Effect of Cultivar and Environment on Quality Characteristics of Spring Wheat

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ABSTRACT

The eight spring wheat cultivars used in this study displayed a broad range in milling and baking quality. The best and poorest in overall breadmaking quality were represented by the cultivars Columbus and UM841, respectively. The semidwarf wheats Len and Norseman compared most favorably to Columbus and were also among the most environmentally stable cultivars. Both cultivar and environment had a significant effect on quality parameters. Cultivar by environment effects were statistically significant but relatively small in magnitude for most parameters, as confirmed by the rank correlation results. Composited samples over locations would be suitable for quality assessment for semidwarf wheats grown in western Canada for most of the characteristics studied. For the quality parameters that displayed large cultivar by environment interactions (i.e., test weight and thousand-kernel weight), samples from several environments should be used for quality evaluation, particularly in advanced generation breeding lines.

The effect of cultivar and environment and their interaction on semidwarf hard red spring wheat quality characteristics has never been determined for western Canada, although the Canadian wheat cultivar registration system requires that advanced lines meet rigorous quality requirements before they can be released as new cultivars. Candidate cultivars must exhibit acceptable quality characteristics in all intended environments and therefore must exhibit minimal cultivar by environment interactions.

Very little information exists on the relative importance of cultivar, environment, and cultivar by environment interaction effects on the quality characteristics of any of the spring wheat cultivars grown in Canada, although the importance of environmental effects on wheat quality was recognized many years ago (Sandstedt and Fortmann 1944, Harris et al 1945). The first study of this kind by Fowler and de la Roche (1975) involving hard and soft red spring wheats grown in eastern Canada reported that cultivar effects were important for all quality parameters and that large environmental effects were observed for protein content and protein-related quality parameters, while a relatively small environmental effect was observed for mixograph peak time. The authors also reported that cultivar by environment interactions had relatively little impact compared to the effect of cultivar or environment on physical, chemical, or rheological properties (Fowler and de la Roche 1975). A subsequent study examining tall-statured hard red spring wheat lines with genetically similar backgrounds grown in western Canada reported that both cultivar and environment had large effects on all quality parameters measured, and further, that cultivar by environment interaction effects were important for some quality characteristics (e.g., mixograph development time, falling number, and remix loaf volume) but were relatively unimportant for other quality characteristics (e.g., flour protein, flour yield, grinding time, and sedimentation values) (Baker and Kosmolak 1977). Both of these studies were preliminary, covered only a narrow range of wheat cultivars, and did not provide sufficient information to quantify precisely the effect of cultivar by environment interactions on quality parameters in diverse cultivars of spring wheat. The suggestion that physical, chemical, and rheological characteristics may have varying degrees of cultivar by environment interaction requires further clarification and verification. In addition, western Canadian wheat breeding programs are now developing Canada prairie spring wheats, which are semidwarf in stature. These wheats are quite different, genetically and agronomically (Lukow et al 1989), from the traditional tall hard red spring wheats, and therefore they may require different evaluation procedures.

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Evaluation of wheat quality involves the measurement of a large number of properties. Since many of the tests for quality evaluation are time-consuming and expensive, they have been performed traditionally on a limited number of samples. The number of samples to be evaluated may be reduced by compositing samples over replicates, locations, or years. However, this procedure reduces the precision with which quality characteristics are estimated and may lead to erroneous conclusions if large cultivar by environment interactions for quality parameters occur.

Therefore, the relative effect of cultivar, environment, and cultivar by environment interactions must be characterized and quantified to identify superior quality advanced lines prior to their registration and their use in breeding programs to ensure adequate assessment of the quality differences among advanced lines when grown in western Canada.

The objectives of this study, therefore, were to 1) evaluate the overall breadmaking quality differences in a diverse group of primarily semidwarf spring wheats; 2) estimate the magnitudes of cultivar, environment, and cultivar by environment interaction effects on quality parameters when these wheats are grown in western Canadian environments; and 3) determine appropriate quality evaluation procedures for these wheats.

MATERIALS AND METHODS

Samples

Eight genetically diverse spring wheat cultivars, including seven semidwarf (HY320, Len, Norseman, Oslo, RL4452, UM841, and Wheaton), and one tall (Columbus) were used. All cultivars were agronomically suitable for production in the growing locations. Pedigrees, wheat class, and country of origin of these cultivars are given in Table I. To determine the relative effect of cultivar, environment, and cultivar by environment interaction, trials using these eight adapted wheats were planted at three locations (Winnipeg, Glenlea, and Portage la Prairie) over two years (1986 and 1987) in a randomized complete block design with four replicates at each location. Growing conditions in both years at all locations were favorable for wheat. Rainfall equaled the long-term average for 1986 and was approximately 20% above the long-term average for 1987. Temperatures were well above average in May and June and average in July and August of both years. Yields were near average for 1986 and well above average in 1987. The Winnipeg tests were grown on well-drained Riverdale silty loam soil, Glenlea on poorly drained Red River clay soil, and Portage la Prairie on well-drained Newhurst clay loam soil. All tests were grown on summer-fallowed land that was high in fertility without the addition of fertilizer. Plots of 5 m, with four rows spaced 30 cm apart, were seeded at a rate of approximately 135 kg/ha. The center two rows were hand harvested, dried, and threshed. Quality tests were performed on the harvested seed of each cultivar for each replicate.

Quality Analyses

Flour yields were determined on a Buhler pneumatic laboratory mill after tempering wheat samples to 16.5% moisture. Test weight, thousand-kernel weight, kernel hardness, flour protein content, ash content, damaged starch content, falling number values, mixograms, and farinograms were determined as previously described (Buckley et al 1990, Lukow et al 1990). Sedimentation values were determined according to AACC approved method 56-60, and extensigrams were produced using 100 g of flour according to AACC approved method 54-10 (AACC 1983). Resistance to extension at the peak and extensibility were measured after a rest period of 135 min. The remix loaf volume was determined according to Kilborn and Tipples (1981), with baking absorption equal to 2% less than that of the farinograph absorption.

Statistical Analyses

All statistical analyses were performed using the Statistical Analysis System package (SAS 1985). The analysis of variance and estimates of the components of variance due to cultivar, cultivar by environment, and error were calculated according to Comstock and Moll (1963). The contribution of each variance component as a percentage was estimated by summing appropriate terms to give an estimate of total variance and then dividing the specific variance component by the total variance (Brandle and McVetty 1988). Rank correlation coefficients were determined for cultivars in all environments. The means of the rank correlations were calculated by summing the individual rank correlation coefficients and dividing by the number of environment comparisons (15) for every quality parameter. The relative stabilities of the cultivars for all quality parameters were compared using the procedure of Moll et al (1978).

RESULTS AND DISCUSSION

Cultivar Comparisons

The milling, physicochemical, and baking quality properties of the spring wheat cultivars are presented in Table II. Wide ranges in each quality parameter and significant differences among cultivars for all parameters were observed. Although there were cultivars equal to or better than Columbus, the majority of semidwarf cultivars were inferior in overall milling and breadmaking quality. For example, cultivars Len, RL4452, and Wheaton were equal to Columbus in flour yield, and Len and Norseman were equal to Columbus in bread loaf volume, but Columbus had significantly higher flour protein than all semidwarf cultivars tested (Table II). Len was equal to Columbus with the exception of lower flour protein content and farinograph absorption. The cultivar UM841 was the poorest in overall milling and breadmaking quality, with its relatively soft kernels resulting in poor milling performance, low flour protein content and absorption, weak mixing properties, and low bread-loaf volume. These results therefore confirm, in large part, the findings of McGuire et al (1980), who reported that semidwarf hard red spring wheats grown in Montana had lower flour yield, ash content, and protein content than did tall-statured hard red wheats in some trials and equal

TABLE I
Pedigree, Class, and Country of Origin of the Spring Wheat Cultivars

Cultivar[a]	Pedigree	Class	Country of Origin
Columbus	Neepawa*6/5/Frontana/3/McMurachy/Exchange //Redman*2/4/Thatcher*6/Kenya Farmer	Red spring	Canada
HY320	Tobari 66/Romany	Prairie spring	Canada
Len	ND499//Justin/RL4205/WI1261	Dark northern spring	United States
Norseman	HS781139-NAPB composite selection	Dark northern spring	United States
Oslo	Sonora 64/Yaqui 50 E/Guajolote/3/Inia/4 /Crano//Elgan/Sonora 64	Dark northern spring	United States
RL4452	Glenlea*6/Kitt	Utility	Canada
UM841	Junco//Heral/Glenlea/large-seeded winter	Utility	Canada
Wheaton	Crim/Era*2//Buitre/Gallo	Dark northern spring	United States

[a] All cultivars are semidwarf except for Columbus, which is tall statured.

TABLE II
Cultivar Means for Milling, Physicochemical, and Baking Quality Parameters[a]

	Quality Parameters[b]															
Cultivar	TW (kg/hl)	TKW (g)	GRT (min)	FLY (%, 14% mb)	FLP (%, 14% mb)	ASH (%, 14% mb)	FN (sec)	SED (cm^3)	SD (%)	MDT (min)	ABS (%)	DDT (min)	MTI (BU)	E (cm)	R (cm)	RLV (cm^3)
Columbus	79.6	34.0	0.57	75.2	14.5	0.42	308	67	19.6	2.3	63.5	6.0	25	23.2	7.7	927
HY320	76.6	32.5	0.92	70.4	11.2	0.45	293	62	7.6	3.4	54.6	4.8	36	26.6	11.3	709
Len	79.1	33.8	0.50	75.6	13.8	0.40	272	78	20.8	3.9	61.4	8.1	24	26.5	12.5	979
Norseman	76.9	32.6	0.49	74.1	13.2	0.41	266	53	20.4	2.4	59.7	4.6	40	24.7	6.5	873
Oslo	76.6	33.3	0.70	73.9	12.8	0.39	311	82	9.5	3.6	56.6	7.0	28	27.1	12.3	811
RL4452	76.2	38.7	0.50	74.9	12.4	0.47	332	63	25.8	5.0	56.8	9.9	12	22.8	18.4	717
UM841	75.5	38.2	0.92	68.6	10.9	0.42	203	59	6.1	3.0	55.0	4.2	55	24.3	12.1	666
Wheaton	76.2	32.5	0.56	75.6	12.2	0.43	294	61	19.1	4.0	58.0	7.6	28	26.6	11.9	843
LSD[c]	1.2	2.3	0.09	1.0	0.5	0.02	22	5	1.9	0.5	1.0	1.1	7	1.2	1.7	58
Range	4.1	6.2	0.42	7.0	3.6	0.08	128	28	19.7	2.7	8.9	5.7	43	4.3	6.0	313
CV[d]	1.1	3.9	5.38	0.9	2.4	3.77	6	5	7.7	6.4	1.1	9.9	22	4.2	8.1	5

[a] Means are averages for four replicates and six environments combined (24 observations per mean).
[b] TW = test weight, TKW = thousand-kernel weight, GRT = grinding time, FLY = flour yield, FLP = flour protein, ASH = flour ash, FN = falling number value, SED = sedimentation value, SD = starch damage, MDT = mixograph development time, ABS = farinograph absorption, DDT = farinograph dough development time, MTI = farinograph mixing tolerance index, E = extensigraph extensibility, R = extensigraph resistance to extension, RLV = remix loaf volume.
[c] LSD = least significant difference at $P = 0.05$.
[d] CV = coefficient of variation.

or better breadmaking quality in other trials. It should be noted, however, that recent breeding efforts have been successful at producing semidwarf wheats with equal protein content and quality to that of tall-statured wheats (Busch et al 1990).

Environment Comparisons

Environment means, least significant differences, and associated ranges for all quality parameters are presented in Table III. Variation due to environment was pronounced for all characteristics. All the cultivars had harder kernels, which resulted in greater starch damage in the first three environments (all from 1986) than in the last three environments (all from 1987). Dough extensibility decreased and resistance to extension increased in the last three environments compared with the first three environments.

Estimation of Relative Effects of Cultivar and Environment and Their Interaction

The relationship between the effects of cultivar and environment and their interaction on the quality parameters, was investigated by analysis of variance (Tables IV and V). Each location in each year was considered as a separate environment. All main effects (cultivar, environment) were highly significant ($P < 0.01$) or significant ($P < 0.05$) (for effect of environment on mixing tolerance index) except for environment effects on flour yield and farinograph dough development time. The cultivar by environment interactions were highly significant ($P < 0.01$) for all quality parameters. These results are in agreement with previous findings for hard red spring wheats (Baker and Kosmolak 1977), hard red winter wheats (Baenziger et al 1985), and soft white winter wheats (Bassett et al 1989) but in contrast with those of Fowler and de la Roche (1975), who reported no significant cultivar by environment interactions for hard red spring wheat quality characteristics. The environmental range used by the latter authors was apparently quite narrow, reducing the likelihood of significant cultivar by environment interactions.

Components of variance for each quality characteristic expressed as percentages illustrate the relative contribution of each source to the total variance (Table VI). The variance component for cultivars accounted for most of the total variation, ranging from 52.8 to 93.5% of the variability associated with each quality parameter. Effects of cultivar by environment interaction ranged from a low of 3.8% of total variance for starch damage content to a high of 30.3% of total variance for thousand-

TABLE III
Environment Means for the Quality Parameters

	Quality Parameters[a]															
Environment[b]	TW (kg/hl)	TKW (g)	GRT (min)	FLY (%, 14% mb)	FLP (%, 14% mb)	ASH (%, 14% mb)	FN (sec)	SED (cm^3)	SD (%)	MDT (min)	ABS (%)	DDT (min)	MTI (BU)	E (cm)	R (cm)	RLV (cm^3)
1	77.3	37.1	0.55	73.6	12.6	0.43	266	63.7	18.1	2.8	60.1	5.9	38	26.8	9.0	863
2	75.9	32.0	0.60	73.1	11.3	0.44	289	59.7	16.9	3.4	56.2	6.5	29	26.0	10.5	796
3	75.5	34.9	0.59	73.9	12.8	0.41	254	69.8	17.6	3.2	59.3	7.2	30	27.1	9.7	865
4	77.8	36.2	0.72	73.5	12.3	0.42	303	60.9	14.9	3.8	58.1	6.2	31	22.8	12.2	758
5	78.6	32.1	0.69	73.4	13.1	0.45	303	65.5	13.8	4.0	57.1	6.6	32	24.4	14.7	797
6	77.3	34.4	0.72	73.9	13.6	0.40	293	73.7	15.3	3.5	58.4	6.9	27	24.2	13.3	814
LSD[c]	1.2	2.2	0.08	1.0	0.6	0.02	20	5.9	1.7	0.5	0.9	1.1	7	1.1	1.5	52
Range	3.1	5.1	0.17	0.8	2.3	0.05	49	14.0	4.3	1.2	3.9	1.3	9	4.4	5.9	107

[a] TW = test weight, TKW = thousand-kernel weight, GRT = grinding time, FLY = flour yield, FLP = flour protein, ASH = flour ash, FN = falling number value, SED = sedimentation value, SD = starch damage, MDT = mixograph development time, ABS = farinograph absorption, DDT = farinograph dough development time, MTI = farinograph mixing tolerance index, E = extensigraph extensibility, R = extensigraph resistance to extension, RLV = remix loaf volume.

[b] 1 = Winnipeg 1986, 2 = Glenlea 1986, 3 = Portage la Prairie 1986, 4 = Winnipeg 1987, 5 = Glenlea 1987, 6 = Portage la Prairie 1987.

[c] LSD = least significant difference at $P = 0.05$.

TABLE IV
Mean Squares for the Analysis of Variance of Milling and Analytical Quality Parameters[a]

		Quality Parameters[b]								
Source of Variation	df	TW	TKW	GRT	FLY	FLP	ASH	FN	SED	SD
Environment	5	42.90**	142.74**	0.191**	3.14NS	20.40**	0.0093**	13231.01**	918.28**	90.44**
Rep (environment)	18	2.70	5.95	0.003	1.01	1.09	0.0002	360.19	60.92	2.52
Cultivar	7	51.97**	153.89**	0.784**	163.70**	37.27**	0.0164**	36726.81**	2260.47**	1274.79**
Cultivar × environment	35	3.97**	15.12**	0.023**	2.99**	0.60**	0.0011**	1432.29**	86.64**	10.04**
Error	126	0.66	1.85	0.001	0.47	0.09	0.0003	245.42	10.49	1.55

[a] *, $P = 0.05$; **, $P = 0.01$; NS, nonsignificant.

[b] df = degrees of freedom, TW = test weight, TKW = thousand-kernel weight, GRT = grinding time, FLY = flour yield, FLP = flour protein, ASH = flour ash, FN = falling number value, SED = sedimentation value, SD = starch damage.

TABLE V
Mean Squares for the Analysis of Variance of Rheological and Baking Quality Parameters[a]

		Quality Parameters[b]						
Source of Variation	df	MDT	ABS	DDT	MTI	E	R	RLV
Environment	5	5.85**	63.23**	6.93NS	474.90*	87.82**	164.64**	56,592.40**
Rep (environment)	18	0.04	0.95	1.20	49.56	1.99	1.75	2,278.73
Cultivar	7	19.23**	232.04**	94.41**	3,912.50**	64.74**	298.82**	295,300.30**
Cultivar × environment	35	0.81**	2.74**	3.66**	163.53**	4.27**	8.40**	9,955.25**
Error	126	0.05	0.40	0.42	47.78	1.15	0.87	1,611.77

[a] *, $P = 0.05$; **, $P = 0.01$; NS, nonsignificant.

[b] df = degrees of freedom, MDT = mixograph development time, ABS = farinograph absorption, DDT = farinograph dough development time, MTI = farinograph mixing tolerance index, E = extensigraph extensibility, R = extensigraph resistance to extension, RLV = remix loaf volume.

TABLE VI
Percentage of Total Variance for Each Source of Variation and Means and Frequencies of the Rank Correlations of the Quality Parameters[a]

	TW	TKW	GRT	FLY	FLP	ASH	FN	SED	SD	MDT	ABS	DDT	MTI	E	R	RLV
Source of variation																
Cultivar	57.4	52.8	82.9	85.9	87.4	58.0	73.1	75.4	93.5	76.1	90.7	75.5	67.1	57.4	81.7	76.3
Cultivar × environment	23.7	30.3	14.9	8.1	7.3	18.6	14.7	15.8	3.8	18.9	5.6	16.2	12.4	17.8	12.7	13.4
Error	18.9	16.9	3.1	6.0	5.3	23.4	12.2	8.8	2.7	5.0	3.7	8.3	20.5	24.8	5.6	10.3
Rank correlation results																
Mean of the rank correlations	0.55	0.45	0.82	0.72	0.92	0.70	0.83	0.67	0.86	0.78	0.96	0.88	0.82	0.76	0.74	0.78
No. of significant rank correlations	5	2	15	9	15	7	13	9	15	14	15	15	12	10	10	15

[a]TW = test weight, TKW = thousand-kernel weight, GRT = grinding time, FLY = flour yield, FLP = flour protein, ASH = flour ash, FN = falling number value, SED = sedimentation value, SD = starch damage, MDT = mixograph development time, ABS = farinograph absorption, DDT = farinograph dough development time, MTI = farinograph mixing tolerance index, E = extensigraph extensibility, R = extensigraph resistance to extension, RLV = remix loaf volume.

kernel weight. For most wheat quality parameters investigated in this study, the cultivar by environment interactions were statistically significant but very small in magnitude compared to cultivar effects. These results confirm those of Peterson et al (1986), who noted that although cultivar by environment interactions were statistically significant, the effects of cultivar on mineral and protein contents of wheat grain, flour, and bran were far greater than the interaction effects. Baenziger et al (1985) reached similar conclusions for soft red winter wheat quality parameters. The relatively large (more than 20% of cultivar variance) cultivar by environment interactions for test weight and thousand-kernel weight suggest that these quality parameters may require multiple environment testing to accurately assess genetic potential of wheat lines. Bassett et al (1989) found relatively large cultivar by environment interactions for kernel hardness, alkaline water retention capacity, and cookie diameter in soft wheats.

Rank Correlations

For every quality parameter, the mean of the rank correlations for all 15 environment comparisons and the number of significant rank correlations among the possible 15 combinations are presented in Table VI. The mean of the rank correlations and the frequency of significant rank correlations fall into two broad categories: 1) high mean rank correlation values and high frequency of significant rank correlations and 2) low mean rank correlation values and low frequency of significant rank correlations. Grinding time, flour protein content, falling number value, starch damage value, mixograph development time, farinograph absorption, dough development time, mixing tolerance index, and remix loaf volume belong to category 1. Thus, the rank correlation data for these parameters confirm the finding of small and unimportant interaction components in the total variation. Such results suggest that analyses of samples from a single environment or samples composited over environments might be adequate to predict cultivar performance over many environments for certain quality characteristics such as flour protein content and bread loaf volume, whereas quality parameters such as test weight and thousand-kernel weight may require separate samples taken from a number of different environments for adequate differentiation of quality among advanced lines.

For quality characteristics with very high cultivar by environment interactions (test weight and thousand-kernel weight) and for certain other quality characteristics with moderate to high cultivar by environment interactions such as flour yield, ash content, sedimentation value, extensibility, and resistance to extension, rank correlations between environments indicated that the interactions observed for these parameters were caused by changes in magnitude and reversals in rank. Only 5 of 15 and 2 of 15 rank correlation coefficients were significant for test weight and thousand-kernel weight, respectively. These results further substantiate that for these parameters, separate samples taken

TABLE VII
Regression Coefficients with Standard Errors and R^2 for the Quality Parameters

Cultivar	Parameter[a]	Slope of Regression	Standard Error	R^2
Columbus	TKW	1.22	0.31	0.42
	FLP	1.03	0.18	0.60
	ASH	1.77	0.29	0.63
	ABS	1.72	0.17	0.83
	E	1.35	0.17	0.74
HY320	GRT	2.19	0.27	0.75
	MDT	1.46	0.15	0.81
	MTI	1.04	0.44	0.20
	E	1.00	0.20	0.56
	R	1.28	0.14	0.80
Len	TW	1.56	0.23	0.68
	FN	1.12	0.17	0.65
	SED	1.18	0.14	0.77
Norseman	FLP	1.18	0.11	0.84
	SD	1.30	0.22	0.61
	E	1.30	0.19	0.69
Oslo	TW	1.37	0.19	0.70
	SED	1.53	0.23	0.67
	DDT	1.08	0.27	0.42
RL4452	FLP	1.47	0.12	0.87
	FN	1.06	0.17	0.63
	MDT	1.87	0.47	0.42
	ABS	1.27	0.12	0.84
	R	2.14	0.34	0.67
	RLV	2.92	0.42	0.68
UM841	TW	1.14	0.21	0.57
	TKW	1.27	0.28	0.48
	GRT	3.31	0.34	0.82
	FLY	1.04	0.66	0.10
	SD	1.40	0.32	0.46
	ABS	1.11	0.14	0.74
	MTI	2.43	1.03	0.20
	E	1.60	0.19	0.79
Wheaton	TKW	1.06	0.15	0.71
	FLY	1.33	0.38	0.36
	ASH	1.39	0.25	0.58
	FN	1.42	0.15	0.81
	SD	1.03	0.33	0.31
	MDT	1.24	0.29	0.46
	ABS	1.08	0.11	0.81
	DDT	1.83	0.43	0.45

[a]TKW = thousand-kernel weight, FLP = flour protein, ASH = flour ash, ABS = farinograph absorption, E = extensigraph extensibility, GRT = grinding time, MDT = mixograph development time, MTI = farinograph mixing tolerance index, R = extensigraph resistance to extension, TW = test weight, FN = falling number value, SED = sedimentation value, DDT = farinograph dough development time, RLV = remix loaf volume, FLY = flour yield.

from a number of different locations may be required for adequate cultivar evaluation. For the majority of quality parameters measured in the predominately semidwarf wheat cultivars used in this study, samples from a single environment or samples composited over environments would appear to be adequate to assess quality differences among lines and to predict relative performance.

Stability Analyses

To further investigate the nature of the cultivar by environment interaction, cultivar stability parameters were estimated for all quality characteristics for all cultivars. One or two cultivars that are very responsive to changes in environment could substantially reduce the rank correlation values and lead to incorrect conclusions regarding the cultivar by environment interaction for the majority of the cultivars used in this study. Table VII lists the cultivar stability parameters of the quality traits with b values (slope of the regression) greater than 1. Cultivars with $b > 1$ were considered more responsive to the environment than cultivars with $b < 1$, which were considered less responsive to the environment. The spring wheats used in this study differed in degree of responsiveness to the environment for all quality characteristics. Wheaton and UM841 were most responsive to the environment (i.e., the least stable) based on the number of quality traits with $b > 1$. Len, Norseman, and Oslo showed the greatest environmental stability. Only RL4452 responded to environmental variation for bread-loaf volume. In all other cultivars this parameter was relatively stable. From a breeding goal of developing cultivars with wide range adaptability, Wheaton and UM841 would be undesirable. The suitability of RL4452 would be questionable as well because of the importance of bread-loaf volume to end-use quality.

The semidwarf cultivars responded differently to changes in the environment, with cultivars such as Wheaton and UM841 contributing much more to the cultivar by environment interactions observed in quality characteristics than Len, Norseman, or Oslo. The degree of stability displayed by the latter three cultivars is desirable for wheats grown on the prairie. In addition, composited sample quality analyses would be most accurate for environmentally stable cultivars.

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