Effect of Spring and Winter Growth Habitat on Compositional, Milling, and Baking Characteristics of Winter Wheats

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ABSTRACT

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Seven commercial winter wheat cultivars were vernalized and grown under winter and spring habitat at two locations for three consecutive years. Winter-planted wheats (WPW) were higher in test and kernel weight and generally harder but were lower in protein and ash contents than their spring-planted (SPW) counterparts. Alkaline water retention capacity was consistently higher in SPW than in WPW. No consistent differences were recorded in soluble and total pentosans. Hardness and protein concentration were not significantly correlated. Differences in hardness, protein, ash, soluble and total pentosans, and alkaline water retention capacity of flours paralleled those in whole grains. Milling properties such as flour yield and milling score depended on test and kernel weight. Total flour yields (with higher reduction flour yields) and milling scores were consistently higher in the WPW than in their SPW counterparts. Protein dispersibility in urea was correlated with dough development time, water absorption, and loaf volume. Cookie diameter, generally, was higher in WPW than in SPW.

Studies involving genetic, biochemical, and structural differences between hard red spring and hard red winter wheats are an active area of research. Reasons for the interest are differences in price and postulated differences in end-use properties. Availability of clearly identifiable hard red spring and hard red winter wheats is of interest to growers, and the competitiveness in the local and international grain trade demands identification of wheats from the two classes (Endo et al 1990a). Various approaches have been undertaken to define which spring and winter wheat characteristics could be used as markers or criteria of quality. Four criteria (time or place of sowing, phenology [vernalization and photo period], physiology [winter hardiness], and genetics) were proposed to characterize a winter wheat (H. McMaster, *personal communication*). Of the four criteria, McMaster suggested that the genetic approach, based on the complement of the vernalization genes (*Vrn*), would be the most appropriate criterion to classify winter and spring wheats. In general, hard red spring wheats are higher in protein content and hardness and lower in test weight and kernel weight than are hard red winter wheats (Watson et al 1968). There is an overlap among varieties in any of these characteristics, and differentiation is particularly difficult in commercial blends. In addition, both protein content and hardness can be affected by cultural practices and growth conditions.

Much of the difference in bread-making potential of hard red winter and red spring wheats can be explained by differences in protein content. The question arises, however, whether there are still differences in bread-making potential when the results are expressed (or analyzed) on a common protein basis. Another question is whether there are any compositional differences (other than protein) between the two classes of wheat that may affect functional properties.

In addition to the overlap in inherent protein content and hardness, differentiation between spring and winter wheat has become a more difficult task because new varieties have been developed by crossing spring and winter wheat cultivars. Thereby, physical and chemical properties used in the past to classify wheats (morphological characteristics, hardness, protein content, etc.) are difficult to apply now. Many of these parameters show wide variations in spring and winter hard red wheats and even in soft red winter wheats (Pomeranz et al 1988). Endo et al (1990 a,b) analyzed gliadin composition of 15 commercial U.S. hard red spring and hard red winter wheats by high-performance liquid chromatography (HPLC) and concluded, based on milling data and total peak areas for two late-eluting gliadin fractions, that winter and spring wheats could be differentiated. The authors emphasized the rather tentative nature of the findings and recommended additional extensive studies on well-identified wheat varieties. Jack (1991), using restriction fragment length polymorphism (RFLP) and a DNA probe, discriminated between spring and winter barleys with RFLP markers associated with vernalization requirements and winter hardiness.

Recent studies on the genetic and biochemical basis of winter hardiness and vernalization have increased our understanding of the physiological differences between spring and winter wheats. Still, the field is open to much work and controversy. Another point to consider, pertaining to this work, is whether differences between spring and winter wheats, with regard to end-use properties, are related to intrinsic biochemical or genetic characteristics or are related to growth habitat. Winter wheat basically has a longer growing period than spring wheat, so the question arises whether the growth habitat affects end-use properties. This research was conducted to determine the gross composition and end-use properties of seven winter wheats grown for three years in winter and spring habitats at two locations.

MATERIALS AND METHODS

Wheat Cultivars

Seven winter wheat cultivars were grown in Lind and Pullman, WA, in spring and winter habitats, for three consecutive years (1986–87, 1987–88, and 1988–89). Each wheat cultivar was seeded in randomized plots. Plot dimensions were 3.6 × 3.6 m and consisted of 10 rows spaced 20 cm. A replicate, within a specific variety, comprised seeds harvested from three different plots.

Spring-planted wheats (SPW) were sown in the middle of February to vernalize the wheats and to assure proper heading and flowering. Winter-planted wheats (WPW) were sown during late October of the preceding year at both locations. The winter wheat cultivars were Crew and Tres (Club); Daws, Stephens, and Hill 81 (SWW); and Batum and Hatton (HRW) obtained from the Washington State University Agricultural Experimental Station in Lind and the Spillman Farm in Pullman. On the average, temperature is higher and precipitation is lower in Lind than in Pullman.

The harvested wheats were cleaned on a Hart-Dockage Tester (Simon-Carter Co., Minneapolis, MN) and an air-aspirator separator (KICE Metal Products Co., Wichita, KS).

Analytical Methods

All determinations were made at least in duplicate and expressed on a 14% mb, whenever applicable. Moisture, test weight, protein (N × 5.7), and ash were determined according to AACC (1983) approved methods 44-15A, 55-10, 46-12, and 08-01, respectively. An electronic seed counter (The Old Mill Co., Savage, MO) was used to determine 1,000-kernel weight. To determine hardness scores, kernels were ground in a Udy cyclone sample mill (Udy Corp., Fort Collins, CO) fitted with a sieve with 0.5-mm round

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openings. The whole wheat flours and the white flours (milled on a Buhler mill, Uzwill, Switzerland) were allowed to equilibrate in a chamber maintained at 21°C and 52% rh to produce an equilibrium moisture content of 10 ± 0.3%. Hardness was estimated by near-infrared reflectance (Technicon InfraAlyzer 400) using the two-wavelength (1,680 and 2,230 nm) AACC method 39-70 (AACC 1983). Hardness was also estimated by the Stenvert hardness tester (resistance to grinding in seconds, according to Pomeranz et al 1985); the longer the grinding time, the harder the wheat. Dispersibility of wheat proteins in 3*M* urea (a measure of protein aggregation) was determined as proposed by Pomeranz (1965). Total and soluble pentosans were measured by the colorimetric method of Hashimoto et al (1987).

Milling

The mature wheats were experimentally milled, in duplicate, into straight-grade flours on a Buhler pneumatic laboratory mill. Hard and soft wheats were tempered overnight to 16 and 14% moisture, respectively.

Break, reduction, and total flour yields and milling scores were determined for the WPW and SPW wheats. Milling scores were calculated by a weighted formula as described by Rubenthaler et al (1985).

Alkaline Water Retention Capacity

Alkaline water retention capacity (AWRC) of whole wheat and straight-grade flours were measured according to the method of Kitterman and Rubenthaler (1971). Five grams of flour (14%, mb) was suspended in 25 ml of 0.1*N* Na_2CO_3.

Alveograph Tests

Alveograph tests were conducted on dough with constant water content and mixing times according to the standard approved AACC method 54-30 (1983). Data acquisition and storage were performed by interfacing the alveograph to an XT-IBM computer. Hardware and software of the modified alveograph procedure were described elsewhere (Addo et al 1990).

Baking Methods

Pan bread. Bread was baked according to the procedure of Finney (1984) at optimum water absorption, as determined by mixograph analysis, and at optimum mixing time, as determined by an experienced experimental baker. The bread formula included 100 g of flour (14%, mb), 1.5 g of NaCl, 1.8 g of dry baker's yeast, 6 g of sucrose, 4 g of nonfat dry milk, 3 g of shortening, 40 ppm of ascorbic acid, and 5–30 ppm of potassium bromate (depending on the oxidation requirements of the flours). The straight-dough procedure was used. The dough was fermented and proofed for 90 min and 30 min at 30°C, respectively. Loaf volume was determined immediately after baking by the dwarf rapeseed displacement method. Specific loaf volume was calculated as follows:

$$SLV = (LV - 400)/P$$

where:

SLV = specific loaf volume (cm^3 per gram of protein);
LV = pan bread loaf volume (cm^3); and
P = protein (14%, mb).

The value of 400 cm^3 represents the volume of a loaf containing no functional protein (Hoseney et al 1966).

Steamed bread. Volume and score of steamed bread were determined according to the procedure of Rubenthaler et al (1990). The steamed bread formula included: 160 g of flour (14%, mb), 8% sugar, 2% shortening, 1% NaCl, and 1% dry baker's yeast, using optimum water absorption and mixing time. Steaming of the fermented and proofed dough was carried out for 10 min in a Market Forge Ultra Steamer (model 3005, Market Forge Company, Everett, MA). Bread crumb texture was measured using a Fudoh rheometer (Fudoh Company Inc., Tokyo, Japan). Scoring was done by an experienced experimental baker on a numerical basis of one to 10: one identifies excellent and 10 is highly unsatisfactory texture, crumb grain, and color (Rubenthaler et al 1990).

Cookie baking. The procedure of Finney et al (1950) was employed for the cookie-baking experiments.

Statistical Analysis

Analysis of variance and least significant difference were calculated using the SAS (SAS 1986).

RESULTS AND DISCUSSION

Wheat Compositional Characteristics

Average (for three years) test weight, 1,000-kernel weight, protein, and ash (the latter three expressed at 14% mb) for the seven winter wheat cultivars grown in winter and spring habitats at two locations are summarized in Table I. Test weight and 1,000-kernel weight were consistently higher, and protein content and ash were consistently lower for the WPW than for the SPW.

TABLE I
Test Weight, Kernel Weight, Protein, and Ash (Three Year Averages) for Seven Winter Wheat Cultivars Grown in Winter (WPW) and Spring (SPW) Habitats at Two Locations in 1986–1987, 1987–88, 1988–89[a]

Variety and Location	Test Weight (lb/bu)		1,000-Kernel Weight[b] (g)		Protein[b] (N × 5.7, %)		Ash[b] (%)	
	WPW	SPW	WPW	SPW	WPW	SPW	WPW	SPW
Pullman								
Tres (Club)	62.6 a	57.9 b	35.9 a	22.8 b	10.64 b	12.62 a	1.28 b	1.46 a
Crew (Club)	60.5 a	55.6 b	32.9 a	20.3 b	10.53 b	12.57 a	1.33 b	1.43 a
Hill 81 (SWW)[c]	62.0 a	56.9 b	37.8 a	27.1 b	11.30 b	13.01 a	1.35 b	1.51 a
Stephens (SWW)	61.2 a	54.0 b	51.7 a	35.7 b	10.66 b	12.69 a	1.33 b	1.55 a
Daws (SWW)	63.0 a	57.6 b	44.0 a	28.0 b	10.20 a	11.80 a	1.37 b	1.48 a
Batum (HRW)	62.2 a	55.3 b	43.4 a	26.7 b	11.04 b	13.76 a	1.26 b	1.59 a
Hatton (HRW)	65.0 a	58.1 b	38.1 a	28.3 b	11.10 b	13.06 a	1.25 b	1.37 a
Lind								
Tres (Club)	62.7 a	57.4 b	38.4 a	25.0 b	10.38 b	14.55 a	1.20 b	1.44 a
Crew (Club)	60.5 a	54.7 b	31.3 a	22.1 b	10.76 b	13.78 a	1.27 b	1.37 a
Hill 81 (SWW)[c]	62.1 a	55.9 b	36.2 a	28.6 b	11.30 b	15.50 a	1.18 b	1.49 a
Stephens (SWW)	61.3 a	52.6 b	51.6 a	32.9 b	10.55 b	14.86 a	1.20 b	1.51 a
Daws (SWW)	63.1 a	56.3 b	44.9 a	26.9 b	9.90 b	14.30 a	1.22 b	1.50 a
Batum (HRW)	62.3 a	56.2 b	40.9 a	29.5 b	11.24 b	16.09 a	1.16 b	1.51 a
Hatton (HRW)	65.2 a	62.7 b	36.2 a	28.1 b	11.61 b	15.20 a	1.14 b	1.32 a

[a] Values with different letters between pairs in consecutive columns are statistically different at least at the 5% level of significance.
[b] 14% moisture basis.
[c] SWW = soft white winter, HRW = hard red winter.

WPW generally were harder than SPW, as determined by the Stenvert hardness test, for one year at one location and as determined by near-infrared reflectance for two years at two locations (results not shown), regardless of the protein content.

The higher protein and ash content of the SPW may be the result of a concentration effect of less starch deposition in the SPW than in the WPW; SPW had smaller and more shrunken kernels than did WPW. A similar effect of growth habitat on kernel weight was observed by Wiegand et al (1981) in a study on development of hard red winter wheats under semitropical conditions. The number of kernels per head and the kernel weights of the hard red winter wheats sown under semitropical conditions were smaller than those of winter wheats sown during the regular fall season. They concluded that a short grain-filling period imposed a major restriction on kernel development. Influence of growth habitat on spring wheats could not be tested as the winter season in the U.S. Northwest does not allow spring wheat survival. However, studies by Matuz and Aziz (1990) showed that fall-planted Hungarian spring wheats were consistently higher in yield than the SPW counterparts. Again, probably, a longer growing period of the fall-planted spring wheats than of the SPW equivalents could account for the increase in yield.

The consistently lower test weights and kernel weights of the SPW compared to the WPW in this study were probably due to two factors: 1) incomplete vernalization, and 2) a lower rate of grain filling of the SPW than of the WPW counterparts. As the differences in kernel weight and test weight were consistent for three consecutive harvest years, the effect of growth habitat (by artificially vernalizing and planting the winter wheats during the spring season) was further investigated.

The period from plant emergence to anthesis was approximately 220 days for all WPW cultivars. For the SPW, the period was 68–72 days. The WPW headed and flowered significantly earlier than the SPW (8–10 days, results not shown). Grain filling period was approximately 35–38 and 30–32 days for the SPW and WPW, respectively. However, rate of grain filling was significantly higher in the WPW than in the SPW. Results for AWRC and pentosans (soluble and total) are summarized in Table II. The SPW were consistently higher in AWRC than the WPW. The lower the AWRC, the better the wheat (flour) quality for pastry uses. There

TABLE II
Alkaline Water Retention Capacity (AWRC) and Pentosans for Seven Winter Wheat Cultivars Grown in Winter (WPW) and Spring (SPW) Habitats at Two Locations in 1986-87[a]

Variety and Location	AWRC[b] (%)		Soluble Pentosans[b] (%)		Total Pentosans[b] (%)	
	WPW	SPW	WPW	SPW	WPW	SPW
Pullman						
Tres (Club)	69.7 b	76.9 a	0.80 b	0.93 a	5.45 a	5.69 a
Crew (Club)	70.4 b	78.3 a	0.87 b	1.03 a	5.64 b	6.71 a
Hill 81 (SWW)[c]	68.1 b	70.4 a	0.72 a	0.71 a	4.87 b	6.44 a
Stephens (SWW)	71.0 b	73.7 a	0.83 a	0.81 a	5.82 a	5.83 a
Daws (SWW)	75.0 b	82.1 a	1.06 b	1.18 a	5.70 b	6.45 a
Batum (HRW)	79.3 b	86.9 a	1.05 b	1.14 a	5.01 b	6.41 a
Hatton (HRW)	79.6 b	82.1 a	0.95 a	0.90 b	5.44 a	5.48 a
Lind						
Tres (Club)	71.6 b	76.0 a	0.85 b	0.91 a	4.63 b	5.52 a
Crew (Club)	69.8 b	75.2 a	0.73 b	0.84 a	5.19 b	5.89 a
Hill 81 (SWW)[c]	67.7 b	73.4 a	0.65 b	0.85 a	5.34 a	5.63 a
Stephens (SWW)	71.1 b	72.9 a	0.78 a	0.73 b	5.24 a	5.38 a
Daws (SWW)	75.8 b	82.4 a	1.28 a	1.29 a	6.02 a	5.98 a
Batum (HRW)	77.6 b	84.5 a	1.03 b	1.08 a	4.57 b	6.01 a
Hatton (HRW)	77.2 b	78.9 a	0.93 a	0.95 a	4.99 b	5.80 a

[a] Values with different letters between pairs in consecutive columns are statistically different at least at the 5% level of significance.
[b] 14% moisture basis.
[c] SWW = soft white winter, HRW = hard red winter.

TABLE III
Milling Characteristics of Flours Milled from Wheats Grown in Winter (WPW) and Spring (SPW) Habitats at Two Locations in 1986-1987, 1987-88, and 1988-89[a]

Variety and Location	1986-87 Flour Yield (%)		1986-87 Milling Score (%)		1987-88 Flour Yield (%)		1987-88 Milling Score (%)		1988-89 Flour Yield (%)		1988-89 Milling Score (%)	
	WPW	SPW	WPW	SPW	WPW	SPW	WPW	SPW	WPW	SPW	WPW	SPW
Pullman												
Tres (Club)	74.2 a	70.9 b	80.7 a	73.0 b	73.0 a	70.7 b	78.2 a	71.9 b	72.8 a	64.9 b	78.6 a	66.5 b
Crew (Club)	73.1 a	70.2 b	78.7 a	73.1 b	71.6 a	68.8 b	75.7 a	72.1 b	71.5 a	69.6 b	77.8 a	71.2 b
Hill 81 (SWW)[b]	74.0 a	69.5 b	82.2 a	70.6 b	71.8 a	68.5 b	77.2 a	69.1 b	71.4 a	66.6 b	78.0 a	69.6 b
Stephens (SWW)	73.5 a	67.5 b	83.0 a	69.5 b	71.1 a	66.3 b	76.2 a	65.7 b	70.0 a	66.2 b	76.6 a	69.3 b
Daws (SWW)	71.4 a	66.5 b	79.9 a	70.1 b	70.0 a	65.2 b	77.6 a	70.1 b	71.3 a	64.2 b	80.9 a	66.8 b
Batum (HRW)	73.8 a	67.3 b	84.6 a	71.9 b	69.3 a	67.1 b	76.7 a	71.7 b	69.0 a	67.4 b	79.5 a	73.5 b
Hatton (HRW)	74.3 a	71.8 b	83.3 a	77.2 b	68.3 a	68.9 a	72.6 a	72.2 a	68.0 a	65.7 b	76.0 a	70.0 b
Lind												
Tres (Club)	74.3 a	67.3 b	83.4 a	66.0 b	71.4 a	69.2 b	74.8 a	69.3 b	...	...	...	...
Crew (Club)	73.4 a	68.6 b	81.9 a	66.0 b	68.6 a	65.2 b	68.7 a	64.1 b	...	...	...	...
Hill 81 (SWW)[b]	73.7 a	68.6 b	84.6 a	64.6 b	69.9 a	67.3 b	78.2 a	69.9 b	...	...	...	...
Stephens (SWW)	71.9 a	69.5 b	81.0 a	67.8 b	68.8 a	63.6 b	73.0 a	61.8 b	...	...	...	...
Daws (SWW)	70.6 a	63.0 b	80.6 a	57.5 b	65.3 a	60.6 b	71.7 a	65.1 b	...	...	...	...
Batum (HRW)	71.6 a	70.7 b	81.8 a	79.9 b	68.0 a	65.8 b	74.2 a	69.3 b	...	...	...	...
Hatton (HRW)	71.5 a	70.4 b	80.8 a	71.7 b	64.5 a	65.0 a	69.0 a	66.2 a	...	...	...	...

[a] Values with different letters between pairs in consecutive columns are statistically different at least at the 5% level of significance.
[b] SWW = soft white winter, HRW = hard red winter.

were no consistent differences in soluble pentosans for the WPW and the SPW at the two locations. SPW were higher than or equal to WPW in total pentosans.

Milling Properties

Flour yields were consistently higher in the WPW than in the SPW, except for Hatton in 1987–88 (Table III). Higher flour yields of the WPW, as compared to those of the SPW counterparts, are a reflection of differences in kernel weight and test weights (Table I). The relationship between test weight and kernel weight and between test weight and flour yield was further supported by examining the simple correlation coefficients among these parameters (calculated from pooled values for three years, Table IV). Correlation coefficients of 0.72 and 0.74 in Table IV ($P > 0.001$) were recorded between test and kernel weight and between test weight and flour yield, respectively. As expected, WPW had higher milling scores than did the SPW counterparts, except for Hatton, at both locations in 1987–88 (Table III), because flour yields and milling scores were highly correlated ($r = 0.80^{**}$, Table IV). The higher flour yields and milling scores of the WPW were due to higher levels of reduction flours. Percentage of reduction is a main factor in calculating milling scores (Rubenthaler et al 1985).

Wheat and Flour Hardness

Hardness, as measured by flour near-infrared reflectance, was higher in the WPW than in the SPW counterparts for the 1986–87 and the 1987–88 crops, except for the hard red wheats grown in Lind, in which an increase in protein was accompanied by an increase in hardness (Table V). The trend in hardness, measured

TABLE IV
Correlation Coefficients of Pooled Data for Wheats and Flours Milled from Wheats Grown in Winter and Spring Habitats at Two Locations

	Wheats							Milling		Flours				
					Pentosans[b]									
	Test[a] Weight	Kernel[a] Weight	Protein[a]	Ash[a]	Soluble	Total	AWRC[a]	Flour[c] Yield	Milling[c] Score	Hard-ness[c]	Mixing[b] Time	Water[b] Absorption	Loaf[b] Volume	Cookie[c] Diameter
Wheats														
Test weight[a]	...	0.72** [d]	−0.73**	−0.82**	NS	NS	−0.38*	0.74**	0.75**	NS	NS	NS	NS	NS
Kernel weight[a]	0.72**	...	−0.81**	−0.65**	NS	NS	−0.41*	0.56**	0.56**	NS	NS	NS	NS	NS
Milling														
Flour yield[c]	0.74**	0.54**	NS	−0.79**	−0.48*	−0.58**	−0.49*	...	0.80**	NS	NS	NS	NS	NS
Milling score[c]	0.75**	0.56**	NS	−0.78**	NS	NS	NS	0.80**	...	NS	NS	NS	NS	NS
Flours														
Protein[a]	−0.83**	−0.79**	0.98**	0.77**	NS	NS	NS	−0.40*	0.61**	NS	NS	NS	0.68**	−0.73**
Ash[a]	−0.76**	−0.81**	0.65**	0.88**	NS	0.54*	NS	−0.71**	NS	NS	NS	NS	NS	NS
Hardness[c]	NS	NS	NS	NS	NS	NS	NS	NS	0.69**	...	0.43*	0.42*	0.52**	−0.60**
Soluble pentosans[b]	NS	NS	NS	NS	0.76*	NS	0.63**	NS	NS	NS	0.50**	0.50**	NS	−0.58**
Total pentosans[b]	NS	NS	NS	NS	0.50*	NS	NS	−0.45**	NS	NS	0.68**	0.69**	NS	−0.49**
AWRC[a]	NS	NS	NS	NS	0.53*	NS	0.80**	−0.49**	NS	NS	0.52**	0.53**	NS	−0.80**
Urea dispersibility[a]	NS	NS	NS	NS	−0.41*	NS	−0.55**	NS	−0.62**	−0.57**	−0.80**	−0.74**	−0.50**	0.57**

[a] For the 1986–87, 1987–88, and 1988–89 crops.
[b] For the 1986–87 crop.
[c] For the 1986–87 and 1987–88 crops.
[d] At least *5% and **1% levels of significance, respectively. NS = nonsignificant.

TABLE V
Some Characteristics of Flours Milled from Seven Winter Wheats Grown in Winter (WPW) and Spring (SPW) Habitats in Two Locations[a]

Variety and Location	Hardness[b] (NIR)[g]		Protein[c] (%)		Ash[c,d] (%)		AWRC[c,d,f] (%)		Soluble Pentosan[c,e] (%)		Total Pentosan[c,e] (%)		Urea Dispers.[c,d] (%)	
	WPW	SPW	WPW	SPW	WPW	SPW	WPW	SPW	WPW	SPW	WPW	SPW	WPW	SPW
Pullman														
Tres (Club)	27.2 a	20.1 b	9.21 b	11.20 a	0.42 b	0.50 a	59.5 b	69.1	0.50 b	0.65 a	1.66 b	2.06 a	0.58 a	0.56 b
Crew (Club)	25.9 a	19.3 b	8.70 b	10.72 a	0.41 b	0.48 a	60.6 b	69.8 a	0.50 b	0.56 a	1.80 b	2.04 a	0.53 b	0.55 a
Hill 81 (SWW)[h]	26.1 a	23.9 b	9.58 b	11.51 a	0.40 b	0.48 a	62.3 a	63.2 a	0.48 a	0.44 b	1.81 a	1.71 a	0.52 b	0.57 a
Stephens (SWW)	25.8 a	15.7 b	8.85 b	10.78 a	0.40 b	0.47 a	62.0 b	65.8 a	0.52 a	0.46 b	2.09 b	2.35 a	0.56 a	0.52 b
Daws (SWW)	24.8 a	17.7 b	8.34 b	10.03 a	0.34 b	0.41 a	69.3 b	75.3 a	0.84 a	0.77 b	2.26 b	2.42 a	0.46 b	0.48 a
Batum (HRW)	52.8 a	52.3 a	9.66 b	10.84 a	0.33 b	0.40 a	76.8 b	82.5 a	0.74 b	0.79 a	2.11 b	2.45 a	0.51 a	0.51 a
Hatton (HRW)	58.2 a	55.6 a	10.10 b	11.96 a	0.37 b	0.43 a	73.9 b	76.8 a	0.67 a	0.68 a	2.27 a	2.33 a	0.46 b	0.49 a
Lind														
Tres (Club)	31.0 a	25.5 b	9.00 b	12.98 a	0.38 b	0.50 a	59.9 b	65.3 a	0.68 a	0.65 a	1.83 b	1.97 a	0.56 a	0.57 a
Crew (Club)	30.6 a	23.3 b	8.90 b	12.25 a	0.37 b	0.47 a	59.7 b	70.8 a	0.54 b	0.72 a	1.90 a	2.01 a	0.54 b	0.56 a
Hill 81 (SWW)	33.5 a	31.8 b	9.67 b	14.15 a	0.32 b	0.47 a	60.2 b	71.2 a	0.48 b	0.64 a	1.98 a	1.90 a	0.54 b	0.58 a
Stephens (SWW)	29.2 a	21.0 b	8.79 b	13.50 a	0.35 b	0.48 a	61.2 b	64.8 a	0.51 b	0.58 a	1.85 b	2.08 a	0.55 b	0.59 a
Daws (SWW)	29.9 a	20.6 b	8.05 b	12.36 a	0.30 b	0.47 a	67.2 a	69.2 a	0.92 a	0.68 b	2.05 b	2.25 a	0.49 b	0.54 a
Batum (HRW)	53.2 b	68.7 a	9.80 b	13.99 a	0.29 b	0.41 a	75.4 a	73.2 b	0.69 a	0.63 b	1.89 a	1.85 a	0.52 a	0.45 b
Hatton (HRW)	58.5 b	70.4 a	10.53 b	13.97 a	0.32 b	0.44 a	71.9 a	71.3 a	0.79 a	0.73 b	2.05 b	2.20 a	0.47 b	0.51 a

[a] Values with different letters between pairs of consecutive columns are statistically different at least at the 5% level of significance.
[b] Mean values for the 1986–87 and 1987–88 crops.
[c] 14% moisture basis.
[d] Mean values for the 1986–87, 1987–88 and 1988–89 crops.
[e] Values for the 1986–87 crop.
[f] AWRC = alkaline water retention capacity.
[g] NIR = near-infrared reflectance.
[h] SWW = soft white winter, HRW = hard red winter.

by flour near-infrared reflectance, for two years was confirmed for the 1988–89 crop in Pullman (whole wheat) using the independent Stenvert hardness test (data not shown). The results suggest that growth habitat can affect hardness. On the other hand, a nonsignificant correlation between total protein and hardness (Table IV) reflected the lack of relationship between these two parameters, as previously suggested by several authors (Simmonds 1974, Yamazaki and Donelson 1983, Miller et al 1984, Pomeranz and Williams 1990).

Flour Compositional Characteristics

As expected, differences in hardness, protein, ash, soluble and total pentosans, and AWRC of flours paralleled those previously noted for the whole wheat flours (compare Tables I and V). Protein, ash, and total pentosans were higher in flours from SPW than from WPW. AWRC and urea dispersibility were generally higher in SPW, and hardness (measured by flour near-infrared reflectance) was generally higher in WPW.

TABLE VI
Water Absorption and Mixing Time of Flours Milled from Wheats Grown in Winter (WPW) and Spring (SPW) Habitats at Two Locations in 1986–87[a]

Variety and Location	Absorption[b] (%)		Mixing Time[b] (min)	
	WPW	SPW	WPW	SPW
Pullman				
Tres (Club)	53.5 a	52.5 a	1.00 a	1.05 a
Crew (Club)	55.0 a	54.5 a	1.15 a	1.18 a
Hill 81 (SWW)[c]	60.5 a	58.5 b	1.38 b	1.75 a
Stephens (SWW)	56.5 a	58.0 a	1.30 b	2.08 a
Daws (SWW)	56.5 a	58.0 a	2.30 b	3.15 a
Batum (HRW)	64.5 a	65.0 a	1.70 b	3.06 a
Hatton (HRW)	68.0 a	65.0 b	2.40 b	3.00 a
Lind				
Tres (Club)	50.5 b	53.5 a	1.08 a	0.48 a
Crew (Club)	54.5 b	57.0 a	1.18 a	1.08 a
Hill 81 (SWW)[c]	59.0 b	66.0 a	1.40 a	1.15 a
Stephens (SWW)	57.0 b	66.0 a	1.30 a	1.23 a
Daws (SWW)	56.0 b	66.0 a	2.30 a	1.38 b
Batum (HRW)	62.5 b	71.5 a	1.45 a	1.75 a
Hatton (HRW)	66.0 b	69.5 a	2.35 a	2.65 a

[a] Values with different superscripts between pairs of consecutive columns are statistically different at the 5% level of significance.
[b] 14% moisture basis.
[c] SWW = soft white winter, HRW = hard red winter.

No consistent differences were found in water absorption between flours milled from SPW and WPW (Table VI). Water absorption can increase as a result of increases in protein, pentosans, or damaged starch. The latter may be affected by increases in hardness or protein. The higher protein and lower hardness of SPW may cancel their effect on water absorption. Mixing time was generally higher in SPW flours in Pullman; however, no consistent difference was observed for the Lind-grown wheats (Table VI). Similarly, no consistent differences were recorded for the three alveograph parameters (extensibility L, elasticity P, and work W) for flours milled from SPW and WPW at the two locations (not shown).

Baking Properties

Pan bread. Volume of pan bread was higher when baked from SPW flours milled from wheats grown in Lind (Table VII). No consistent difference was recorded for the Pullman-grown wheats. The higher loaf volume for the SPW from Lind can be explained by the higher protein content. Of interest is the highly significant interrelationship among urea dispersibility, mixograph development time, water absorption, and loaf volume (Table IV). Urea dispersibility was negatively correlated with gluten strength (peak development time, Table IV), presumably due to the negative correlation between urea dispersibility and glutenin contents (Pomeranz 1965).

Steamed bread. No consistent pattern in bread volumes between WPW and SPW for the two locations could be established (Table VII). Generally, the crumbs of the SPW breads were softer, as determined by penetration tests, than those of the WPW breads (results not shown). Protein contents and protein quality, as they affect steamed bread volume, probably also affected bread crumb structure.

Cookie diameter. Corrected (to a constant 9% protein content) diameter was higher, or equal, in cookies baked from WPW than those from SPW at both locations and for both years (Table VIII). Two factors that govern cookie diameter are protein content and wheat hardness. The results summarized in Tables IV and VIII indicate that increases in both protein content and wheat hardness decreased cookie diameter.

CONCLUSIONS

Vernalized winter wheats were grown in winter and spring habitats. Wheats grown in a winter habitat were higher in test weight, kernel weight, and general hardness. Wheats grown in

TABLE VII
Breadmaking Characteristics of Flours Milled from Wheats Grown in Winter (WPW) and Spring (SPW) Habitats in Two Locations in 1986–87[a]

Variety and Location	Pan Bread: Loaf Volume (cm^3)		Pan Bread: Specific Loaf Volume (cm^3/1% protein)		Steamed Bread: Volume (cm^3)	
	WPW	SPW	WPW	SPW	WPW	SPW
Pullman						
Tres (Club)	555.0 a	585.0 a	15.49 b	20.97 a	748.8 b	829.2 a
Crew (Club)	615.0 b	727.5 a	23.63 b	36.19 a	850.8 a	904.3 a
Hill 81 (SWW)[b]	767.5 a	755.0 a	35.13 a	39.02 a	845.6 b	918.9 a
Stephens (SWW)	620.0 a	655.0 a	23.66 a	28.00 a	853.8 a	907.7 a
Daws (SWW)	690.0 a	687.5 a	32.22 a	31.76 a	802.5 a	738.8 b
Batum (HRW)	850.0 a	742.5 b	44.23 a	36.75 b	738.7 a	629.1 b
Hatton (HRW)	837.5 a	707.5 b	38.38 a	32.88 b	852.8 a	814.4 a
Lind						
Tres (Club)	485.0 b	555.0 a	9.09 a	10.73 a	796.1 a	757.5 a
Crew (Club)	625.0 b	755.0 a	24.17 a	24.62 a	866.9 b	941.3 a
Hill 81 (SWW)[b]	760.0 b	845.0 a	35.29 a	30.22 b	820.8 a	720.0 b
Stephens (SWW)	632.5 b	930.0 a	24.71 b	33.92 a	771.4 b	1091.8 a
Daws (SWW)	602.5 b	1000.0 a	24.95 b	42.68 a	820.7 a	568.6 b
Batum (HRW)	792.5 b	1062.5 a	38.77 b	43.23 a	747.7 b	940.1 a
Hatton (HRW)	802.5 b	980.0 a	36.21 a	40.31 a	802.5 b	960.4 a

[a] Values with different letters between pairs of consecutive columns are statistically different at least at the 5% level of significance.
[b] SWW = soft white winter, HRW = hard red winter.

TABLE VIII
Corrected (to 9% protein) Cookie Diameter from Flours Milled from Wheats Grown Under Winter and Spring Habitats at Two Locations in 1986-87 and 1987-88[a]

Variety and Location	Corrected Cookie Diameter (cm) 1986-87		1987-88	
	WPW	SPW	WPW	SPW
Pullman				
Tres (Club)	18.4 a	17.7 b	19.5 a	18.4 b
Crew (Club)	18.1 a	17.4 b	18.7 a	17.5 b
Hill 81 (SWW)[b]	17.4 a	17.8 a	18.0 a	16.9 b
Stephens (SWW)	17.5 a	17.5 a	18.5 a	16.9 b
Daws (SWW)	17.0 a	16.8 a	17.4 a	17.0 b
Batum (HRW)	16.3 a	15.8 b	16.1 a	16.1 a
Hatton (HRW)	16.8 a	16.1 b	15.7 a	15.9 a
Lind				
Tres (Club)	18.3 a	17.2 b	19.6 a	18.4 b
Crew (Club)	18.1 a	17.1 b	19.1 a	17.8 b
Hill 81 (SWW)[b]	18.0 a	16.9 b	18.8 a	17.5 b
Stephens (SWW)	18.0 a	17.1 b	19.0 a	17.2 b
Daws (SWW)	17.2 a	16.9 a	18.3 a	17.5 b
Batum (HRW)	16.1 a	16.3 a	15.8 a	15.6 a
Hatton (HRW)	16.4 a	16.6 a	15.7 a	15.9 a

[a] Values with different superscripts between pairs of consecutive columns are statistically different at least at the 5% level.
[b] SWW = soft white winter, HRW = hard red winter.

a spring habitat were higher in protein and ash. An increase in test weight and kernel weight was associated with an increase in flour milling yield and milling score. An increase in protein content resulted in an increase in volume of pan bread and a decrease in cookie diameter.

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