Environmental Influences on Flour Composition, Dough Rheology, and Baking Quality of Spring Wheat

G. G. Mikhaylenko,[1] Z. Czuchajowska,[1] B.-K. Baik,[1] and K. K. Kidwell[2,3]

ABSTRACT

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The highly variable environmental conditions across the Pacific Northwest (PNW) influence the milling and baking quality of wheat grain produced in this region. This study was conducted to compare the flour composition, dough rheology, and baking quality of soft and hard spring wheat grain produced in diverse environments. Thirteen soft and five hard spring wheat cultivars were grown at Lind, WA (semiarid) and Fairfield, WA (high precipitation) for three years. Grain was evaluated for flour composition, rheology, and experimental baked product quality. Flour composition, rheological properties, and baking qualities were primarily influenced by the environment. Protein contents, microSDS values, and water absorption levels were significantly ($P < 0.0001$) higher for all cultivars grown at Lind compared with those from Fairfield. Cookie diameters were larger ($P < 0.0001$) for soft flours from Fairfield, whereas loaf volumes were higher ($P < 0.0001$) for hard wheat flours from Lind. Results indicate that producing soft or hard wheat outside of its optimal climatic zone reduces experimental baked product quality.

A majority of the soft wheat produced in the Pacific Northwest (PNW) is exported to countries in the Pacific Rim and the Middle East (Lin and Czuchajowska 1997). The wide array of climatic conditions and market classes of wheat produced in this region impede the ability of exporters to supply wheat with predictable, consistent milling and baking quality to foreign consumers. A detailed investigation of the influence of environmental factors on flour composition and final product characteristics is required to define optimal production regions for each market class to improve the quality of PNW wheat grain.

Wheat flour quality is a complex derivative of flour composition components and the interactions of these components during the mixing and baking processes. Important wheat flour components include starch, gluten and nongluten proteins, lipids, nonstarch carbohydrates, and minerals (Graybosch et al 1996). Ash and protein contents are commonly used to assess flour quality. Ash is an indicator of the proportion of bran in flour, which can affect flour color and influence baking quality (Shogren et al 1981, Kaldy and Rubenthaler 1987). Wheat flour protein content affects its suitability for making specific final products (Delwiche 1998). Protein content is strongly influenced by environmental conditions and crop management practices; however, protein quality is genetically determined (Cornish et al 1991).

Rheological properties of dough during the mixing process are evaluated to understand and predict the behavior of flour in experimental baking tests. The gluten matrix, which encloses the starch granules and fiber fragments, is a major determinant of dough rheology. Environmental conditions during grain production also influence rheological properties of resulting wheat flour (Ciaffi et al 1996). Each class of wheat is characterized by unique rheological properties that determine its suitability for making specific products.

The sugarsnap cookie test is used to assess the quality of soft wheat flour; the test reflects cookie spread during the baking process (Kaldy and Rubenthaler 1987). Flour composition, its physical characteristics, and its milling properties significantly affect cookie quality. High protein levels are related to undesirable cookie texture (Posner and Hibbs 1997), and development of a strong gluten matrix during baking increases the viscosity of cookie dough, which is undesirable because cookie spread is restricted (Gaines 1990, Hoseney 1994). Grain hardness also is negatively correlated with cookie diameter because damaged starch increases water absorption and viscosity, which hinders cookie spread (Monsalve-Gonzales and Pomeranz 1993). Cultivar, environment, and cultivar × environment interaction significantly influence cookie diameter (Hazen and Ward 1997).

The breadmaking test is important for evaluating the quality of hard wheat flour (Souza et al 1993). High-quality bread flour is characterized by high protein content and strong gluten. In breadmaking, high water absorption is usually desirable, and high protein content, high levels of starch damage, and large particle size increase the water-holding capacity of dough (Mailhot and Patton 1988). Breadmaking potential is highly influenced by cultivar × environmental interactions (McGuire and McNeal 1974).

Physical and chemical properties of wheat flours are influenced by environmental factors and by cultivar (Lin and Czuchajowska 1997). Climatic conditions during plant growth and development have a more significant impact on flour quality traits than does cultivar (Gaines et al 1996). The industry requires uniform grain lots to predict milling and baking performance of wheat shipments; therefore, assessing the effects of environmental factors on flour composition and performance through experimental baking tests is essential for predicting changes in final product quality when using grain from diverse production regions.

The objective of this study was to monitor changes in flour composition, rheological behavior, and experimental baked products from soft and hard spring wheat grain produced in diverse climatic regions in eastern Washington.

MATERIALS AND METHODS

Grain Sources

In 1995, 1996, and 1997, 18 spring wheat cultivars and experimental breeding lines (hereinafter called cultivars), consisting of 12 soft white common and one soft white club (referred to as the soft wheat class) and five hard red (referred to as the hard wheat class) cultivars, were grown in two distinct environments that were selected based on differences in annual precipitation and average daily temperature during the frostfree period (March to August). Lind, a semiarid environment with an average total annual precipitation of 238 mm and an average daily temperature 14.8°C, is predominately a hard wheat production region, whereas soft wheat is typically grown in Fairfield, WA, which has an annual precipitation average of 453 mm and an average daily temperature 12.6°C (http//www.worldclimate.com 1998). Grain from every cultivar grown in each crop year from both environments was evaluated for rheological and baking performance.

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[1] Graduate assistant, late associate professor, and assistant professor, respectively. Department of Food Science and Human Nutrition, Washington State University, Pullman, WA, 99164-6376.

[2] Associate professor, Department of Crop and Soil Sciences, Washington State University, Pullman, WA, 99164-6420.

[3] Corresponding author. Phone: 509/335-7247. Fax: 509/335-4815. E-mail: kidwell@mail.wsu.edu

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Milling

Wheat grain was milled into flour using a Chopin laboratory mill according to the procedure described in the manual (CD1 instruction manual 1995). Soft and hard wheat was conditioned to 16 and 16.5% moisture, respectively, 24 hr before milling. The feeding rate for soft and hard wheat was 100 and 120 g/min, respectively. Flour yield was recorded as the percentage of flour recovered compared with the amount of grain introduced to the mill. Flour was stored at 4°C and aged for at least 15 days before analyses.

Flour Composition

Flour moisture content was determined by Approved Method 44-15A (AACC 2000), protein content (N × 5.7) was determined by a nitrogen analyzer (FP-428, Leco Corp., St. Joseph, MI), and ash content was measured by Approved Method 08-01.

Rheological Properties of Flour

A 10-g mixograph (National Mfg. Co., Lincoln, NE) was used to evaluate the rheological properties of the flours. Mixing time and mixograph water absorption were determined according to Approved Method 54-40 (AACC 2000). Mixograph water absorption was recorded as the amount of water absorbed by the flour sample to optimize mixing consistency and was reported as a percentage of flour weight. Mixing time was determined as the time required to mix the flour to optimum water-flour dough consistency.

Protein and Baking Quality Assessment

The microSDS sedimentation test (microSDS test) was performed according to Dick and Quick (1983) with a modification: flour samples were analyzed on a constant weight (0.6 g) basis and then were recalculated on a constant protein basis using the formula: microSDS constant protein = microSDS constant weight × 10/protein content of sample.

Experimental product quality evaluations included breadbaking according to the procedure of Finney (1984) for hard wheat flours and cookie diameter assessment through Approved Method 10-52 (AACC 2000) for soft wheat flours.

Statistical Analysis

At least two independent measurements per sample were collected for each quality parameter tested, and values were averaged for statistical analyses using the SAS computer software package (SAS Institute, Cary, NC). Analysis of variance was conducted using the general linear model procedure, and the cultivar × year × environment component was used as the error term. Sources of variation in the model were considered to be fixed effects. Pearson's correlation coefficients also were determined and statistical significance levels were $P < 0.05$ unless otherwise specified.

RESULTS AND DISCUSSION

Flour Composition and Rheological Characteristics

Year, cultivar, environment, and their interactions significantly influenced protein content, ash content, mixograph water absorption, and mixing time of soft and hard wheat flours (Table I). Flour composition and rheological properties were significantly influenced by production environment. Environment was the major source of variation for most of the chemical and rheological properties of flours extracted from both soft and hard wheat (Table I), as reported previously (Hazen and Ward 1997).

TABLE I
Effects of Year, Environment, Cultivar, and Their Interactions on Flour Chemical Composition of Soft and Hard Spring Wheat Grain

		F-Values[a]					
				MicroSDS			
Source	df	Flour Protein	Flour Ash	Constant Weight	Constant Protein	Mixograph Absorption	Mixing Time
Soft wheat							
Year (Y)	2	212.2***	36.7***	150.8***	65.0***	121.7***	25.7***
Environment (E)	1	2093.0***	38.9***	1450.5***	363.6***	611.2***	84.9***
Cultivar (C)	12	14.5***	18.0***	61.8***	56.5***	5.8***	37.0***
Y × E	2	25.3***	199.8***	8.3***	5.5**	54.0***	4.5*
Y × C	23	4.5***	4.0***	3.8***	2.7**	3.6***	10.2***
E × C	12	9.1***	4.9***	10.6***	5.4***	6.9***	5.4***
Hard wheat							
Y	2	216.5***	14.4***	1.5	94.8***	85.9***	42.2***
E	1	1460.6***	59.4***	326.9***	1.1	298.2***	377.1***
C	4	3.2*	4.8**	68.0***	92.2***	7.7***	307.3***
Y × E	2	85.5***	20.5***	53.6***	24.7***	20.5***	28.8***
Y × C	8	2.5*	3.5**	5.7***	6.8***	6.0***	8.2***
E × C	4	5.9***	1.1	3.3*	3.2*	5.6**	8.3***

[a] *, **, and *** = significant at 5, 1, and 0.1%, respectively.

TABLE II
Mean Values, Averaged Over Years, for Flour Chemical Composition and Rheological Properties for Soft and Hard Spring Wheat Cultivars Grown in Two Environments

				MicroSDS Values (mm)			
Endosperm Type	Environment	Flour Protein (%)	Flour Ash (%)	Constant Weight	Constant Protein	Mixograph Absorption (%)	Mixing Time (sec)
Soft[a]							
	Lind	11.5 ± 1.3	0.44 ± 0.06	50 ± 13	22.0 ± 4.6	54.5 ± 3.2	138 ± 38
	Fairfield	8.3 ± 0.9	0.41 ± 0.07	28 ± 9	16.8 ± 4.5	49.8 ± 1.6	169 ± 37
LSD[b]		0.14	0.01	1.13	0.54	0.38	4.64
Hard[c]							
	Lind	14.8 ± 1.6	0.53 ± 0.04	74 ± 11	25.4 ± 3.3	63.4 ± 3.2	207 ± 46
	Fairfield	11.2 ± 0.8	0.59 ± 0.07	57 ± 11	25.7 ± 5.4	58.3 ± 2.3	251 ± 44
LSD[b]		0.19	0.02	1.95	0.66	0.59	4.59

[a] Average of values for 13 soft spring wheat cultivars.
[b] Least significant difference ($P < 0.05$).
[c] Average of values for five hard spring wheat cultivars.

MicroSDS sedimentation values, mixograph water absorption, and mixing times are mainly influenced by protein quality; however, protein content also is important (Dick and Quick 1983, Bloksma and Bushuk 1988, Baik et al 1994). The microSDS method is based on the ability of SDS, lactic acid and soluble proteins to imbibe water (Lorenzo and Kronstadt 1987). MicroSDS volumes based on constant flour weight reflect gluten strength governed by protein quality and protein quantity, whereas microSDS volumes based on constant protein reflect differences in protein quality among cultivars.

All sources of variation in the model significantly affected microSDS volumes of soft wheat (Table I). Environment accounted for the largest proportion of the variation among microSDS volumes based on constant weight and constant protein (86 and 73%, respectively), suggesting that protein content and protein quality of soft wheat dramatically changed with production environments. MicroSDS volumes of hard wheat, based on constant weight, were significantly affected by all sources of variation except for year. However, when microSDS volumes of hard wheat were recalculated on a constant protein basis, all sources of variation were significant except for environment. The protein quality of hard wheat appeared to be more stable across diverse production environments than was the protein quality of soft wheat.

Average flour protein contents, ash contents, microSDS volumes based on constant weight and constant protein, and mixograph absorption levels were significantly higher for soft flours from Lind than those from Fairfield (Table II). Typically, high temperature during grain fill results in higher grain protein content accumulation (Hoseney 1994), which explains the higher protein content averages for wheat grown at Lind compared with wheat from Fairfield. As a result, higher microSDS volumes and mixograph water absorption values were obtained for flours extracted from grain produced at Lind compared with those from grain at Fairfield.

Average ash contents of soft wheat flours also were higher for grain from Lind compared with grain from Fairfield, whereas average ash content of flours from hard wheats was significantly higher when grain was produced at Fairfield compared with samples from Lind (Table II). In general, ash contents were higher than typical ash contents obtained at this extraction level, which may reflect differences in milling efficiencies using the Chopin mill compared with other types of experimental mills (*personal communication*).

Mixograph water absorption averaged over soft cultivars and years was significantly higher for flours extracted from grain from Lind compared with those from grain from Fairfield (Table II). Averages for flour protein content, microSDS volumes, and mixograph water absorption of hard cultivars also were significantly higher for flours from Lind than for flours from Fairfield (Table II). High grain-protein contents are usually desirable for bread wheats because increased protein content is typically associated with higher loaf volumes (Pomeranz 1988). Increased water absorption is desirable for hard wheat because loaf volume and loaf weight increase, whereas staling is delayed.

Average mixograph mixing time for flours from both soft and hard cultivars was significantly higher for grains produced in Fairfield compared with samples from Lind. Mixing time is determined by glutenin and gliadin seed storage protein composition, as well as by protein content. Low-protein flours (<12%) usually require longer mixing times than high-protein flours if extracted from grain of the same cultivar (Hoseney 1994). Average flour protein contents of both hard and soft wheat from Fairfield were lower than those for grain from Lind (Table II), which may have contributed to the extended mixing times required for flours extracted from grain from Fairfield.

Protein content for soft cultivars was 10.4–13.8% at Lind and 7.6–9.7% at Fairfield (Table III). Ranges of microSDS sedimentation volumes for soft wheat, based on constant weight, were 32–81 mm at Lind and 19–49 mm at Fairfield. Calorwa, Pomerelle, ID 488, and Whitebird had relatively low microSDS volumes, based on constant weight, over years at Fairfield. Conducting microSDS sedimentation tests on a constant protein basis neutralized the effect of protein content on sedimentation volume, allowing a more accurate comparison of protein quality differences among cultivars. MicroSDS volumes of soft wheat based on constant protein levels were significantly lower for Fairfield compared with values from Lind (Table III). Among soft wheats, low microSDS volumes based on constant protein were detected for Calorwa, Pomerelle, Whitebird, ID 488, and Wakanz across years and environments. Low microSDS sedimentation volumes usually indicate weaker gluten (Mosleth and Uhlen 1991), which is desirable for a majority of products made from soft wheat flour. Soft wheat flours with strong gluten produce cookies with small diameter, sponge cakes with low volumes, and noodle of poor texture compared with soft wheat flour with weak gluten (Gaines 1990, Baik et al 1994, Lin 1997).

TABLE III
Mean Values for Flour Protein, MicroSDS, Mixograph Absorption, and Mixograph Mixing Time for Soft and Hard Spring Wheats Averaged Over Three Crop Years Grown for Two Environments

			MicroSDS Values (mm)							
	Flour Protein (%)		Constant Weight		Constant Protein		Mixograph Absorption (%)		Mixing Time (sec)	
Cultivar	Lind	Fairfield	Lind	Fairfield	Lind	Fairfield	Lind	Fairfield	Lind	Fairfield
Soft										
Centennial	11.4 ± 1.2	7.9 ± 0.5	55 ± 7	26 ± 6	26 ± 4	17 ± 3	55.0 ± 1.5	51.3 ± 1.9	128 ± 18	170 ± 15
Whitebird	11.8 ± 1.2	8.0 ± 0.7	45 ± 7	22 ± 7	19 ± 2	14 ± 4	54.7 ± 1.9	51.0 ± 1.8	110 ± 15	180 ± 0
Pomerelle	11.3 ± 1.6	7.9 ± 1.0	45 ± 11	20 ± 7	20 ± 3	13 ± 3	54.7 ± 2.3	50.7 ± 1.0	113 ± 19	150 ± 69
ID 488	11.9 ± 0.5	7.6 ± 0.6	45 ± 6	21 ± 6	19 ± 3	14 ± 3	53.6 ± 1.4	49.3 ± 0.5	120 ± 27	170 ± 12
Edwall	10.6 ± 0.9	8.3 ± 0.5	41 ± 4	29 ± 5	20 ± 0	17 ± 2	53.0 ± 3.1	50.3 ± 1.4	113 ± 10	150 ± 27
Penawawa	11.0 ± 1.1	9.0 ± 1.0	56 ± 9	37 ± 10	26 ± 2	21 ± 5	52.7 ± 2.6	49.8 ± 0.9	165 ± 36	180 ± 0
Wakanz	11.8 ± 1.3	8.6 ± 0.9	43 ± 7	26 ± 4	19 ± 2	15 ± 1	53.7 ± 4.0	49.9 ± 0.2	123 ± 27	165 ± 17
Wadual 94	13.8 ± 2.6	9.7 ± 0.4	81 ± 5	49 ± 2	30 ± 3	26 ± 2	58.0 ± 4.6	51.0 ± 1.2	205 ± 40	210 ± 35
Alpowa	10.4 ± 0.6	8.4 ± 0.6	51 ± 1	38 ± 6	25 ± 1	23 ± 2	52.7 ± 3.6	50.0 ± 0.0	185 ± 80	220 ± 0
Wawawai	11.4 ± 1.0	8.9 ± 1.1	51 ± 7	30 ± 6	23 ± 1	17 ± 3	55.5 ± 3.4	49.7 ± 0.5	190 ± 16	210 ± 35
Sprite	12.1 ± 1.2	8.5 ± 0.7	55 ± 6	30 ± 4	23 ± 0	18 ± 2	56.0 ± 4.1	48.3 ± 1.9	113 ± 10	143 ± 34
Vanna	11.2 ± 1.3	7.6 ± 0.4	59 ± 17	26 ± 3	26 ± 4	17 ± 1	54.7 ± 2.7	47.3 ± 1.9	145 ± 28	190 ± 31
Calorwa	11.5 ± 1.0	8.5 ± 0.4	32 ± 6	19 ± 5	14 ± 2	11 ± 3	54.8 ± 4.5	48.7 ± 0.5	100 ± 90	125 ± 8
LSD[a]	0.76	0.43	5.14	3.30	2.21	2.06	2.85	0.78	13.72	21.33
Hard										
Spillman	14.8 ± 1.8	11.0 ± 1.0	67 ± 4	50 ± 6	23 ± 2	23 ± 5	63.7 ± 3.4	59.7 ± 2.6	180 ± 24	243 ± 14
Butte 86	14.4 ± 1.7	11.7 ± 0.8	61 ± 3	50 ± 1	22 ± 2	21 ± 2	63.0 ± 3.9	59.7 ± 2.7	178 ± 16	220 ± 16
WPB 926	14.6 ± 1.7	11.0 ± 0.4	80 ± 6	61 ± 16	28 ± 3	28 ± 7	61.7 ± 4.4	57.0 ± 0.9	227 ± 14	250 ± 15
WPB 936	15.1 ± 1.4	11.0 ± 1.0	86 ± 8	68 ± 8	29 ± 0	31 ± 4	64.3 ± 1.9	58.0 ± 2.7	277 ± 36	327 ± 23
Express	15.2 ± 1.8	11.4 ± 0.6	78 ± 8	56 ± 3	26 ± 1	25 ± 2	64.3 ± 1.9	57.3 ± 1.4	172 ± 17	213 ± 5
LSD[a]	1.98	0.43	7.55	10.02	1.27	4.33	3.92	1.59	20.39	16.38

[a] Least significant difference ($P < 0.05$).

Ranges of mixograph water absorption values for soft wheat were wider than those obtained for hard wheat across environments (Table III). Mixograph water absorption was higher for cultivars grown at Lind compared with those from Fairfield, and protein contents were elevated in the semiarid environment. Results of mixograph analyses of soft wheat are often inconclusive because a distinct peak is not established, and optimum mixing times of soft wheat flours are difficult to interpret (Lin 1997). Mixing times of soft wheat from Fairfield were longer from those for soft wheats from Lind.

The flour protein content range of hard wheat cultivars was relatively narrow: 14.4–15.2% at Lind and 11.0–11.7% at Fairfield (Table III). Express and WPB 936 had the highest protein contents among hard cultivars grown at Lind. Ranges of microSDS sedimentation volumes of hard wheat, based on constant weight, were 61–86 mm at Lind and 50–68 mm at Fairfield. Among hard wheats, WPB 936 had the largest microSDS volume across environments. Ranges of microSDS sedimentation volumes of hard wheat, based on constant protein, were similar across locations (22–29 mm at Lind and 21–31 mm at Fairfield), indicating that protein quality of hard wheat was not significantly altered by environmental factors. However, flour protein contents were significantly influenced by environment. Among hard wheats, WPB 936 had the largest microSDS volume, regardless of measurement method. The gluten strength of this cultivar appears to be environmentally independent.

Hard wheat flours from grain produced at Lind had higher water absorption values than hard wheat flours extracted from grain from Fairfield. Mixing times for hard wheat flours were significantly longer than those for soft wheat flours (Table III). Mixing times of hard wheat from Lind were 172–277 sec, which falls within the optimal mixing time interval for a bread dough with acceptable elasticity and mixing tolerance (Finney and Shogren 1972). Mixing times of hard wheat from Fairfield were longer than those from Lind.

TABLE IV
Effects of Year, Environment, Cultivar, and Their Interactions on Cookie Diameter and Bread Volume for Soft and Hard Spring Wheat Grain

	F-Values[a]			
	Soft		Hard	
Sources	df	Cookie Diameter	df	Bread Volume
Year (Y)	2	20.9***	2	0.1
Environment (E)	1	111.8***	1	77.0***
Cultivar (C)	12	7.7***	4	4.9*
Y × E	2	10.1***	2	2.6
Y × C	23	1.4	8	1.4
E × C	12	2.8*	4	0.5

[a] *, **, and *** = significant at 5, 1, and 0.1%, respectively.

TABLE V
Mean Values for Cookie Diameter and Bread Volume of Soft and Hard Spring Wheat Cultivars, Respectively, Averaged Over Three Crop Years Grown for Two Environments

	Cookie Diameter (cm)		Bread Volume (mL)	
Cultivar	Lind	Fairfield	Lind	Fairfield
Soft				
Centennial	18.0 ± 0.1	18.5 ± 0.3	…	…
Whitebird	18.5 ± 0.2	18.9 ± 0.2	…	…
Pomerelle	18.4 ± 0.4	18.8 ± 0.5	…	…
ID 488	18.2 ± 0.2	18.4 ± 0.4	…	…
Edwall	18.2 ± 0.1	18.5 ± 0.2	…	…
Penawawa	17.9 ± 0.3	18.2 ± 0.2	…	…
Wakanz	18.2 ± 0.3	18.7 ± 0.4	…	…
Wadual 94	17.5 ± 0.3	18.5 ± 0.2	…	…
Alpowa	18.0 ± 0.3	18.1 ± 0.2	…	…
Wawawai	18.4 ± 0.2	18.6 ± 0.1	…	…
Sprite	17.6 ± 0.3	18.6 ± 0.3	…	…
Vanna	18.2 ± 0.3	19.1 ± 0.3	…	…
Calorwa	18.1 ± 0.4	18.5 ± 0.3	…	…
LSD[a]	0.26	0.32	…	…
Hard				
Spillman	…	…	886 ± 33	612 ± 27
Butte 86	…	…	799 ± 64	649 ± 71
WPB 926	…	…	890 ± 50	706 ± 34
WPB 936	…	…	982 ± 31	716 ± 54
Express	…	…	998 ± 55	746 ± 13
LSD[a]	…	…	38.28	157.08

[a] Least significant difference ($P < 0.05$).

Variation for protein content was notably lower at Fairfield than at Lind for both wheat classes. The optimal, low-protein level for soft wheats was obtained at Fairfield, whereas the high-protein content target for hard wheat was achieved at Lind.

Cookie and Breadmaking Quality

Cookie diameter of soft wheat was significantly influenced by environment, year, cultivar, year × environment, and environment × cultivar interactions, whereas the bread volumes of hard wheats was significantly influenced only by environment and cultivar (Table IV). Average cookie diameter for soft wheat grown at Lind (18.1 ± 0.4) was significantly lower ($P < 0.0001$) than that for soft wheat grown at Fairfield (18.6 ± 0.4), although the difference was small in magnitude. Average bread volumes for hard wheat grown at Lind (912 ± 90 mL) were significantly higher ($P < 0.0001$) than for those at Fairfield (688 ± 92 mL). Cookies of larger diameter were obtained from soft wheat grown at Fairfield, whereas hard wheat grown at Lind had the largest bread loaf volumes.

These results suggest that experimental baked product quality improved when grain was produced in the most suitable growing environment for each market class. Mild climatic conditions with sufficient precipitation and moderate temperatures are desirable for producing high quality soft white wheat (Lin 1997). In comparison, high quality hard wheat is produced in high temperature climates with low precipitation levels. Fairfield and Lind are considered to be optimal production zones for soft and hard wheat, respectively. Therefore, we compared the stability of experimental baked products quality for both wheat classes in each environment.

Average cookie diameters for soft wheat were 17.5–18.5 cm at Lind and 18.1–19.1 cm at Fairfield (Table V). Among soft cultivars, Vanna, Whitebird, Wakanz, and Pomerelle produced cookies with the largest diameter regardless of environment, suggesting that some soft cultivars are less vulnerable to environmental changes than others. Cookie diameters for soft wheat from Fairfield were not drastically different from those for soft wheat from Lind, even though average cookie diameter differed statistically between environments (Table V). However, cookie-handling properties were clearly inferior for cookie dough made from soft flours from Lind when compared with those from Fairfield. Cookie doughs from Lind flours were sticky, cut edges adhered to the cookie cutter, and cookies were dark in color (data not shown).

Bread volume averages for hard wheat produced at Lind (799–998 mL) were significantly higher ($P < 0.0001$) than those for hard wheat from Fairfield (612–746 mL) (Table V). That was expected because the protein contents of hard wheat were higher for grain from Lind. Variation among bread volumes was lower among

TABLE VI
Correlation Coefficients Between Flour Composition and Rheology with End-Use Product Quality Parameters of Soft and Hard Spring Wheat Grain[a]

	End-Use Product Parameters	
	Cookie Diameter[b]	Bread Volume[c]
Protein	–0.70***	0.74***
MicroSDS	–0.74***	0.73***
Mixing time	0.08	–0.26
Mixograph absorption	–0.58***	0.66***

[a] Correlation coefficients for 13 soft and five hard spring wheat cultivars averaged across years and environments. *, **, and *** = correlation coefficient significant at 5, 1, and 0.1%, respectively.

[b] Averaged for 13 soft wheat cultivars across years and environments.

[c] Averaged for five hard wheat across years and environments.

hard grain lots from Lind compared with those from Fairfield. Overall, soft wheat produced superior sugarsnap cookies when grown at Fairfield, whereas hard wheat exhibited the largest loaf volumes when grown at Lind.

Correlation Among Flour Composition, Rheological Properties, and Final Product Quality

Pearson's correlation coefficients were calculated among protein content, microSDS volumes on constant weight basis, mixograph mixing time and water absorption, and experimental baked product quality of soft and hard wheat flour (Table VI). A significant, negative correlation was detected between protein content and cookie diameter for soft wheat, whereas bread volume was positively correlated with protein content for hard wheat. Kaldy and Rubenthaler (1987) also detected a significant, inverse relationship between protein content and cookie quality. Bread volume was highly influenced by both protein quantity and protein quality. MicroSDS volumes based on constant weight also reflect both protein quantity and protein quality (Mikhaylenko 1999), which explains why flour microSDS volumes on constant weight were significantly correlated with bread loaf volume. Flour microSDS volumes on constant weight also were significantly correlated with cookie diameter. Similar results were obtained between protein content and mixograph water absorption, although the correlations were slightly lower in magnitude. Mixograph mixing time was not predictive of either test product quality parameter; however, it was highly predictive of dough mixing time during experimental breadmaking ($r^2 = 0.94$; $P < 0.0001$).

CONCLUSIONS

Flour composition, protein quality, and mixograph characteristics were influenced by environmental factors, cultivar, and their interactions. The protein quality of hard wheat, as measured by microSDS sedimentation test, was more stable than that of soft wheats. Based on flour composition, protein quality, and rheological characteristics evaluations, the level of variability for these quality characteristics increased when soft wheat cultivars were grown in the semiarid environment and hard wheat cultivars were grown in the low-temperature, high-precipitation environment.

Cookie diameter was significantly influenced by environment, year, cultivar, and their interactions, whereas bread volume was influenced mainly by environmental effects. Environment was the largest source of variation among the quality parameters tested for both soft and hard wheat; therefore, the choice of growing environment will have an impact on final product quality. Our results indicate that producing soft and hard wheat outside of their target production zones has a negative impact on experimental baked product quality. Producing soft wheat in a semiarid region resulted in increased flour protein content, stronger gluten, higher mixograph water absorption, poor dough handling properties, and smaller diameter cookies. Producing hard wheat in the low-temperature, high-precipitation zone resulted in decreased protein content, decreased water absorption, prolonged mixing times, and significantly reduced bread loaf volumes. Therefore, targeting production of each wheat class to its optimal production region based on climatic factors may enhance the overall rheological performance and baking quality of grain lots exported from the PNW.

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