, 16.0–20.2; 12, 20.2–25.4;13, 25.4–32.0; 14, 32.0–40.3; 15, 40.3–50.8; and 16, 50.8–64.0.

Mixograms were obtained on doughs prepared from 10 g of flour, 14% moisture basis, at optimum absorptions. Strong mixing flours were characterized by a long mixing time, a high peak consistency, and a wide mixing curve compared to medium and weak flours. Starch lipids (SL) in wheat starch were estimated from phosphorus levels (Morrison 1964), because wheat starch contains negligible phosphorylated amylopectin (Lim et al 1994). Starch lipids (SL) were calculated according to the equation SL (mg/g) = 16.4 × phosphorus (mg/g) (Morrison 1985). The tests were done in duplicate.

Starch in Flour

Starch in flour was assayed by method 76-11 (AACC 1983) using glucoamylase and glucose oxidase, except the sample preparation was modified. Flour (500 mg) was wet with 95% ethanol (1 ml), and 1*M* sodium hydroxide (40 ml) was added with swirling. The mixture was warmed for 3 min at 55°C, and the solution was adjusted to pH 7 with 2*M* acetic acid (≈20 ml). After addition of glacial acetic acid (≈1ml) to pH 4.8, the standard method was followed. All samples were run in duplicate.

Nonstarch Lipids (NSL) and Total Lipids (TL) in Flour

NSL in flour (1.0 g, dry basis) were extracted at 25°C with water-saturated butanol (8.0 ml) (Morrison et al 1975). An aliquot (4 ml) of the extract and methanol (2 ml) containing 2.0 mg of internal standard heptadecanoic acid (C17:0) were placed in a screw-capped vial (30 ml) and vacuum-dried. After addition of 2 ml of methanolic boron trifluoride/methanol/benzene (35:35:30, v/v/v) under nitrogen, the tube was capped and heated at 60°C in a water bath for 1 hr. Fatty acid methyl esters (FAME) were extracted from the methanolysis reaction mixture by partitioning into hexane (5 ml), and the top layer was assayed for FAME on a Varian gas chromatograph (GC), model 3600 (Walnut Creek, CA) equipped with a flame-ionization detector. The capillary column was SUPELCOWAX 10, 30 m × 0.25 mm, with a film thickness of 0.25 μm (Supelco, Inc., Supelco Park, Bellefonte, PA). Column temperature was 200°C, injector temperature was 280°C, and detector temperature was 280°C. Flow rate was 3 ml/min. Response curves to the internal standard (C17:0) were determined for standard methyl esters of C16:0, C18:0, C18:1, C18:2, and C18:3 purchased from Supelco. The responses of those six methyl esters were summed in a chromatogram to calculate the total fatty ester level. Nonstarch lipids in wheat flour = FAME × 1.20, according to Morrison et al (1975).

TL lipids were determined by adding concentrated 12*M* hydrochloric acid (1.8 ml) to flour (0.5 g, dry basis) with methanol (2 ml) containing 2.0 mg of internal standard (C17:0) in a screw-capped vial under nitrogen (Morrison et al 1975). The tube was capped and heated in a boiling water bath for 45 min. After cooling, lipids were extracted by adding chloroform (2 ml), shaking vigorously, and centrifuging. An aliquot (1 ml) of the chloroform layer was transferred to a tube with a Pasteur pipette, and the solvent was removed by drying under high vacuum. The lipids then were treated with boron trifluoride methanolysis reagent, and the FAME extracted and assayed as described above. Total lipids = FAME × 1.32, according to Morrison et al (1975). All samples were run in duplicate.

Starch Isolation

Starch was recovered by the dough-washing method of Wolf (1964) with a slight modification by Kim and Seib (1993). The protease-digestion method was that of Soulaka and Morrison (1985). The protease (Pronase E, P-5147, Sigma Co., St. Louis, MO) contained <0.1 Ceralpha Unit/g of α-amlyase activity.

SP and WHC

SP of a starch or flour (1.0 g, dry basis) in 30 ml of water at 92.5°C was assessed by the method of Crosbie (1991) or by a

modification of that method. In the modified method, sample size was reduced to 0.5 g, and the quenching step in an ice bath was eliminated. Instead, the paste was centrifuged directly after heating. SP = $G/(A-B)$, where G is the gel weight, A is the dry sample weight, and B is the dry weight of soluble material in the supernatant. WHC was measured by the modified SP method, WHC = G/A. SP and WHC were determined in triplicate.

Total Amylose (TAM) and Lipid-Complexed Amylose (LAM) in Starch

TAM in starch was determined by iodine binding capacity (IBC) as described by Schoch (1964), except that lipids were removed before assay by extraction with a 3:1 (v/v) mixture of *n*-propanol and water at 100°C (Morrison and Coventry 1985). TAM was calculated from IBC assuming pure amylose complexes with 19.9 wt% iodine (Schoch 1964). Lipid-complexed amylose (LAM) was estimated by 7 × % lysophospholipids, according to Morrison et al (1993). All samples were run in duplicate.

Storage Modulus (G')

A starch paste was prepared by heating an aqueous starch slurry in a 50-ml polycarbonate centrifuge tube. The tube was immersed in a 90°C water bath and agitated by hand continuously for 3 min. Heating was continued for an additional 17 min with occasional agitation, and the hot paste was transferred to the cup of a concentric cylinder cell (C-14) of a Bohlin VOR rheometer fitted with a 90-g force/cm torsion bar (Bohlin Rheologi, Edison, NJ). The upper probe was lowered into the warm paste to a preset gap of 1 mm, and a thin layer of light mineral oil was used to cover the exposed surface of the gel. After the paste had cooled to 25°C, measurements were taken at an applied strain of 2% and a frequency of 0.2 Hz (Gudmundsson, and Eliasson 1989, Steeneken 1989). The instrument was calibrated with a viscosity standard fluid 1,000 (Brookfield Eng. Labs, Stoughton, MA) having 625 centipoise viscosity at 25°C. Storage moduli were determined in duplicate samples of gels, and the coefficient of variation was <3%.

Statistical Analysis

The general linear model and multiple regression procedures of the Statistical Analysis System (SAS 1986) were used for data analysis. Fisher's Least Significant Difference (LSD) procedure was used to compare means at the 5% significance level.

RESULTS AND DISCUSSION

Flour Samples

The three Australian soft wheat flours and the 12 U.S. flours contained ash levels of 0.41–0.44% and falling numbers (FN) above 379, except for two US soft red flours (Table I). The seven Korean commercial noodle flours also had low ash and high falling numbers. α-Amylase levels in the flours were low and ranged from 0.02–0.06 U/g (data not shown); malted bread flours often contain levels 20 times higher. The Australian and Korean noodle flours had protein levels between 8.5–9.2%, except the two commercial flours Daehan-2 and Daesun-2 with 10.4 and 11.5% protein, which were probably Chinese noodle flours. Starch levels in the 22 flours ranged from 77 to 83%. The usual inverse relationship was observed between protein and starch levels, except that the flour from Klasic-1 with 8.6% protein appeared somewhat low in starch (78%), whereas Karl flour with 12.3% protein appeared somewhat high (79%).

The damaged starch (DS) levels were <3% and >5%, respectively, for most of the soft and hard wheat flours (Table I). The DS levels in five of the commercial noodle flours were at intermediate levels, indicating mixtures of soft and hard wheat flours, again except for the Daehan-2 and Daesun-2 flours, which contained high DS. Mixograms indicated medium mixing strength for the three Australian flours and for four of the commercial noodle flours (Table I). The soft and hard wheat flours, except for FFR-555W and Larned, showed their expected weak and strong mixing properties, respectively. The flours from hard and soft wheats also gave the expected particle size distributions (Table II). Total lipid (TL) levels in the Australian flours were reduced, whereas NSL were not (Table I), which suggested that their starch lipids were low. NSL and TL were both low in the WW wheat flour, but were both high in the SR wheat flours.

Isolation of Wheat Starch

Wheat starch was isolated from representative flours in ≈65% recovery by dough washing and in ≈90% recovery by protease digestion. Doughs that were weakly cohesive, such as those from soft wheats, gave gluten particles in the first two dough-washing

TABLE I
Properties[a] of Flours Milled from Wheat Cultivars or Obtained from Korean Flour Mills

Wheat Class[b]	Cultivar or Mill Source	Protein (%)	Ash (%)	FN	Color	MS	DS (%)	TL (mg/100 g)	NSL (mg/100 g)	Starch
Australian soft (noodle)	Eradu	9.2	0.41	390	72	M	2.2	1,833 c[c]	1,295 b	83
	Gamenya	9.2	0.44	384	73	M	2.6	1,775 d	1,285 b	82
	Cadoux	9.1	0.41	388	72	M	2.4	1,784 d	1,253 b	82
Korean noodle flours	High value	9.0	0.41	452	78	M	5.6	2,007	1,385	82
	Mean value	8.4	0.37	452	74	M	4.8	1,954	1,249	80
	Low value	7.1	0.32	407	70	M	4.0	1,872	1,160	79
	Daesun-2[d]	11.5	0.40	426	62	S	6.0	1,889 bc	1,214 bc	78
	Daehan-2	10.4	0.38	512	70	S	7.0	1,812 c	1,123 c	79
U.S. SW	Geneva	7.9	0.40	440	71	W	1.2	1,833 c	1,201 bc	80
	Harus	8.6	0.41	400	72	W	1.5	1,965 b	1,259 b	83
U.S. SR	Madison	8.2	0.45	420	71	W	1.3	2,087 a	1,352 a	80
	FFR-555W	8.4	0.43	363	70	M	1.1	2,082 a	1,353 a	83
	Coker 9803	8.2	0.42	334	69	W	2.0	2,082 a	1,355 a	82
U.S. HWS	Klasic-1	8.6	0.50	408	68	S	7.5	1,958 b	1,352 a	78
	Klasic-2	10.5	0.43	436	68	S	6.1	1,944 b	1,262 b	79
U.S. HRS	Eagle	10.2	0.47	678	67	S	5.4	1,907 bc	1,305 a	78
	Larned	10.5	0.45	470	64	M	6.3	1,907 bc	1,183 bc	79
	Karl	12.3	0.44	570	65	S	4.0	1,911 bc	1,121 c	78
U.S. HWW	Rio Blanco	11.8	0.40	398	70	S	5.2	1,863 c	1,224 b	77
U.S. SWW	92 CLUB:SWW (10:90)	8.7	0.40	380	74	W	3.5	1,737 d	1,061 d	82

[a] FN = falling number (14% mb); MS = mixing strength; DS = damaged starch (14% mb); TL = total lipids (db); NSL = nonstarch lipids (db); starch (14% mb).
[b] SW = soft white; SR = soft red; HWS = hard white spring; HRS = hard red spring; HWW = hard white winter; SWW = soft white winter.
[c] Mean values in the same column with different letters are significantly different ($P < 0.05$).
[d] DNS to WW is 1:1.

steps that tended to plug the filter cloth. In the dough-washing procedure, small starch granules and many damaged granules were lost in the tailings fraction after centrifugation. Because small wheat starch granules contain approximately one-third more lipid than the large granules (Seib 1994), the lipid levels in the starches isolated by the protease method increased by 7–17% (Table III). Protein contamination in the wheat starches isolated by dough washing and protease digestion were 0.3–0.7% and 0.2–0.3%, respectively.

In the protease-digestion method, low-gravity centrifugation of a digested flour slurry gave supernatant plus three layers. Above the bottom white layer and below the top brown layer (tailings) was an off-white layer. The bottom layer of prime starch accounted for approximately three-fourths of the volume of the mixture, and the off-white layer about one-fourth. Light microscopy of the off-white layer showed that it was predominantly small wheat starch granules. The increased lipid and protein associated with the small wheat starch granules would explain their segregating atop the large granules.

Swelling of Starches from Flours

In the present investigation, a modification of the SP test of Crosbie (1991) gave excellent precision with a 2% cv. The SP of a wheat starch sample increased only slightly after heating past 30 min at 92.5°C (data not shown), in agreement with the observations of Tester and Morrison (1990) determined on a slurry of ≈5% wheat starch. The SP of wheat starches isolated by dough washing were the same when determined by either SP method (Fig.1A), but the SP of starches isolated by the protease method were sometimes lower by 1.2–2.0% when determined by the modified Crosbie method (Fig.1B). Differences in SP data occurred in high swelling starches, but nevertheless, the SP order remained the same. Unless otherwise stated, SP reported in this work were done by the modified method.

Wheat starches isolated by protease-digestion of wheat flour swelled more at 92.5°C than did those isolated by dough washing (Table IV). Once again, differences in SP were independent of the method of isolation. Perhaps, the extra damaged starch in the protease-isolated samples (Table III) or a reduced protein-lipid contamination of the starch accounted for their somewhat elevated SP.

The SP of all 33 starch samples ranged from 13.5 to 24.8 g/g (Table IV), which is comparable to the range of 14.9 to 21.9 g/g reported by Crosbie (1991). The SP of the 22 starches isolated by dough washing correlated well ($r^2 = 0.93$, $P = 0.0001$) with the WHC of the starches (data not shown). This result indicates that the amounts of amylose leached from the various wheat starches at 92.5°C were almost equal, and that differences in the swelling of the starches were caused mostly by other factors.

Flour SP

The SP at 92.5°C of the 22 flours and their starches isolated by dough washing (Table IV) were highly correlated (Fig. 2). The correlation was improved from $r^2 = 0.79$ to 0.93 ($P = 0.001$) by multiple regression analysis of the SP of the flour (SP_{flour}) with its starch's swelling power (SP_{starch}) and the flour's protein level (% protein on 14% mb) according to the equation:

$$SP_{flour} = 8.13 - 0.34\ (protein) + 0.73\ (SP_{starch})$$

The protein content of flour has a negative impact on the SP_{flour}, at least in part because of its inverse relation to the level of starch in flour. Multiple linear regression of SP_{flour} with the levels of lipids, protein, starch, and damaged starch gave $r^2 = 0.55$ with $P < 0.01$. Those data indicate that differences in flour swelling are

TABLE II
Particle Size Distributions of Flours (wt%)[a]

Size, μm	HWW	HWS	HRS	SR	SW	ASN
<38	23	27	24	40	40	46
38–53	21	17	18	14	12	13
53–75	29	30	30	14	14	15
75–106	26	26	28	26	26	26
106–125	1	0–1	0–1	5	6	1–2
>125	0	0	0	1	2	0

[a] HWW = hard white winter; HWS = hard white spring; HRS = hard red spring; SR = soft red; SW = soft white; ASN = Australian soft noodle flour. Values are means of the two or three flours in each class, except HWW. Data on the Australian soft noodle flour are the means of the Eradu, Gamenya, and Cadoux distributions.

TABLE III
Starch Lipids (SL) and Damaged Starch (DS) in the Starches Isolated by the Dough Washing and Protease Digestion Methods[a]

	Dough Washing		Protease Digestion	
Starch Sample	SL (mg/100 g)	DS (%)	SL (mg/100 g)	DS (%)
Gamenya	826	0.35	926	1.90
Cheil	871	···	927	···
Daehan-2	905	···	980	···
Geneva	838	0.32	921	0.70
FFR-555W	885	0.66	973	0.50
Klasic-2	949	1.71	1,002	1.92
Karl	1,003	1.74	1,175	3.10
Rio Blanco	842	0.92	960	1.95
Daesun-2[b]	970	···	1,058	···

[a] SL estimated by phosphorus level; DS estimated by glucoamylase digestion. Coefficient of variation: SL < 1%; DS < 8%.
[b] DNS to HRW is 50:50.

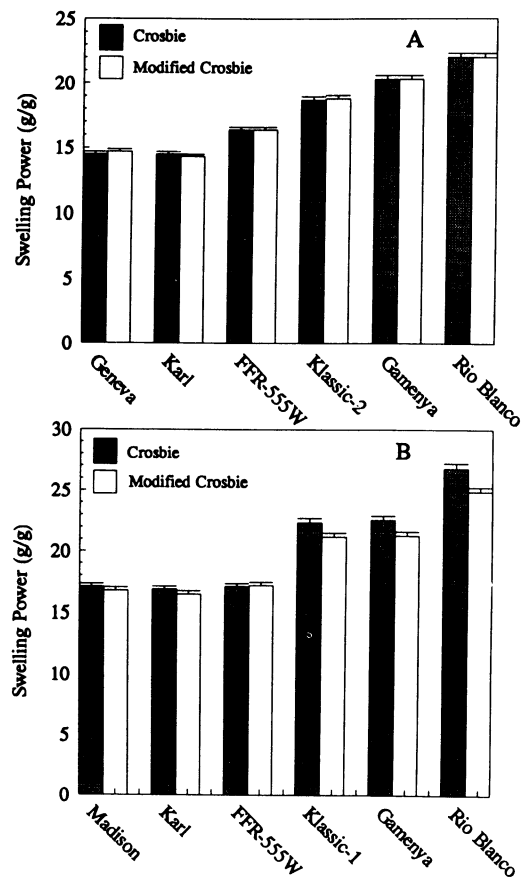

Fig. 1. Swelling powers of wheat starches at 92.5°C determined by the Crosbie and modified Crosbie methods; starches isolated by dough washing (**A**) and protease digestion (**B**).

caused mainly by differences in starch SP. SP_{flour} and SP_{starch} have been correlated with noodle quality previously (Toyokawa et al 1989, McCormick et al 1991), as well as with SV of flour and SP_{starch} (Crosbie 1991).

Starch SP and Lipid and Amylose Levels

The SP of the 22 wheat starches correlated negatively with their lipid levels, which ranged between 0.8 and 1.1% (Fig. 3). The SP of five of the starches, which were selected to cover the range of SP in the 22 samples, also correlated ($r^2 = -0.92$, $P = 0.01$) negatively with their amylose levels (data not shown). The latter correlation might be anticipated from the positive correlation between the amylose and lipid levels in wheat starch (Morrison and Gadan 1987, Morrison 1994) and in corn starch (South et al 1991).

TABLE IV
Flour and Starch Swelling Powers (SP) at 92.5°C

Cultivar or Mill Source	Protein (%)	SP_{flour} (g/g)	SP_{starch} (g/g)	
			Dough Washing	Protease Digestion
Eradu	9.2	21.1a[a]	21.7a	22.0b
Cadoux	9.1	21.0a	21.4a	22.0b
Gamenya	9.2	20.0a	20.3a	21.3b
Klasic-2	10.5	19.3b	18.8b	21.8b
Deahan-1	7.1	19.2b	17.8b	...
Daesun-1	8.6	19.2b	18.9b	21.8b
Rio Blanco	11.8	19.0b	22.0a	24.8a
Klasic-1	8.6	18.4b	17.8b	21.2b
Dongae-1	9.0	18.3b	17.4c	...
Cheil	8.5	18.3b	18.5b	...
Madison	8.2	17.8c	16.4d	17.7c
Daehan-2	10.4	17.3c	17.6c	...
FFR-555W	8.4	17.3c	16.4d	16.6d
Coker 9803	8.2	17.3c	17.0c	...
Harus	8.6	16.6d	16.5d	...
Club:SWW	8.7	16.4d	16.2d	...
Dongae-2	8.9	16.2d	15.8d	...
Daesun-2	11.5	16.0d	16.0d	...
Geneva	7.9	15.5e	15.4e	16.2d
Larned	10.5	15.5e	18.2b	...
Karl	12.3	15.2e	17.0c	16.5d
Eagle	10.2	14.8e	13.5 f	...

[a] Mean values in the same column with different letters are significantly different ($P < 0.05$).

The lysophospholipids in wheat starch, like those in barley starch, probably occur in the form of amorphous, lipid-complexed amylose (LAM) (Morrison et al 1993). The level of LAM in the 22 wheat starches ranged from 5.6 to 8.3%. For the five wheat starches selected for their range of SP, LAM varied from 5.8 to 7.2% and TAM from 27.4 to 29.6% (data not shown). Thus, LAM accounted for ≈20–30% of TAM in the five starches. Morrison (1994) reported that LAM accounted for 18–22% of TAM in mature wheat starch granules.

The swelling of barley starches has been found to be promoted strongly by amylopectin content and inhibited strongly by LAM (Morrison et al 1993). Our results on the swelling of wheat starches are in accord with those conclusions. High-swelling wheat starches had reduced levels of both total phospholipids and TAM. When TAM increased, then the level of the AP decreased. As the level of TAM increased in the wheat starches, the level of LAM increased, which further reduced swelling. Whether a third factor, amylopectin structure, differs in high- and low-swelling wheat starches remains to be determined. Kobayashi et al (1986) found no differences in amylopectin structure among 10 starches from five classes of wheats, but Shibanuma et al (1994) found different chain lengths in one fraction of debranched wheat amylopectins.

Reduced levels (≈2%) of TAM in starch from Western Australia's ASW wheats has been reported previously (Loney et al 1975, Moss 1980, Oda et al 1980, Endo et al 1989, Toyokawa et al 1989). Moreover, the differences in level may be as high as 5%, if corrections are made for iodine-amylopectin reaction in the amylose assay procedure (Shibanuma et al 1994). In U.S. wheats, soft wheat starches contain 2.0–2.5% less TAM than that of durum wheat starches and 1.0–1.5% less TAM than that of HRW and HRS wheat starches (Seib 1994). Moreover, the lysophospholipid in durum wheat starch was elevated by 0.20% compared to that of soft wheat starches and 0.05–0.10% compared to hard wheat starches (Seib 1994). Thus, the order of increasing SP (85°C) of the starches from the various U.S. wheat classes was durum < HRS < HRW < SRW.

Gelling of Five Wheat Starches

Upon cooling of a 6% wheat starch paste prepared from Gamenya at 90°C and holding at 25°C, a low value of elastic modulus was observed after 40–60 min (Fig. 4A), in agreement with previous reports (Ring 1985; Biliaderis and Zawistowski 1990). At 8–10.5% concentration of Gamenya starch, G' rose rapidly with storage time up to 20–30 min, and then rose much

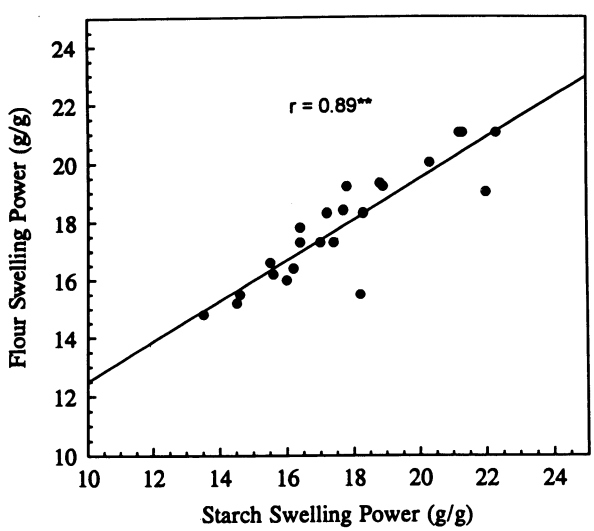

Fig. 2. Swelling powers of wheat flours correlated with swelling powers of their starches at 92.5°C.

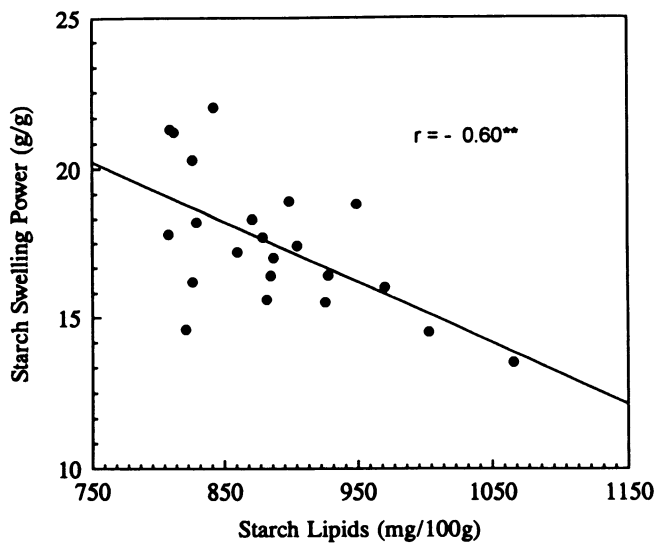

Fig. 3. Starch lipids and starch swelling power at 92.5°C.

more slowly after ≈60 min. (Fig. 4A). The rapid rise to a metastable value of gel strength is understood to be the gelation of amylose in the continuous phase of a paste. The swollen granules imbedded in the AM gel are more or less deformable depending on size, swelling, and recrystallization, and they behave like fillers in the continuous amylose phase (Miles et al 1985, Orford et al 1987, Steeneken 1989, Morris 1990).

The starch from Karl wheat, which swelled much less than Gamenya wheat starch (17.0 vs. 20.3 g/g, Table IV), had gels with G' values (Fig. 4B) that were surprisingly near those observed for Gamenya (Fig. 4A). Steeneken (1989) showed that

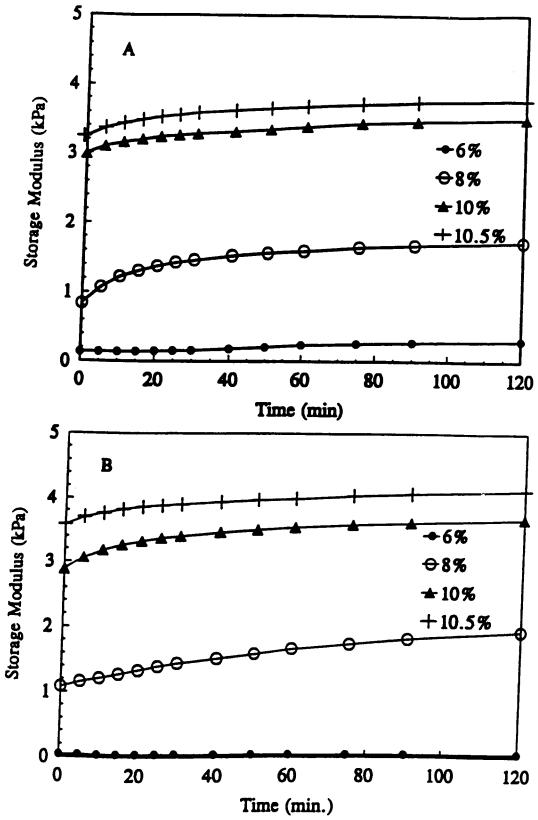

Fig. 4. Storage moduli (G') in kPa of (A) Gamenya and (B) Karl wheat starch gels at different concentrations determined at 25°C, 2% strain, and 0.2 Hz frequency. Starches were isolated by dough washing.

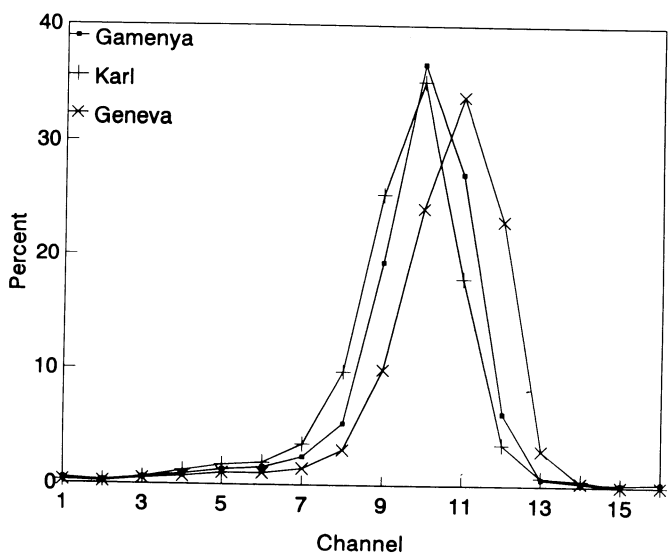

Fig. 5. Granule size distributions (Coulter Counter) of wheat starches isolated by dough washing.

low-swelling, cross-linked starches at 4–8% solids had gels with greater G' values than the high-swelling parent starches; the same was found by Ring (1985). However, granule size distributions of wheat starches have been found to influence G' (Eliasson and Bohlin 1982). Figure 5 shows that Karl wheat starch contained smaller average granules than Gamenya. Dengate and Meredith (1984) reported that, among 59 cultivars grown in New Zealand, Gamenya had a population of extra large granules with a mean diameter (Coulter Counter) of 36 μm, although our sample of Gamenya failed to show extra large granules (Fig 5). Six other samples of Karl wheat grown in different locations and years consistently have shown reduced sizes of starch granules (data not given). The small granules in Karl wheat starch may weaken its macroscopic gel at 6.0–10.5% solids. Gels prepared at 90°C from oat starch with its tiny granules had G' values ≈50% below those of wheat starch with the same SP_{90}, although the oat starch also contained elevated lipids (Gudmundsson and Eliasson 1989).

At 6% starch solids, the metastable G' values of other wheat starch gels increased with the SP of the starch (Fig. 6). Apparently, the strength of a wheat starch gel at 6% was dominated by the concentration of amylose in the continuous phase. The high-swelling starch of Gamenya, for example, gave ≈20% solubles (amylose) compared to ≈15 and ≈17% for the starches from Karl and Geneva, respectively, all at 92.5°C and 1.7% solids. The granule size distributions decreased in the order of Geneva > Gamenya > Karl (Fig. 5), whereas Rio Blanco and Klasic 2 granules had size distributions closely resembling that of Gamenya (data not shown).

The metastable values of G' increased for all starches when starch concentration was increased from 6 to 10.5%. However, the increase was less for Gamenya starch than for the other wheat starches, except for Karl (Fig. 6). This indicates a convergence or possibly a crossover (Steeneken 1989) of G' values for the high- and low-swelling starches as the concentration of starch is in-

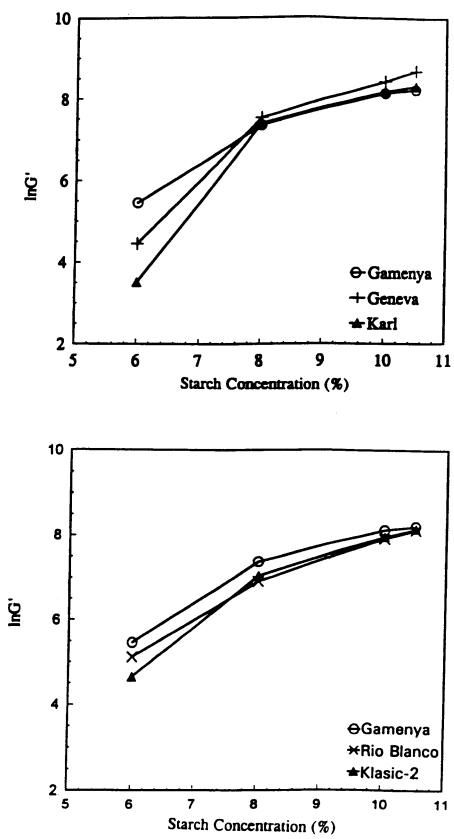

Fig. 6. Natural log of storage moduli (G') in Pa of wheat starch gels after 1 hr and 25°C for five starches isolated by dough washing.

creased >11% in the gels. Geneva starch, with its large granules and low SP, gave the most elastic gels >10% solids (Fig. 6).

The viscoelastic properties of a concentrated wheat starch gel may be explained in terms of the composite model of gel structure and depend on 1) the rigidity of the dispersed particles (swollen granules); 2) the viscoelasticity of the continuous phase; and 3) the adhesion between the dispersed and continuous phase (Evans and Haisman 1979, Eliasson and Bohlin 1982, Ring 1985, Steeneken 1989). The close-packing concentration of wheat starch has been estimated to be 5.4–7.9% (Steeneken 1989, Shi et al 1991). As concentration is increased >8% solids, the magnitude of the storage modulus of a wheat starch gel is thought to depend increasingly on the size and deformability (rigidity) of the swollen granules. Wheat starch gels at 20 and 35% starch solids increased in elasticity when 2% (based on starch) of lysophosphatidylcholine was added (Biliaderis and Tonogai 1991). Presumably, the monoacyl lipid reduced granule swelling, and the extra water between granules somehow promoted adhesion or gelation of amylose.

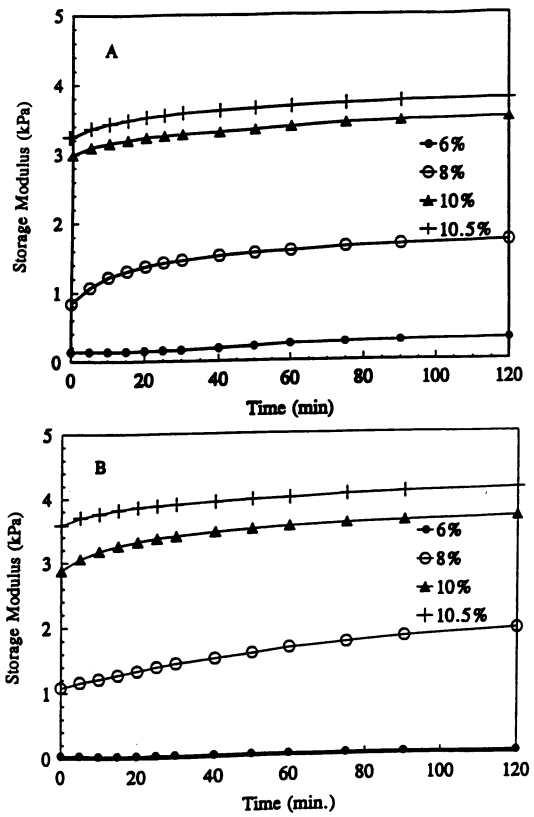

Fig. 7. Storage moduli (G') in kPa of starch gels **(A)** compared to flour gels **(B)**.

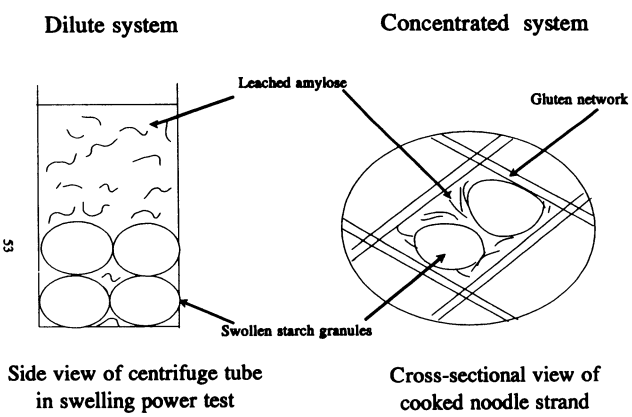

Fig. 8. Sketch of wheat starch behavior in a swelling power test and inside a cooked noodle.

Gamenya starch swelled more than the other wheat starches in a dilute paste, but above the close-packing concentration of wheat starch (≈8%), water is limiting. Concentrated gels of Gamenya wheat starch may be less elastic than those of other wheat starches because of differences in granule rigidity brought on by reduced amylose content and other molecular differences. More rheological data are needed on gels with starch concentrations up to 30%.

The low-swelling wheat starch of Harus ($SP_{92.5}$, 16.6 g/g) had a high metastable modulus (G') at 10% solids compared to G' values of the higher swelling starches from Klasic-1 ($SP_{92.5}$, 17.8 g/g) and Daesun-1 ($SP_{92.5}$, 18.9 g/g) (Fig. 7). The flours from those three wheats all had protein levels of 8.6%, and the flour gel of Harus had the highest G', whereas the other two flour gels had almost the same G' (Fig. 7).

Working Model of Starch in Wheat Noodles

A working model of starch in a cooked wheat noodle must differentiate between at least two regions on a strand (Dexter et al 1979, Moss et al 1987). At or near the surface, starch is cooked in excess water and subjected to the shear forces of boiling water. Under the surface of the strand, water is limited, salt concentration is high, and shear forces are mild because of bending of the strand. In a salt noodle made from low protein flour, we may hypothesize that large, highly swollen granules at its surface are enmeshed in the thin gluten matrix or attached to the matrix by exuded amylose. On the other hand, small and relatively rigid granules are held weakly. Moreover, the large deformable granules fill voids and cracks at the surface. The net result is a smooth, clean, and shiny surface for salt noodles made from high-swelling flours with large granules. Low-swelling flours with small starch granules give cooked noodles whose surface is rough in mouthfeel and dull in appearance. At the surface of alkaline noodles, which are prepared from flours with moderate to high protein levels, the increased density of the gluten matrix ensures trapping of small granules. Starch granule size declines in importance.

In the interior of a salt noodle, high-swelling starch causes extra water to be imbibed, which has been demonstrated by the increased noodle yield from high-swelling flours (Crosbie et al 1992). The extra swelling of starch inside a strand (Fig. 8) together with low flour protein produces a noodle with a soft bite. Meanwhile, low levels of amylose may be leached between granules and produce good elasticity when the continuous amylose phase gels. Krüsi and Neukom (1984) reported ≈5% cold-water extractables from fresh wheat starch gels prepared at 40% solids and 100°C.

In the interior of alkaline noodles, the inherently low-swelling starches of hard wheats (Seib 1994) are restricted further from swelling by the carbonate salts (Moss et al 1986). The resulting starch gels are hard and strongly elastic, which together with the high protein in hard wheat flours and relatively small voids (Moss et al 1987), produces chewy noodles.

CONCLUSIONS

Starches from three Australian soft wheats that are segregated for salt noodle production swell highly in hot water. The high swelling is associated with reduced levels of amylose and lipid in the granules. One U.S. hard white wheat, Rio Blanco, appears to have high-swelling starch.

ACKNOWLEDGMENTS

We thank Bob Bequette, Graham Crosbie, Charles Deyoe, Patrick L. Finney, Patrick J. McCluskey, and Kwan Hei Park for samples of wheats and flours. Sincere appreciation is extended to Y. T. Liang for assistance

in determining damaged starch, total starch, amylose, and granule-size distributions.

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[Received February 27, 1995. Accepted October 23, 1995.]