Genetic Improvement in Milling and Baking Quality of Hard Red Spring Wheat Cultivars[1]

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ABSTRACT

Genetic selection for improved milling and baking quality of hard red spring wheat (*Triticum aestivum* L.) has been well documented. Few studies have examined whether improved cultivars have resulted from selection for quality. Forty-five hard red spring wheats developed from 1911 to 1990 and commercially produced in the U.S. Pacific Northwest region were evaluated for milling and baking quality using grain harvested from three Idaho locations in 1989 and two locations in 1990. Regression analysis, using year of release as the independent variable, indicated significant improvement in mixing tolerance (0.046 degrees yr^{-1}), mixing time (0.019 min yr^{-1}), and corrected loaf volume (0.079 ml yr^{-1}). Flour protein content declined significantly (−0.018 g kg^{-1} yr^{-1}). There was no significant change in flour yield. The relative improvement of cultivar baking quality over time was greater for flour from irrigated environments than that from dryland environments. Rank summary of eight important quality traits indicated that nine of the 10 best quality wheat cultivars have been released since 1970. When grown under contemporary cultural practices, recently released cultivars are generally superior to older cultivars in overall baking quality and are comparable to older cultivars in milling performance.

Wheat breeders routinely evaluate breeding lines for end-use quality. There is some concern that recently released high-yielding wheat cultivars may have inferior milling and baking quality (Pates 1988, OTA 1989). Unfortunately, such concern is generally based on perception rather than on statistical comparison of the relative performance of cultivars for important indicators of milling and baking quality. Most hard wheat improvement programs have incorporated methods for selecting genotypes with improved milling and baking quality. Test weight and flour yield are frequently used as indicators of milling quality. Flour protein concentration, mixograph tolerance, mixing time, dough absorption, loaf volume, and loaf texture are important measures of baking quality (Finney et al 1987). The quality of a wheat can be described using these physical characteristics, which are individually reproducible and heritable. Intermediate heritabilities of quality traits (Schlehuber et al 1967, Lofgren et al 1968) have afforded opportunities for genetic improvement.

Molecular aspects of bread quality also can be partially defined. Payne (1987) reviewed the effects of high molecular weight glutenin alleles with causal effects on bread quality and concluded that significant portions of the variation in wheat quality can be attributed to high molecular weight glutenins. Primard et al (1991) found that the end-use qualities of wheat could be improved, in some populations, through selection for favorable quantitative content of protein solubility (Osborne) fractions, glutenin and gliadin alleles, and total protein content. If overall bread quality, as well as physical and chemical components of quality, can be measured reproducibly, should not the quality of wheat be improved through the selection practiced in most breeding programs?

Case studies of genetic improvement in the wheat crop examined the improvement in agronomic traits (Dalrymple 1980, Cox et al 1988). Cox et al (1989) conducted one of the few systematic studies of changes in the quality of wheat cultivars. They demonstrated that genetic improvement in quality traits had occurred over the past 70 years in the hard red winter wheat market class. Comparative studies of changes in end-use quality of hard red spring wheats have not been conducted.

The Pacific Northwest (PNW) states of Idaho, Oregon, and Washington have had major dryland and irrigated wheat-producing regions since the beginning of this century. Although this region is better known for soft white wheat production, a substantial number of hard red spring wheats have been introduced or released to PNW wheat growers for commercial production. In this study, the milling and baking quality of 45 hard red spring wheats released from 1911 to 1990 was evaluated. Our objective was to characterize the changes in the milling and baking quality traits of PNW hard red spring wheats due to genetic selection over this period.

MATERIALS AND METHODS

Grain Source

Cultivars and their release dates are shown in Table I. Cultivars selected were: 1) grown on a large area (e.g., Thatcher and WPB 906R); 2) grown over a long period of time (e.g., Ceres, Komar, Rival); or 3) represented unique genetic improvements (e.g., Pitic 62 and Bronze Chief). Seed of each line was grown in a single environment in 1988 (Moscow, ID). The 1988 seed increase plots were rogued for purity and inspected for conformation to published descriptions. Field experiments were conducted in 1989 and 1990 using seed from the 1988 Moscow grow-out. In 1989, test plots were grown at the Aberdeen, Twin Falls, and Tetonia research farms of the Idaho Agricultural Experiment Station. Aberdeen and Twin Falls are irrigated locations; Tetonia is a dryland, high-elevation location. The spring wheat trials were grown in a crop-fallow rotation. In 1990, test plots were grown at Aberdeen and Tetonia. In 1989, each field trial had one replicate. In 1990, each field trial was grown in a randomized complete block design with two blocks. The 1989 and 1990 experimental units were a five-row 4.6-m^2 plot and a four-row 4.0-m^2 plot, respectively. The seeding rate was 100 kg ha^{-1}. Plots were harvested with a small-plot combine. In 1990, replicates were bulked, providing one grain sample per entry, per location, for quality analysis.

Milling and Baking Analyses

Milling and baking evaluations were conducted at the University of Idaho, Aberdeen quality lab. Methods for tempering, milling, measuring flour yield, and baking were in general accordance with those described by the American Association of Cereal Chemists (AACC 1983).

Wheat samples were cleaned and tempered to a 14% moisture level (AACC methods 44-11 and 26-10). Wheat was milled into a straight-grade flour using a C. W. Brabender Quadrumat Senior Mill (AACC method 26-21). Flour protein was determined using near-infrared reflectance measured with a Dickey-John GAC III analyzer (AACC method 39-10). Mixographs determined mixing

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time to peak, mixing tolerance, and dough-water absorption using 10 g of flour (AACC method 54-40). Mixing tolerance was measured as the degree of the acute angle formed by the straight line drawn through the rise to peak mixing resistance and line drawn through the decline in mixing resistance.

Bread was baked from each sample using the optimized straight-dough method from 100 g of flour (AACC method 10-10B). Loaf volumes were measured and loaves were rated for exterior appearance and internal grain structure (texture). Internal grain scores were based on visual evaluation of loaf cell size, cell-wall thickness, elongation of cell structure, and uniformity of cells within a specific radius of the swirl. The external texture scores summarized the structure of the break, shred type, molding crease, and any structural deformities (wrong side break, shell top, and rough exterior). Grain and texture scores were based on a 0–5 scale with an ideal loaf scored as 5. Corrected loaf volume was estimated for each sample by standardizing the loaf volume to the mean protein percentage (13.3%) of all cultivars across all environments using the linear regression equation for predicting loaf volume from flour protein (slope $b = 30.1$ cm^3 per percentage point of flour protein; intercept 550 ml). The test for heterogeneity of correction slope was nonsignificant for this data set; therefore, a common slope was used for the loaf-volume correction. Dough handling characteristics (dough type) were visually evaluated at four stages: out of the mixer, first punch, second punch, and loaf molding/into the pan. Doughs were scored as ideal, less than ideal, or deficient. Doughs that were sticky, tacky, dry, or weak were rated as less than ideal or deficient, depending on the intensity of the flaw. A dough that was ideal in three or more stages was rated 2, doughs that were deficient at one stage, or less than ideal at two or three stages, were scored 1. Doughs were rated 0 if deficient at two or more stages or less than ideal at all stages.

Flaws to the dough and baked loaf were recorded. These flaws included sticky dough; the loaf deficiencies included wrong side break, shell top, yellow interior, coarse texture, and texture indicative of underoxidation (pin holes).

Statistical Analyses

Pearson's correlation analysis was used to assess relationships between milling and baking data. Phenotypic correlations were measured on the correlations between traits across all combinations of cultivars and environments. Correlations between cul-

TABLE I
Release Date, Place of Origin, Peak Production Area, and Quality Ranking for 45 Hard Red Spring Wheats Grown in the U.S. Pacific Northwest from 1911 to 1990

Cultivar	Origin	Release Year	Year of Peak Area[a]	Peak Area (ha)	Quality Rank Summaries[b] All	Irrigated	Dryland
Marquis	Ontario	1911	1919	178,524	226	213	189
Ruby	Ontario	1917	1929	2,392	198	165	220
Red Bobs	Saskatchewan	1918	1934	2,451	234	238	206
Ceres	N. Dakota	1926	1979	4,165	222	197	196
Komar	N. Dakota	1930	1974	27,302	153	152	161
Thatcher	Minnesota	1934	1964	54,210	185	204	171
Premier	N. Dakota	1938	1954	257	232	238	205
Rival	N. Dakota	1939	1974	122	223	211	227
Regents	Manitoba	1939	1949	985	241	213	244
Pilot	N. Dakota	1939	1969	2,511	255	219	250
Comet	Montana	1940	1964	1,702	218	196	238
Henry	Wisconsin	1944	1969	1,089	224	178	254
Redman	Manitoba	1947	1954	1,516	184	193	168
Saunders	Ontario	1948	1954	3,426	202	177	203
Selkirk	Manitoba	1953	1959	1,960	232	228	233
Centana	Montana	1958	1964	2,893	236	213	229
Canthatch	Manitoba	1959	1964	1,363	207	244	145
Justin	N. Dakota	1962	1974	4,005	118	95	142
Pitic 62	CIMMYT[c]	1962	1969	122	307	309	298
Fortuna	N. Dakota	1966	1979	22,031	186	168	223
Moran	Idaho	1967	1974	6,282	136	119	152
Red River 68	CIMMYT	1968	1969	1,701	147	139	181
Fremont	Utah	1970	1984	6,930	142	157	155
Bounty 208	CIMMYT	1971	1979	4,953	112	124	133
Peak	Idaho	1971	1974	5,476	139	146	206
Anza	California	1971	1979	1,773	250	243	263
Bannock	Idaho	1972	1979	19,382	115	114	122
Peak 72	Idaho	1972	1974	4,265	134	150	141
Wared	Washington	1972	1979	3,382	185	203	158
Prodax	CIMMYT	1972	1979	18,077	205	214	229
Bounty 309	CIMMYT	1974	1984	1,667	217	188	220
Borah	Idaho	1974	1984	12,667	217	215	258
Yecora Rojo	California	1975	1984	7,441	132	125	190
Protor	CIMMYT	1975	1974	1,511	145	134	194
Newana	Montana	1976	1984	7,529	206	200	235
Sawtell	Idaho	1978	1979	993	161	140	222
Wampum	Washington	1978	1984	16,854	195	176	244
Pondera	Montana	1980	1984	98	125	132	170
Probrand 751	Minnesota	1980	1984	5,610	140	144	208
McKay	Idaho	1981	1984	6,095	194	170	239
WPB906R	Montana	1984	1984	34,656	104	67	67
Bronze Chief	Montana	1985	nd	<2,500?	71	95	191
Copper	Idaho	1987	nd	<6,000	111	108	205
Spillman	Washington	1987	nd	<6,000	151	126	229
Vandal	Idaho	1990	nd	nd	131	153	185

[a] Area based on USDA Crop Cultivar Surveys from 1919 to 1984.
[b] Rank summary for least square means of 8 milling baking traits, lower score preferred.
[c] International Center for Wheat and Maize Improvement, Mexico.

tivars were also estimated, based on the mean performance across the five test environments of each the 45 cultivars.

End-use quality characteristics were evaluated for genetic improvement using linear and quadratic polynomial regression models. Year of release was used as the independent variable, and the continuous quality characteristic was the dependent variable. Test year and location effects were included in the model. Interaction of milling and baking trends with trial year and location was tested by the significance of the slope by trial year, slope by location, and slope by trial year by location interaction parameter estimate after fitting location, test year, and the common slope across test years and locations. The cultivars were grouped by release date into four 20-year intervals, and each cultivar value was weighted in the regression equation by the inverse of the number of cultivars in that 20-year period to correct for increased numbers of released cultivars in recent years. Bread grain, external appearance, dough type, and dough-absorption evaluations had limited ranges of discrete rather than continuous observations. These four traits had a poor fit to linear regression models due to their distribution characteristics. Analysis of variance sums of squares are reported but not regression solutions. It is assumed that the cultivar means for the texture and absorption variable are normally distributed according to the central limit theorem (Snedecor and Cochran 1980). Therefore, these traits were only included in the Student *t*-test comparisons described below.

A rank summation to determine the overall cultivar quality was generated from eight traits: flour protein, flour yield, mixograph tolerance, mixing time, dough absorption, corrected loaf volume, external loaf texture, and internal loaf texture. Each cultivar was ranked from best to worst for those traits using means across all environments, and the rankings for each cultivar were summed for the eight traits. A similar summary was used to determine the overall performance of cultivars in irrigated trials and in dryland trials.

For simplified data presentation, cultivars were divided into two groups; the averages across trials for traits of cultivars released before 1970 were compared to the averages across trials for traits of cultivars released after 1970. A Student *t*-test evaluated the significance of differences in cultivar quality between time periods.

RESULTS AND DISCUSSION

Correlations Between Quality Traits

Mixograph information is often used in breeding programs to predict dough and loaf characteristics (Finney et al 1987). Time to mixograph peak is predictive of dough mixing time. In this study, mixograph peak was positively correlated to mixing time in phenotypic comparisons and comparisons between cultivars (r = 0.97 and 0.83, respectively; Table II). Mixograph height and loaf volume were also correlated phenotypically and across cultivars (r = 0.50 and 0.73, respectively). Because of these correlations and the relationship reported in the literature for these two pairs of traits, only dough mixing time and loaf volume are discussed further.

Flour protein was correlated to flour yield, loaf volume, and both loaf grain and texture scores (Table II). Flour protein was also negatively correlated to mixograph tolerance. Mixograph tolerance was independent of corrected and uncorrected loaf volume. Dough type was phenotypically correlated to all other characters except mixing tolerance. Dough type had no genetic correlation to any other trait, indicating it is independent of other cultivar baking characteristics.

The date of cultivar release was positively correlated to mixing time (0.46), dough absorption (0.38), corrected loaf volume (0.48), and exterior loaf texture (0.30). Flour protein content was negatively correlated to date of release (−0.41).

Quality Changes

Regressions of dough mixing time and corrected loaf volume on year of release had significant and positive coefficients (Tables III, IV, and V). This indicates improvement; higher values are considered superior for these traits in the PNW environments. There was an average of 0.019 min yr^{-1} improvement in mixing time, an increase of more than 1 min in this important parameter for the period studied (Table V). Interestingly, mixing time improvement did not have an environmental interaction in this study (Table V). This indicates that mixing time, although responsive to the environment, produces similar cultivar ranking when evaluated in different southeastern Idaho environments. Hard red spring wheats from southeastern Idaho and the PNW typically have mixing times that are too short for the U.S. milling industry. Therefore, lengthening the time to optimum dough development is a desired improvement. Flours with medium to medium-long mixing times usually have good mixing tolerance, good dough handling properties, and good loaf volume (Finney et al 1987).

It was difficult to detect a trend for mixograph tolerance because there were highly significant interaction terms for location by release date, and year by location by release date (Table III). For example, in 1989 at Aberdeen, an improvement of 0.066 degrees yr^{-1} was observed, but, in 1990, a decline of 0.070 degrees yr^{-1} was observed. This genotype by environment interaction strongly suggests that it is impossible to base conclusions about mixograph tolerance on data from a limited set of test environments.

There were no significant changes in uncorrected loaf volume (Table IV). There has, however, been an average improvement, over all environments, of 0.079 ml yr^{-1} in corrected loaf volume. Marquis, the oldest cultivar in the study, had a corrected loaf volume of 929 ml. Corrected loaf volume of Marquis improved 0.9% per 10 years within the period studied. Improvement in corrected loaf volume was relatively greater for Aberdeen and Twin Falls, the irrigated locations (highly significant location by

TABLE II
Correlations Between Milling and Baking Quality Traits for 1989 and 1990 Trials[a]

	Flour Protein (FPRO)	Flour Yield (FYLD)	Mixograph Peak (PEAK)	Mixograph Height (HT)	Mixograph Tolerance (TOL)	Mixing Time (MIX)	Dough Absorption (ABS)	Dough Type (DOT)	Loaf Volume (LV)	Corrected Volume (CLV)	Interior Grain (INT)	Exterior Texture (EXT)
Release	−0.41**[b]	0.01	0.45**	0.23	0.18	0.46**	0.38**	0.24	0.14	0.46**	0.30*	0.29
FPRO	...	0.35*	−0.29	0.54**	−0.32*	−0.22	0.28	−0.12	0.58**	0.03	0.45**	0.15
FYLD	0.41**	...	0.07	0.32*	−0.18	0.11	0.08	−0.05	0.23	0.04	0.62**	0.35*
PEAK	−0.38**	−0.30**	...	0.18	0.47**	0.97**	0.52**	0.19	−0.11	0.07	0.03	0.68**
HT	0.73**	0.51**	−0.28**	...	−0.37*	0.26	0.64**	0.01	0.73**	0.52**	0.57**	0.47**
TOL	−0.47**	−0.34**	0.49**	−0.62**	...	0.48**	0.24	−0.19	−0.25	−0.09	−0.40**	0.25
MIX	−0.05	0.00	0.83**	0.15*	0.29**	...	0.57**	0.01	−0.07	0.07	0.03	0.74**
ABS	0.32**	−0.09	0.30**	0.44**	−0.01	0.48**	...	0.01	0.45**	0.37*	0.27	0.66**
DOT	0.42**	0.14*	0.21**	0.37**	−0.01	0.32**	0.24**	...	0.12	0.11	0.01	−0.09
LV	0.60**	0.08	−0.11	0.50**	−0.17*	0.04	0.39**	0.50**	...	0.83**	0.53**	0.21
CLV	0.00	−0.20**	0.16*	0.07	0.14*	0.08	0.24**	0.31**	0.80**	...	0.34*	0.16
INT	0.11	0.01	0.10	−0.01	0.02	0.04	0.12	0.17*	0.37**	0.38**	...	0.23
EXT	0.26**	0.19**	0.32**	0.33**	0.04	0.05**	0.32**	0.41**	0.31**	0.19**	0.26**	...

[a] Phenotypic correlations (below diagonal), correlations among cultivars (above diagonal).
[b] *, ** Correlation coefficients significant at the 95 and 99% probability level, respectively.

release date interaction, Table IV), than it was for Tetonia (0.079 and 0.183 vs. 0.027 ml yr^{-1}, Table V). However, release date was positively associated with improvement in corrected loaf volume at all locations.

Regression coefficients for flour protein concentration were significant and negative. The protein content of flour has declined an average of 0.018 g kg^{-1} yr^{-1} for the period studied. The magnitude of the regression coefficients for the irrigated locations, Aberdeen and Twin Falls, was greater than for the dryland location, Tetonia (−0.018 and −0.024 vs −0.008 g kg^{-1} yr^{-1}). These findings are in general agreement with a trend reported by Cox et al (1989) in a study of hard red winter wheat. In that study, there was a slight decline in flour protein over time, whereas all other traits showed improvement, except flour yield, which was unchanged. In this study, flour yield was also unchanged by varietal release date. Milling performance, therefore,

TABLE III
Analysis of Variance of Mean Square Terms for Changes in Milling and Mixograph Traits with Release of New Varieties of Wheat

Source[a]	*df*	Flour Protein	Flour Yield	Mixograph Peak	Mixograph Height	Mixograph Tolerance
Test Year	1	6.43	30.69	3.62	8.04	137.29
Location	2	0.67	1.16	0.23	0.21	76.64
Yr × Loc	1	4.40	9.76	0.02	5.05	76.71
Release Date	1	2.06** [b]	0.16	2.25**	0.01	19.17**
Quad. Rel.	1	0.01	0.89	0.38**	0.43**	1.41
Yr × Rel	1	0.02	1.30	0.03	0.00	8.50~[c]
Loc × Rel	2	0.24	1.93	0.04	0.15**	24.21**
Yr × Loc × Rel	1	0.04	2.90	0.01	0.81**	46.19**
Residual	203	0.06	1.15	0.04	0.03	2.47

[a] Yr = year, Loc = location, Rel = release date, Quad = quadratic function of release date.
[b] ** *F*-test significant at 99% significance level.
[c] ~ = *F*-test probability between 75 and 95% confidence interval.

TABLE IV
Analysis of Variance of Mean Square Terms for Changes in Baking Traits with Release of New Varieties of Wheat

Source[a]	*df*	Mix Time	Dough Type	Dough Absorption	Loaf Volume	Corrected Loaf Vol.	Interior Texture	Exterior Texture
Test year	1	0.00	0.43	0.03	0.13	83.50	0.20	0.48
Location	2	0.49	1.60	0.40	0.20	16.68	0.38	0.05
Yr × Loc	1	0.50	0.99	3.23	0.08	0.39	0.29	0.00
Release date	1	3.28** [b]	1.64**	0.59**	0.02	56.40**	0.07	0.15*
Quad. rel.	1	0.53**	3.04**	0.24*	0.35**	30.39**	0.33**	0.00
Yr × Rel	1	0.05	1.51*	0.04	0.10*	2.22	0.06	0.04
Loc × Rel	2	0.02	0.54	0.14*	0.06~	14.7**	0.07~[c]	0.06
Yr × Loc × Rel	1	0.03	0.01	0.02	0.01	4.3~	0.00	0.13*
Residual	203	0.05	0.29	0.04	0.02	1.76	0.03	0.03

[a] Yr = year, Loc = location, Rel = release date, Quad = quadratic function of release date.
[b] *, ** *F* test significant at 95 and 99% significance levels, respectively.
[c] ~ = *F*-test probability between 75 and 95% confidence interval.

TABLE V
Regression Coefficients for Changes in Milling and Baking Traits with Release of New Cultivars[a,b]

Environment	Flour Protein (g kg^{-1} yr^{-1})	Mixograph Peak (min yr^{-1})	Mixograph Height (cm yr^{-1})	Mixograph Tolerance (degree yr^{-1})	Mix Time (min yr^{-1})	Loaf Volume (ml yr^{-1})	Corrected Loaf Volume (ml% yr^{-1})
All years/locations	−0.018	0.016 (−1.2,+0.0003)	0.001 (−1.3,+0.0003)	0.046	0.019 (−1.5,+0.0004)	0.006 (−128,+0.033)	0.079
All years							
Aberdeen	−0.018 (+0.7,−0.0002)	...	...	...	...	−0.145 (−90.5,+0.232)	0.721 (−9.8,+0.0025)
Tetonia	−0.008 (−0.5,+0.0001)	...	...	...	...	−0.138 (−99.9,+0.0260)	0.274 (−5.3,+0.0014)
Twin Falls	−0.024 (+0.7,−0.0002)	...	...	...	...	0.576 (−273.9,+0.0705)	1.83 (−26.9,+0.0069)
1990, Aberdeen	...	...	0.0129 (−1.5,+0.0004)	−0.070 (+10.8,−0.0032)	...	...	...
1990, Tetonia	...	...	−0.009 (−0.7,+0.0002)	0.091 (+1.5,−0.0004)	...	...	...
1989, Aberdeen	...	...	−0.002 (−0.5,+0.0001)	0.066 (−8.4,+0.0022)	...	...	...
1989, Tetonia	...	...	0.018 (−3.6,+0.0009)	−0.096 (+22.6,−0.0058)	...	...	...
1989, Twin Falls	...	...	−0.009 (−0.8,+0.0002)	0.199 (−12.2,+0.0032)	...	...	...

[a] Averaged across locations and years and within locations and years when interactions were significant.
[b] Regression coefficients presented for significant regressions only. Values in parentheses are linear and quadratic regression coefficients, respectively, when quadratic coefficients were significant.

TABLE VI
Means for Quality Traits Across a Total of Five Trials in 1989 and 1990 for Older (23 Cultivars) Versus Newer (22 Cultivars) Hard Red Spring Wheat Cultivars

	Means					
	All Trials		Dryland Trials		Irrigated Trials	
Quality Trait[a]	1911–1970	1971–1990	1911–1970	1971–1990	1911–1970	1971–1990
Flour yield, %	59.4	59.8	60.8	61.2	59.2	58.9
Flour protein, %	13.5	13.0**[b]	13.6	13.2**	13.8	12.9**
Mixograph tolerance, °	65.5	65.6	68.1	67.5	62.5	65.1*
Dough absorption, %	64.9	65.4**	65.1	65.6*	64.8	65.3**
Mixing time, min	2.1	3.0**	2.1	3.3**	1.8	2.9**
Dough type	1.3	1.5*	1.3	1.5	1.3	1.6*
Loaf volume, ml	936	963**	958	964	933	958
Corrected loaf volume, ml	928	968**	949	965	919	970**
External loaf texture[c]	3.1	3.2	2.9	3.3**	3.2	3.2
Internal loaf texture[c]	2.3	2.5**	2.4	2.6	2.2	2.5**
Rank summary (eight traits)	207	155**	206	194	196	153**

[a] Higher values desired for all quality traits, except rank summary.
[b] *, ** Paired data classes significantly different at 95 and 99%, confidence interval based on a *t*-test comparison.
[c] Based on 0–5, where ideal loaf scored 5.

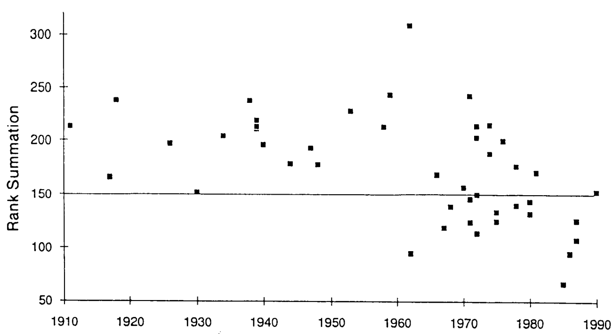

Fig. 1. Changes in rank summary score of hard red spring wheat quality evaluated in irrigated trials, average across locations and years. Lower rank summary scores preferred.

has not suffered a systematic decline in quality with crop improvement (Table III).

It is important to note that in the hard red springs wheats, as in the Cox et al (1990) study of hard red winter wheats, loaf volume has not declined, despite reduced protein content. Loaf volume has generally been linearly and positively dependent on flour protein concentration (He and Hoseney 1992). Therefore, newer cultivars with better quality protein can produce a larger loaf volume per unit of protein, compared to older cultivars.

Comparisons of New and Old Cultivars

Comparing means of 23 cultivars released from 1911 to 1970 with means of 22 cultivars released from 1971 to 1990 for nine quality traits generally reinforces the regression analysis (Table VI). Flour protein averaged 0.5% higher in the older group; however, the older group was not superior for any other trait. Flours from the recent group of cultivars grown under irrigation produced greater loaf volume and improved internal loaf grain and dough type, when compared with flours from the older group. There were no significant differences between old and new cultivars for these three traits when evaluated under dryland conditions. Recent cultivars were much improved in mixing time, averaging about a minute longer than the older cultivars. Dough absorption was higher in newer cultivars than in older cultivars when grown under either dryland or irrigation. This was in spite of the lower protein content of the newer cultivars (Table VI).

Results of this study indicate that, except for flour protein concentration, recently released cultivars are generally superior to older cultivars for end-use quality traits. In these Idaho environments, the cultivars released after 1970 averaged 13.0% protein. Protein level is partly a function of available soil nitrogen. Part of the decline in flour protein content may be due to a uniform application of nitrogen fertilizer. Nitrogen fertility, based on residual soil NO_3^2 and applied fertilizer, was adjusted at the irrigated locations to produce 8 MT ha^{-1}, based on contemporary cultivars (Brown 1986). Some recent releases exceeded yields of 8 MT ha^{-1}. Most cultivars released before 1970 produced below the target yield level and, therefore, were grown under luxuriant levels of available soil nitrogen. Johnson (1978) reported that both high-protein and medium-protein content hard red winter wheat cultivars had protein levels that ranged from unacceptably low to high, because of a wide range of fertilizer application rates. Protein content tends to be negatively correlated with yield, but the correlation is not strong enough to preclude simultaneous improvement of both traits (Johnson et al 1985, Cox et al 1989). Growers can increase protein content by applying N at rates well above levels influencing grain yield. However, this practice is seldom economically feasible. Without economic incentives for higher grain protein levels, growers will continue to select cultivars and fertilizer practices that maximize grain yield and minimize expenditures for chemical amendments.

The Effect of Quality Selection

Results of the rank summary indicate that cultivars in this study released after 1970 were superior to those from the earlier era as evidenced by their lower ranks (Fig. 1). Nine of the 10 lowest ranked (best) cultivars were released after 1970 (Table I). Twelve of the 22 cultivars released since 1970 have rank summaries less than the arbitrary level 150, whereas only four of the 23 cultivars released from 1911 to 1970 had the desirable ranking of less than 150. Cultivars released after 1970 had fewer major flaws (sticky dough, wrong side break, yellow interior, shell top, underoxidation, or coarse texture). Nine cultivars had no major flaws in any of the environments. One (Sanders) was released before 1970; eight (Bounty 208, Peak, Peak 72, Yecora Rojo, Pondera, Westbred 906R, Copper, and Vandal) were released after 1970.

The relative quality of wheat cultivars, as evaluated in the southeast Idaho environment, remained constant until the mid-1960s. After 1960, quality of cultivars (as indicated by declining rank summation values) began improving, particularly when evaluated in irrigated environments (Fig. 1). The significant quadratic regression coefficients (Table V) also point to increasing rates of improvement with time. Prior to this period, hard red spring cultivars grown in the PNW were developed in the U.S. Midwest or the prairie provinces of Canada. Starting with the release of Moran in 1967, cultivars selected and evaluated for quality in PNW environments were released to PNW growers. With the release of semidwarf germ plasm from the International Maize and Wheat Improvement Center, CIMMYT, cultivars selected for productivity and quality in higher yield environments were made available to growers (e.g., Bajio 66 sibs: Red River 68, Peak, and Peak 72). Selection for quality in PNW environments, either through early testing (Moran and Bannock) or before release (Peak), probably has increased rates of progress for quality since the mid-1960s.

Why are the results of this study at odds with milling and baking industry observations of declining quality? The evaluations for quality covered the six key areas of flour performance that millers and bakers consider important: 1) bread grain, 2) mixing tolerance, 3) dough characteristics (dough type), 4) dough absorption, 5) mixing time, and 6) loaf volume, as well as the additional characteristics of milling yield and dough flaws. In each of these areas, quality improved or remained the same. One explanation may involve the region of the study. Most of the PNW hard red spring wheat production is exported. With the exception of flour from a few of the newer cultivars, most of hard red spring flours produced in these environments would be unacceptable to the domestic industry except as a blending flour with stronger gluten wheats. As a result, there may be insufficient sampling by the U.S. milling and baking industry to draw specific conclusions about changes in the PNW hard red spring product. A second explanation may lie with the decline in flour protein. Low-protein cultivars may produce flours with insufficient protein content to develop optimum gluten strength more frequently than high-protein cultivars do. The quality stability of newer versus older wheats remains an important area for future research. This study did find a consistent improvement in the average dough performance through breeding efforts, indicating that plant breeders, through direct selection, have been successful at producing cultivars with the ability to outperform the cultivars of yesteryear, both in the field and in the bakery.

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