

Starch Properties and Stability of Club and Soft White Winter Wheats from the Pacific Northwest of the United States

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ABSTRACT

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Based on examination of 192 club and soft white winter (SWW) wheat samples, club and SWW wheat flours showed comparable levels of starch damage and flour peak viscosity, while differing significantly in starch content. Varietal differences and growing conditions had strong influence on the characteristics of both classes of wheat flour. Club wheat flour exhibited better stability in starch content and starch damage than did SWW wheat flour. A significant correlation between starch damage and cookie diameter in both club and SWW wheat was observed ($r = -0.480$, $P < 0.0001$ for club wheat and $r = -0.430$, $P < 0.0001$ for SWW wheat). Sponge cake volume was positively correlated with starch content in both classes of wheat ($r = 0.362$, $P < 0.01$ for club wheat and $r = 0.181$, $P < 0.05$ for SWW wheat). When wheat samples were grown in one location over three years, club and SWW wheat flours had comparable starch content. However, flour and prime starch peak viscosities were significantly different in club than in SWW wheat. Club wheat flour had lower starch damage and amylose content, as measured by high-performance size-exclusion chromatography (HPSEC), than did SWW wheat flour. Crop year and varietal differences had significant effect on amylose

content, starch damage, and flour and starch peak viscosities, but not on starch content, in both classes of wheat flour. When wheat samples were grown in one year over seven locations, club wheat flour was higher in starch content, lower in starch damage, and comparable in amylose to SWW wheat flour. Both flour and prime starch viscosities were significantly higher in club wheat than in SWW wheat. Varietal differences and growing location had strong influence on starch properties in both classes of wheat. Peak viscosity of the isolated starch did not correlate well with the corresponding flour, indicating that flour pasting property does not reflect the pasting property of starch. The fine structure of isoamylase-debranched amylopectins from club and SWW wheats had a similar trimodal pattern, with maximum at \approx DP 15 and two valleys at \approx DP 20 and 45, respectively. Although wheat flour samples differed widely in their prime starch peak viscosity, no significant difference between debranching patterns was obtained. These results indicate that the fine structure of amylopectin might not be responsible for the large differences in prime starch pasting property.

The starch content of wheat has been reported to be in the range of 54–72% of the kernel's dry weight (Pomeranz and MacMaster 1968, Cerning and Guilbot 1974, Pomeranz 1988). Soft wheat cultivars, in general, have a higher starch content (69%) than do hard wheat cultivars (64%) (Miller 1974). Several starch properties have been reported to be important in end-use performance. Eliasson (1989) stated that wheat starch could affect the texture, viscosity, and water-holding capacity of cake batter and crumb. Udon noodles require flour with starch of high viscosity and rapid breakdown after peak (Baik et al 1994). The quality of the product is thus dependent on the starch gelatinization properties. Starch properties may vary because of the ratio of linear amylose to branched amylopectin, degree of crystallinity, starch granule size distribution, and the amount of minor components in the starch.

In wheat starch, amylose content is \approx 28% (Morrison and Laignelet 1983). The amylose content of wheat starch apparently varies only to a limited extent (Lineback and Rasper 1988). The average chain length of wheat amylopectin was reported to be in the range of 17–23 (Lii and Lineback 1977). Kobayashi et al (1986) studied amylopectins from five classes of wheat and concluded that all wheat amylopectins studied were identical in debranching patterns, indicating no detectable differences in their structures. Yuan et al (1993) studied the fine structure of amylopectin in relation to gelatinization and retrogradation behavior of maize starches. They observed that a higher proportion of longer chains in the amylopectins was associated with higher temperature and enthalpy for both gelatinization and retrogradation.

Zeng et al (1997) reported that higher peak, greater breakdown, lower final viscosity, negative setback, and less total setback were

associated with lower amylose content. The authors also concluded that reduced quantity of starch amylose due to decreased granule-bound starch synthase profoundly affects starch gelatinization, pasting, and gelation properties. Šebecic (1989) investigated factors affecting wheat flour amylograph peak viscosity and found no correlation between the content of amylose and amylopectin with amylograph peak viscosity. A number of minor non-carbohydrate constituents (lipid, protein, phosphorus, and endogenous enzyme) may also be present in wheat starch. Although they are present in small quantities, they can affect the properties and behavior of the starch (Lineback and Rasper 1988, Deffenbaugh and Walker 1989). Phosphorus, existing at concentrations $<0.09\%$, plays an important role in starch functional properties, such as paste clarity, viscosity consistency, and paste stability (Jane et al 1996).

Growing conditions have strong influence on wheat starch characteristics (Mathewson and Pomeranz 1978, Meredith and Pomeranz 1982, Shi et al 1994, Lin and Czuchajowska 1996, Morris et al 1997). Mathewson and Pomeranz (1978) concluded that environmental conditions and differences in starch properties influence the α -amylase susceptibility of starches and, consequently, the values of amylograph peak viscosity. Meredith and Pomeranz (1982) observed a marked varietal and seasonal, but not locational, effect on pasting of wheat flours and starches. Part of the variation in pasting properties of flour can be explained by differences in protein content and starch damage. Shi et al (1994)

TABLE I
Overall Average Values for Starch Content, Starch Damage, and Flour Peak Viscosity of 68 Club and 123 Soft White Winter (SWW) Wheats^a

Measurement	Club	SWW
Starch content (% dwb)	81.00a	80.52b
Starch damage (% dwb)	3.73a	3.78a
Flour peak viscosity (BU)	752a	766a

^a Values followed by the same letter in the same row are not significantly different ($P < 0.05$).

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TABLE II
Analysis of Variance for Properties of Flours of 68 Club and 123 Soft White Winter (SWW) Wheats^a

Property	Source of Variation	Club		SWW	
		Mean Square	F-Value	Mean Square	F-Value
Starch content	Variety	6.7077	1.50	15.1634	5.96**
	Location	11.3982	2.55	18.2250	7.16***
	Year	33.9727	7.61*	62.2220	24.45***
	Variety × location	3.8064	0.85	3.2808	1.29
	Variety × year	5.8180	1.30	28.3028	11.12***
	Location × year	5.9588	1.34	11.2761	4.43**
Starch damage	Variety	2.8337	5.25**	9.0483	118.75***
	Location	1.1688	2.16	1.6337	21.44***
	Year	1.0307	1.91	8.9565	117.55***
	Variety × location	0.7771	1.44	0.1545	2.03*
	Variety × year	1.8553	3.44*	0.8188	10.75***
	Location × year	1.8962	3.51**	1.6833	22.09***
Flour peak viscosity	Variety	64,953.0117	25.79***	109,341.0919	11.60***
	Location	65,240.9884	25.91***	105,062.1818	11.15***
	Year	156,801.5537	62.27***	317,826.3790	33.73***
	Variety × location	11,464.3014	4.55*	6,363.8815	0.68
	Variety × year	11,897.0773	4.72*	5,481.6113	0.58
	Location × year	13,511.2700	5.37**	12,768.2297	1.36

^a *, **, *** = $P < 0.05$, 0.01 , and 0.0001 , respectively.

TABLE III
Starch Content, Characteristics, and Pasting Properties of Club and Soft White Winter (SWW) Wheats Grown in Walla Walla, WA, over Three Years^a

Measurement	Club	SWW
Starch content (% dwb)	80.46a	79.61a
Amylose content(%)		
Iodometric	28.81a	29.87a
HPSEC ^b (%)	33.49b	36.40a
Starch damage (% dwb)	3.56b	3.74a
Flour peak viscosity (BU)	826a	731b
Starch peak viscosity (BU)	441a	372b

^a Values followed by the same letter in the same row are not significantly different ($P < 0.05$).

^b High-performance size-exclusion chromatography.

found that elevated temperature during the grain-filling period can reduce starch accumulation and size of starch granules, resulting in deformed starch granules. With increasing temperature during grain filling, starch lipid levels increase markedly, amylose level increase slightly, gelatinization temperature of the starch increases, and swelling of starches in hot water decreases. Shi et al (1994) also observed that starches from wheats grown at 40°C had increased proportions of unit chains with degree of polymerization (DP) of 10–16 and reduced proportions of unit chains with DP 17–21.

A large number of club and soft white wheat (SWW) cultivars are commercially grown under very diverse climatic conditions in the Pacific Northwest region of the United States. However, variation in starch properties among wheat cultivars and their stability over growing conditions have not been subjected to systematic study. Therefore, the objectives of this study were: 1) to investigate the differences in starch characteristics and quality stability between club and SWW wheats grown in the Pacific Northwest; 2) to evaluate the effect of starch characteristics on pasting properties and end-use performance; 3) to study the relationship between flour and starch pasting properties; and 4) to determine amylopectin fine structure of club and SWW wheats.

MATERIALS AND METHODS

Wheat Samples

This study was conducted in three parts. In the first part, 191 soft wheat flours were used, including 68 club and 123 SWW wheats. The wheat samples were collected from seven locations in the Pacific Northwest (Cavendish, Coulee City, Cunningham, Pomeroy,

Pullman, Ritzville and Walla Walla), from the 1988, 1990, and 1993 crop years. Club wheats included cultivars Moro, Tres, Crew, and Hyak. SWW wheats included cultivars Hill81, Lewjain, Nugaines, Daws, Dusty, Madsen, and Stephens. All samples were provided by C. J. Peterson (USDA-ARS, Pullman, WA).

In the second part of this study, only wheats grown in Walla Walla, WA, were used. To exclude location effects, both classes of wheat were grown in 1988, 1990, and 1993 under the same soil and climatic conditions. Average temperatures and total rainfall during these years were: 12.3°C, 411 mm; 12.7°C, 449 mm; and 10.3°C, 648 mm, respectively.

In the third part of this study, three selected SWW wheats (Hill81, Madsen and Stephens) and three selected club wheats (Crew, Tres, and Hyak) were investigated. To eliminate yearly variation, the cultivars were grown in 1990 in seven locations covering broad soil and climatic conditions. Average temperature range was 9.3–12.7°C and total rainfall range was 239–518 mm for these locations. The differences in protein content in a single cultivar exceeded 4.5%.

All samples were milled on a Bühler experimental mill to ≈60% extraction rate by approved method 26-31 (AACC 1995). Flour moisture content was measured by approved method 44-15A (AACC 1995). Flour protein content ($N \times 5.7$) was determined by an FP-428 N-analyzer (Leco Corp., St. Joseph, MI). Starch content of flour was determined by using a total starch assay kit (Megazyme, Bozeman, MT). The prime starches were isolated from flour according to Czuchajowska and Pomeranz (1993) and purified two times with deionized water. Protein content ($N \times 5.7$, dwb) in the prime starches was <0.5%, indicating highly purified starches. Pasting properties of flour and prime starch were evaluated using a Brabender Visco/amylograph (Shuey and Tipples 1980). Flour (65 g, 14% mc) or prime starch (40 g, dwb) was suspended in 450 mL of distilled water, and peak viscosity was obtained from the amylograph curve. Starch damage of flours was determined by approved method 76-31 (AACC 1995).

Characteristics of Starch

Amylose content of prime starch was determined by iodometric method (Knutson and Grove 1994) and by high-performance size-exclusion chromatography (HPSEC). The starch solubilization procedures for HPSEC for estimation of amylose content were according to Bradbury and Bello (1993). A 20-mg starch sample was solubilized in 4 mL of 90% (v/v) dimethyl sulfoxide (DMSO) at 90°C with continuous stirring for 16 hr. The solubilized starch was centrifuged at $3,000 \times g$ for 5 min, then filtered through a

TABLE IV
Analysis of Variance for Club and Soft White Winter (SWW) Wheats Grown in Walla Walla, WA, over Three Years^a

Property	Source of Variation	Club		SWW	
		Mean Square	F-Value	Mean Square	F-Value
Starch content	Variety	0.9149	1.03	1.9917	3.90*
	Year	0.0058	0.01	1.7139	3.36
	Variety × year	9.7726	10.98**	8.4025	16.45***
Amylose content Iodometric	Variety	57.3463	63.62***	9.0676	6.18**
	Year	35.9933	39.93***	20.5592	14.00**
	Variety × year	7.6522	8.49**	7.2181	4.92**
HPSEC ^b	Variety	97.5830	91.59***	45.8309	38.65***
	Year	11.2253	10.54**	6.4322	5.42*
	Variety × year	12.1117	11.37**	23.7705	20.05***
Starch damage	Variety	1.0240	329.35***	1.7762	419.02***
	Year	0.8937	287.44***	1.8725	441.73***
	Variety × year	0.1252	40.26***	0.2158	50.91***
Flour peak viscosity	Variety	57,810.0694	583.59***	58,056.3521	1,161.13***
	Year	60,918.7500	725.84***	296,437.2179	5,928.74***
	Variety × year	23,981.2500	285.73***	17,663.8726	353.28***
Starch peak viscosity	Variety	35,384.7854	841.58***	24,648.4954	645.34***
	Year	13,281.2500	315.88***	693.8118	18.17***
	Variety × year	4,747.0833	112.90***	2,106.4677	55.15***

^a *, **, *** = $P < 0.05$, 0.01 , and 0.0001 , respectively.

^b High-performance size-exclusion chromatography.

TABLE V
Starch Content, Characteristics, Flour, and Prime Starch Peak Viscosity of Soft White Winter (SWW) and Club Wheat Cultivars Grown in Walla Walla, WA, over Three Years^a

Cultivars	Starch (% dwb)	Amylose (%)		Starch Damage (%, dwb)	Peak Viscosity (BU)	
		Iodometric	HPSEC ^b		Flour	Starch
SWW						
Hill81	79.60a	28.60bc	37.90a–c	4.07bc	649c	338e
Lewjain	80.34a	30.50a–c	34.11de	3.16ef	806ab	323e
Nugaines	79.60a	29.41a–c	31.70ef	3.94bc	874a	459bc
Daws	80.19a	28.27c	36.68b–d	3.54d	708bc	448bc
Dusty	79.50a	31.09ab	37.60a–c	2.79f	835a	391d
Madsen	78.55a	30.73a–c	40.48a	4.58a	634c	333e
Stephens	78.86a	31.93a	38.90ab	4.25ab	591c	274f
Club						
Moro	80.76a	28.57bc	32.22e	2.99f	665c	339e
Tres	79.90a	24.70d	35.53cd	3.85cd	876a	481ab
Crew	80.53a	31.04a–c	28.90f	3.87b–d	895a	515a
Hyak	80.74a	31.99a	39.23ab	3.51de	910a	421cd

^a Values followed by the same letter in the same column are not significantly different ($P < 0.05$).

^b High-performance size-exclusion chromatography.

0.45- μ m nylon filter (Alltech Associates, Deerfield, IL) before injection. The amylose content of starch was determined by HPSEC as the ratio between total peak area and the peak area corresponding to amylose (Kobayashi et al 1985).

The procedure for preparation of isoamylase-debranched amylopectin was adapted from Yuan et al (1993), with modifications as follows. Debranching was performed with 525 units of isoamylase (EC 3.2.1.68, Sigma Chemical Co., St. Louis, MO) and 2 mL of 0.1M sodium acetate buffer (pH 3.8). The final DMSO concentration of sample mixture was adjusted to 30% with pure DMSO before being heated in boiling water to inactivate enzymes. The degree of polymerization (DP) of enzyme debranched amylopectin of selected samples was determined using the same HPSEC system. The number-average degree of polymerization of the linear fractions in debranched amylopectin was calculated as MW/162 (Bradbury and Bello 1993).

HPSEC

Solubilized starch (100 μ L) or isoamylase-debranched starch solution was injected into a two-column HPSEC system (Bio-Sil SEC 125, 300 \times 7.8 mm, Bio-Rad, Richmond, CA) using 30% DMSO as the mobile phase at a flow rate of 0.5 mL/min. The two-column system was preceded by a guard column (80 \times 7.8 mm) and

a 2- μ m precolumn filter (A315, Upchurch Scientific, Oak Harbor, WA). The HPSEC system consisted of an autosampler (model 1050, Hewlett Packard, Wilmington, DE), a solvent-delivering system (model 2350 HPLC pump and model 2360 gradient programmer, ISCO, Inc., Lincoln, NE), a differential refractometer (R401, Waters Associates, Inc., Milford, MA), and a computer equipped with HPLC 3D ChemStation software (Hewlett Packard). The columns and detector (sensitivity at 32 \times) were maintained at a constant temperature (35°C). The HPSEC system was calibrated using four pullulan standards (Polymer Laboratories, Amherst, MA) with MW 112,000, 22,800, 5,900, and 738, respectively. A linear relationship ($r^2 = 0.992$) between log molecular weight and retention time was obtained.

End-Product Quality

The procedure of Finney et al (1950) was used to make sugar-snap cookies. The larger the cookie diameter, the better the flour quality for pastry (Kaldy and Rubenthaler 1987). Japanese sponge cakes were made according to Nagao et al (1976) with modifications as follows. A 50-g flour sample for each cake was used instead of 100 g. A smaller baking pan with inside dimensions of 10.5 cm, depth of 6.0 cm, and inside volume of 520 mL was used. Cake volume was determined after cooling 1 hr at room temperature.

Statistical Analysis

All tests were run at least in duplicate. Least significant difference (LSD), analysis of variance (ANOVA), and correlation analysis were performed using the Statistical Analysis System (SAS Institute, Cary, NC).

RESULTS AND DISCUSSION

Wheats Grown in Seven Locations over Three Crop Years

The overall average starch content, starch damage, and flour peak viscosity of the 68 club and 123 SWW wheat flours are listed in Table I. Club wheat flour was significantly higher in starch content than was SWW wheat flour, although there was no difference in protein content. Both classes of wheat flour had similar levels of starch damage and flour peak viscosity.

The effects of varietal differences, growing location, and crop year on those measurements for club and SWW wheat flours are summarized in Table II. Varietal differences and growing location had significant effect on starch content in SWW wheat flour but not on club wheat flour. Cultivar-by-year and location-by-year interactions caused significant variation in starch content in SWW wheat flour but not in club wheat flour. Crop year contributed the largest variation in starch content in both classes of wheat flour. Growing conditions (crop year and location) did not cause significant variation in starch damage in club wheat flour, while cultivar and growing conditions had stronger influence on starch damage in SWW wheat flour than in club wheat flour. Although interactions caused significant variation in starch damage, varietal

differences represented the largest variation in starch damage in both classes of wheat flour. Starch damage in soft wheat flours is mainly genetically controlled (Lin and Czuchajowska 1996). Varietal differences and growing conditions had strong influence on flour peak viscosity in both wheat flour classes. Cultivar-by-location, cultivar-by-year, and location-by-year interactions in club wheat were significant but small compared to cultivar and growing conditions. A significant correlation was found between starch damage and cookie diameter in both classes of wheat ($r = -0.480$, $P < 0.0001$ for club wheat and $r = -0.430$, $P < 0.0001$ for SWW wheat). This decrease in cookie diameter with increased starch damage has also been reported by Gaines et al (1988). Starch content in both classes of wheat flour correlates positively with sponge cake volume ($r = 0.362$, $P < 0.01$ for club wheat and $r = 0.181$, $P < 0.05$ for SWW wheat). This correlation might have resulted from the

TABLE VI
Starch Content, Characteristics, and Pasting Properties of Club and Soft White Winter (SWW) Wheats Grown in 1990 at Seven Locations^a

Measurement	Club	SWW
Starch content (% dwb)	81.10a	80.07b
Amylose content		
Iodometric (%)	30.80a	31.63a
HPSEC ^b (%)	35.79a	36.98a
Starch damage (% dwb)	3.75b	4.13a
Flour peak viscosity (BU)	811a	744b
Starch peak viscosity (BU)	456a	373b

^a Values followed by the same letter in the same row are not significantly different ($P < 0.05$).

^b High-performance size-exclusion chromatography.

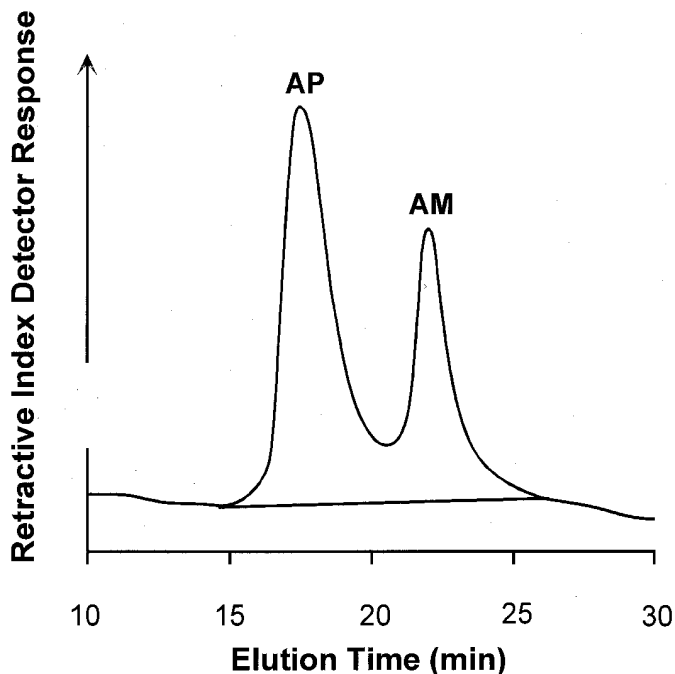


Fig. 1. Amylopectin (AP) and amylose (AM) peaks of solubilized wheat starch eluted with two high-performance size-exclusion columns and 30% (v/v) dimethyl sulfoxide as eluent at a flow rate of 0.5 mL/min.

TABLE VII
Analysis of Variance for Club and Soft White Winter (SWW) Wheats Grown in 1990 at Seven Locations^a

Property	Source of Variation	Club		SWW	
		Mean Square	F-Value	Mean Square	F-Value
Starch content	Variety	4.6518	3.93*	1.2462	1.39
	Location	6.8550	5.80**	13.6494	15.20***
	Variety × location	5.3812	4.55**	2.0622	2.30*
Amylose content	Iodometric				
	Variety	0.1747	0.15	11.0204	6.67**
	Location	11.1840	9.66***	9.5314	5.77**
HPSEC ^b	Variety × location	14.1786	12.25***	5.5636	3.37**
	Variety	30.1209	22.96***	55.1193	57.17***
	Location	10.8153	8.24**	14.8321	15.38***
Starch damage	Variety × location	24.8675	18.95***	25.0096	25.94***
	Variety	0.3849	127.52***	1.4234	617.60***
	Location	0.7060	233.89***	1.5365	666.67***
Flour peak viscosity	Variety × location	0.0827	27.39***	0.2453	106.42***
	Variety	14,879.9206	164.82***	29,761.0863	462.31***
	Location	101,243.1399	1,121.46***	33,535.4001	520.94***
Starch peak viscosity	Variety × location	19,912.4306	220.57***	6,285.2092	97.63***
	Variety	5,701.8045	127.45***	11,082.7381	235.68***
	Location	20,146.1706	450.33***	14,810.7143	314.96***
	Variety × location	2,512.7262	56.17***	5,053.5714	107.47***

^a *, **, *** = $P < 0.05$, 0.01 , and 0.0001 , respectively.

^b High-performance size-exclusion chromatography.

negative correlation between protein and starch content ($r = -0.543$, $P < 0.0001$ for club wheat and $r = -0.567$, $P < 0.0001$ for SWW wheat). Sponge cake volume is positively correlated with flour protein content (Noguchi 1978). Flour peak viscosity of SWW wheat was significantly correlated with starch damage ($r = -0.450$, $P < 0.0001$).

Club wheats exhibited better stability in starch content and starch damage than did SWW wheats over growing conditions (crop year and location).

Wheats Grown in One Location over Three Crop Years

The starch content, characteristics, and pasting properties of club and SWW wheat flours grown in Walla Walla for three crop years are shown in Table III. There was no difference between club and SWW wheat flours in starch content and amylose content, as measured by iodometric method. However, club wheat flour was significantly lower in starch damage and amylose content, as measured by HPSEC, than was SWW wheat flour. Both flour and prime starch peak viscosities were significantly higher in club wheat than in SWW wheat. The effects of cultivar and crop year on starch content, characteristics, and pasting properties are

summarized in Table IV. Neither cultivar nor crop year had significant effect on starch content in club wheat flour. Starch content, characteristics and pasting property of individual club and SWW wheat cultivars grown in Walla Walla over three years are summarized in Table V. Club and SWW wheat cultivars had comparable starch content.

Cultivar and crop year caused significant variation in amylose content as measured by both iodometric and HPSEC methods (Table IV). Amylose content measured by iodometric method was lower than that measured by HPSEC (Table V). This might be the result of partial overlapping between amylopectin and amylose peaks in HPSEC, as shown in Fig. 1. Kobayashi et al (1985) reported that a very accurate measurement of the amylose content, particularly <30%, is difficult to achieve due to peak overlap. Coelution of lower molecular weight amylopectins with amylose can also contribute to the high amylose content in HPSEC (Bradbury and Bello 1993). Amylose content measured by iodometric method did not correlate well with those measured with HPSEC (Table V). Hyak had the highest amylose content (32.0%) and Tres had the lowest amylose content (24.7%), as measured by iodometric method, while Madsen had the highest

TABLE VIII
Starch Content, Characteristics, Flour, and Prime Starch Peak Viscosity of Soft White Winter (SWW) and Club Wheat Cultivars Grown in 1990 at Seven Locations^a

Cultivars	Starch (% dwb)	Amylose (%)		Starch Damage (% dwb)	Peak Viscosity (BU)	
		Iodometric	HPSEC ^b		Flour	Starch
SWW						
Hill81	80.17bc	31.53ab	36.46bc	4.41a	704c	401c
Madsen	79.74c	30.80b	35.31bc	4.19a	748bc	381c
Stephens	80.31bc	32.57a	39.17a	3.78bc	797b	345d
Club						
Tres	80.53bc	30.94ab	35.20bc	3.90b	786b	481a
Crew	81.72a	30.70b	34.60c	3.83b	806ab	468ab
Hyak	80.88ab	30.77b	37.41ab	3.57c	857a	439b

^a Values followed by the same letter in the same column are not significantly different ($P < 0.05$).

^b High-performance size-exclusion chromatography.

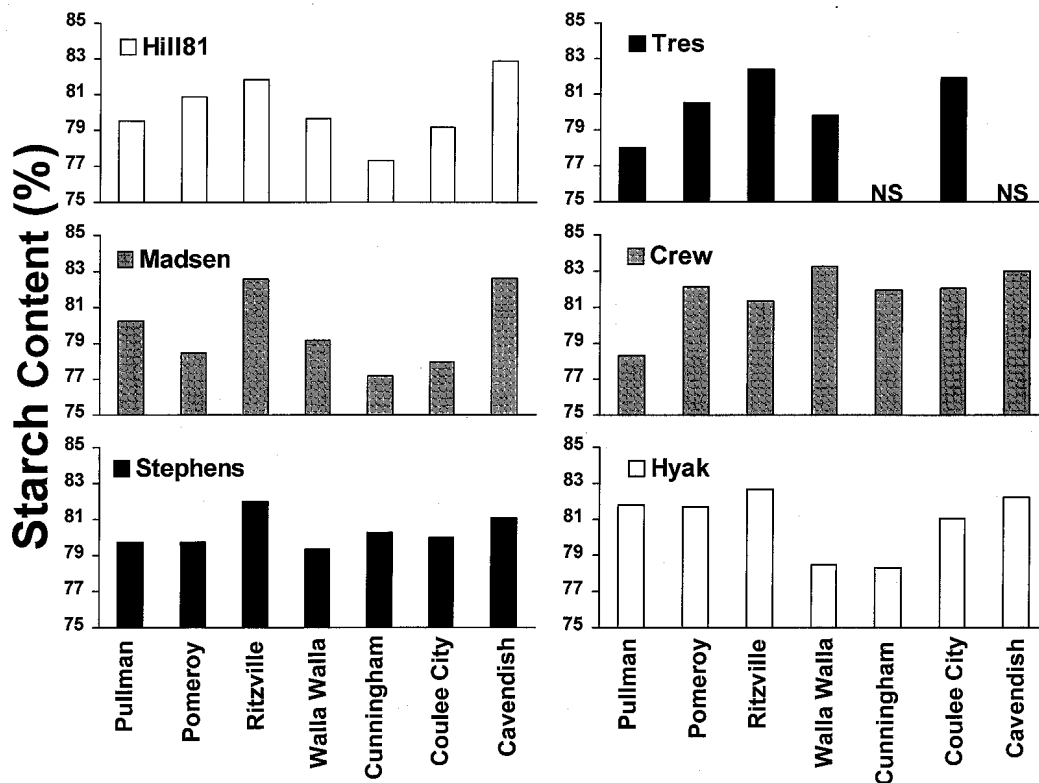


Fig. 2. Starch content of flours from individual club and soft white winter wheat cultivars in seven locations in the Pacific Northwest. NS = no sample.

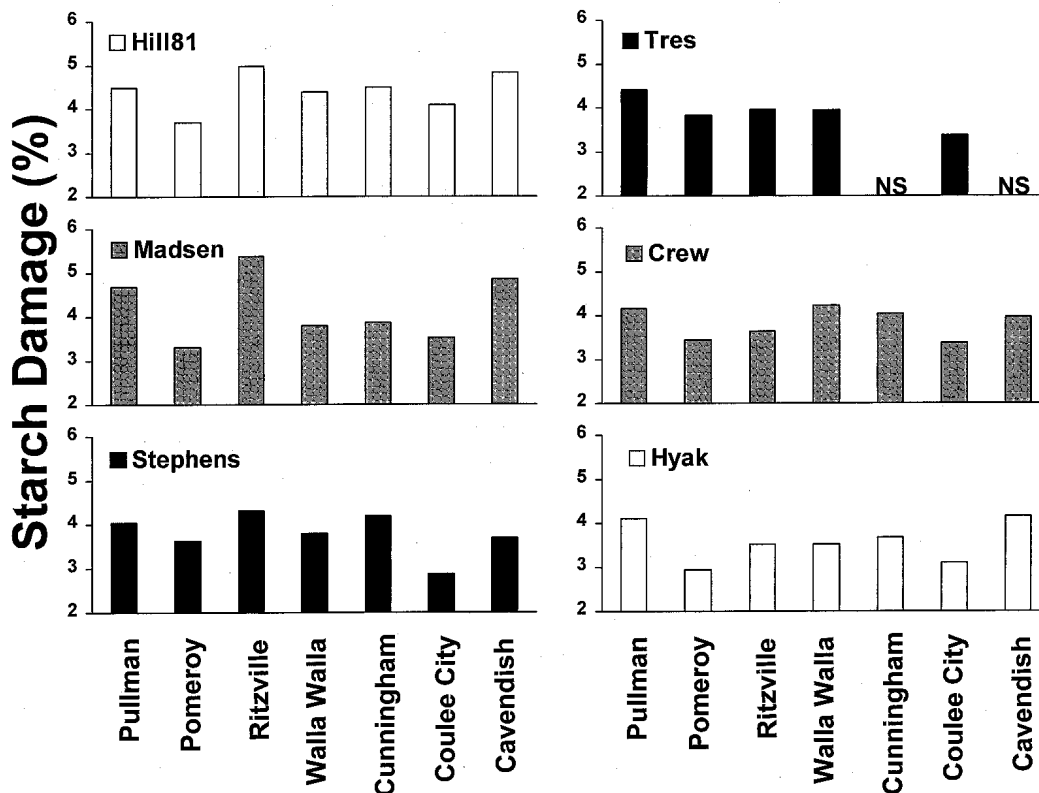


Fig. 3. Damaged starch content of flours from individual club and soft white winter wheat cultivars in seven locations in the Pacific Northwest. NS = no sample.

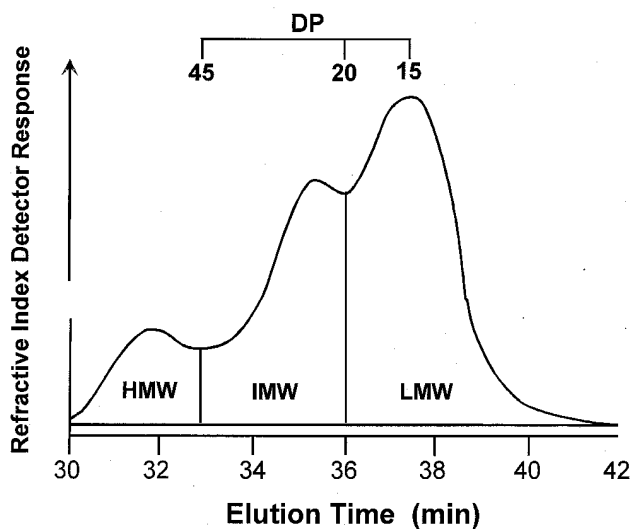


Fig. 4. Elution profile of isoamylase-debranched wheat starch amylopectin with two high-performance size-exclusion columns and 30% (v/v) dimethyl sulfoxide as eluent at a flow rate of 0.5 mL/min. HMW, IMW, and LMW indicate high, intermediate, and low molecular weight, respectively. DP = degree of polymerization.

amylose content (40.5%) and Crew had the lowest amylose content (28.9%), as measured by HPSEC.

Cultivar and crop year had strong influence on starch damage in both classes of wheat grown in the same soil and climatic conditions over three years (Table IV). The average starch damage for individual cultivars grown in Walla Walla over three years is listed in Table V. Moro had the lowest starch damage (2.99%) among club wheats. Madsen had the highest starch damage (4.58%), while Dusty had the lowest starch damage (2.79%) among SWW wheats. A detailed discussion of starch damage in soft wheats of the Pacific Northwest is given in Lin and Czuchajowska (1996).

Amylograph peak viscosities of flours and prime starches were significantly affected by varietal differences and crop year (Table IV). Peak viscosity of flour and prime starch for each cultivar is listed in Table V. In general, club wheats had higher flour and prime starch peak viscosities than did SWW wheats, except for Moro. Nugaines had the highest flour and prime starch peak viscosities (870 and 460 BU, respectively), while Stephens had the lowest peak viscosity in both flour and prime starch (590 and 270 BU, respectively) among SWW wheats. Peak viscosity of prime starch is approximately half the peak viscosity of the original flour in most cultivars. Both flour and starch peak viscosity followed similar patterns, except Lewjain and Daws in SWW wheat and Hyak in club wheat. A significant correlation ($r = 0.756$, $P < 0.05$) between flour peak viscosity and prime starch peak viscosity was found in club wheat but not in SWW wheat. No significant correlation was found between pasting properties of flour or prime starch with starch or amylose content. Similar results have been reported by Meredith and Pomeranz (1982). They found that pasting ability was not clearly related to starch content, and that starch pasting ability was only related in a very general manner to flour pasting ability.

Varietal differences and crop year had strong influence on amylose content, starch damage, and pasting property of flour and prime starch, but not on starch content, in both club and SWW wheats grown in Walla Walla over three years. Cultivar-by-year interaction was significant but small in all measurements except starch content.

Wheats Grown in Seven Locations in One Crop Year

Starch content, characteristics, and pasting properties of club and SWW wheats grown in 1990 over seven locations are summarized in Table VI. Club wheat was significantly higher in starch content, flour, and prime starch peak viscosity, and significantly lower in starch damage than was SWW wheat. There was no difference in amylose content between club and SWW wheats as measured by both iodometric and HPSEC methods. The effect of

TABLE IX
Average Branch Chain Distribution of Amylopectin and Starch Peak Viscosity of Club and Soft White Winter (SWW) Wheats Grown in Walla Walla, WA, in 1990^a

Wheat	Fraction ^b (%)			Starch Peak Viscosity (BU)
	HMW	IMW	LMW	
Club	20.4a	35.3a	44.3a	460a
SWW	20.0a	33.1a	45.9a	360b

^a Values followed by the same letter in the same column are not significantly different ($P < 0.05$).

^b HMW, IMW and LMW indicate high, intermediate, and low molecular weight, respectively.

cultivar and growing location on starch characteristics and pasting property is shown in Table VII. Varietal differences did not cause significant variation in starch content in SWW wheat flour, while location had a stronger influence on starch content in SWW wheat flour than in club wheat flour. The average starch content for each cultivar grown in 1990 in seven locations is summarized in Table VIII. All three club wheat flours in this study had higher starch content than did SWW wheat flours. Crew had the highest starch content (81.72%), while Madsen had the lowest starch content (79.74%) among all cultivars. The starch content for individual cultivars in each location is shown in Fig. 2. All cultivars in this study, except Crew, had the highest starch content in Ritzville and Cavendish, indicating that club and SWW wheats responded similarly to growing location in their starch content. A significant correlation ($r = 0.512$, $P < 0.05$) between starch content and sponge cake volume was found in SWW wheat but not in club wheat.

Varietal differences did not cause significant variation in amylose content in club wheat flour as measured by iodometric and HPSEC methods. In SWW wheat flour, both varietal differences and growing location had strong influence on amylose content as measured by iodometric and HPSEC method (Table VII). The average amylose content for each cultivar averaged over location, measured by both iodometric method and HPSEC, is shown in Table VIII. The amylose content measured by HPSEC is higher than that measured by iodometric method. Stephens had the highest amylose content as measured by both methods.

Cultivar and location had strong influence on starch damage in both classes of wheat flour (Table VII). Starch damage for individual cultivar grown in 1990 averaged over location is shown in Table VIII. In general, SWW wheat flour was higher in starch damage than was club wheat flour. Hill81 had the highest starch damage (4.41%) and Hyak had the lowest starch damage (3.57%) among cultivars in this study. The starch damage for individual cultivars in each location is shown in Fig. 3. Both club and SWW cultivars followed a similar pattern in starch damage. Wheats grown in Pullman, Ritzville, and Cavendish had higher starch damage than those grown in other locations. Stephens was consistently lower in starch damage in all locations than other SWW cultivars.

Varietal differences and growing location had strong influence on flour and prime starch peak viscosities in both classes of wheat flour (Table VII). The average flour and prime starch peak viscosities for individual cultivars grown in 1990 over seven locations are summarized in Table VIII. In general, club wheat flour was higher in both flour and prime starch peak viscosity than was SWW wheat flour. Another interesting observation is that flour peak viscosity did not correlate well with prime starch peak viscosity in either class of wheat flour. Hill81 had the lowest peak viscosity in flour (700 BU) and the highest peak viscosity (400 BU) in prime starch among SWW wheat flours. On the other hand, Hyak had the highest flour peak viscosity (860 BU) but the lowest prime starch peak viscosity (440 BU) among club wheat flours. These results indicate that flour pasting property, which is affected by protein and other minor constituents, does not correctly reflect pasting property of prime starch. Zeng et al (1997) reported that higher peak viscosity was associated with lower

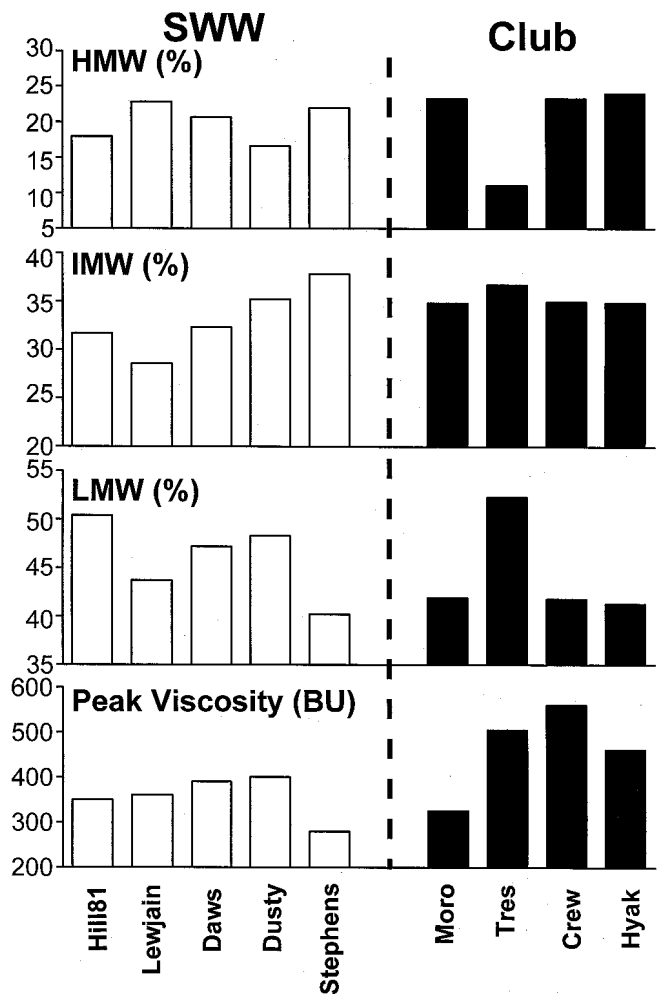


Fig. 5. Isoamylase-debranched amylopectin chain-length distribution and starch peak viscosity of selected club and soft white winter wheat cultivars grown in Walla Walla, WA, in 1990. HMW, IMW, and LMW indicate high, intermediate, and low molecular weight, respectively.

amylose content. In this study, no significant correlation was found between amylose content and flour and starch peak viscosities. Similar results were reported by Šebecic (1989). A significant correlation between flour peak viscosity and starch damage in both classes of wheat was observed ($r = -0.676$, $P < 0.01$ for club wheat and $r = -0.535$, $P < 0.05$ for SWW wheat).

In general, varietal differences and growing location had strong influence on starch content, amylose content, starch damage, and pasting property of flour and prime starch in both club and SWW wheats grown in 1990 over seven locations. Cultivar-by-location interaction was significant but small when compared to cultivar and location.

Fine Structure of Amylopectin

The isoamylase-debranched amylopectin from prime starch of club and SWW wheat flours grown in Walla Walla, harvested in 1990, showed a similar trimodal pattern, as shown in Fig. 4. These results are consistent with those of Kobayashi et al (1986). They investigated the fine structure of amylopectins from five different classes of wheat flour and found no detectable differences in amylopectin structure. In this study, all debranched amylopectins exhibited maximum response at \approx DP 15 and two valleys at \approx DP 20 and 45, respectively. Therefore, the area under the peak was divided into high molecular weight (HMW) (DP >45), intermediate molecular weight (IMW) (DP 20–45), and low molecular weight (LMW) (DP <20) regions (Fig. 4). The average branch chain length distribution of amylopectin and prime starch peak

viscosity for selected club and SWW wheat prime starches grown in Walla Walla in 1990 is summarized in Table IX. For club and SWW wheats grown under the same soil and climatic conditions, there is no significant difference in the ratio of all three fractions of amylopectin, while a significant difference between starch peak viscosity was observed. These results indicate that other factors (e.g., protein and phosphorus content, degree of crystallinity, starch granule size distribution, and endogenous enzyme) rather than fine structure of amylopectin might have strong influence on pasting properties of starch. The chain length distribution and starch peak viscosity for individual cultivars grown under the same conditions are shown in Fig. 5. In general, club wheat had relatively comparable levels of each fraction, except Tres, which had a lower HMW fraction and higher LMW fraction than other club wheat cultivars. Prime starch peak viscosity of club wheat cultivars ranged from 330 BU (Moro) to 560 BU (Crew). On the other hand, SWW cultivars differed widely in each fraction. Dusty had the lowest proportion of HMW fraction (16.6%), while Lewjain had the highest proportion of HMW fraction (22.8%) among SWW wheats. Intermediate molecular weight fraction of SWW wheat cultivars ranged from 28.5% in Lewjain to 37.8% in Stephens. Hill81 had the highest proportion of LMW fraction (50.4%) and Stephens had the lowest proportion of LMW fraction (40.2%) among SWW wheat cultivars in this study. Prime starch peak viscosities of SWW cultivars ranged from 280 BU in Stephens to 400 BU in Dusty. Club wheat cultivars had higher prime starch peak viscosity than SWW cultivars except Moro. No significant correlation was found between the proportion of each molecular weight fraction and prime starch peak viscosity in either class of wheat. In another experiment, one SWW wheat (Madsen) was grown in five locations. Starch peak viscosity for this set of samples ranged from 310 to 510 BU, and no significant difference in the proportion of all three fractions (HMW, IMW, and LMW) between growing locations was observed. These results indicate that the fine structure of amylopectin is not affected by growing location, while prime starch pasting properties are strongly influenced by growing location.

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