IMPROVEMENTS IN THE BREAD-MAKING QUALITY AND AGRONOMIC PERFORMANCE OF CANADIAN SPRING WHEATS RELEASED BETWEEN 1860 AND 1986.

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ABSTRACT

Twenty eight red spring wheat cultivars ranging from "Red Fife" to "Laura" in vintage were field-tested in each of four years (1989-1992). End-use quality analyses were performed on the grain harvested from three experiments. The objective of this study was to measure the rate of cultivar improvement for agronomic and bread-making quality performance. In the absence of disease, the more modern cultivars yielded 18% more than the cultivars released at the turn of this century. The yield advantage of the modern cultivars approached 30% under leaf rust disease pressure. Yield levels are estimated to be increasing at a rate of approximately 20+ kg/ha/yr. Protein quantity and quality have improved over time as has loaf volume. Improvements in agronomic, disease resistance and value-added performance have been off-set by a slight delay in maturity.

INTRODUCTION

It is generally assumed that plant breeding efforts have resulted in the release of spring wheat cultivars that are superior to their ancestors, offering economic advantages to producers and the Canadian agri-food industry as a whole. In the absence of side-by-side comparisons of obsolete versus modern cultivars it is difficult to unequivocally state that modern cultivars are superior to their ancestors. Hucl and Baker (1987) compared 12 spring wheat cultivars ranging from Red Fife to Columbus in vintage in three common field-testing environments at Saskatoon. The cultivar Neepawa out-yielded Red Fife by 5% and headed-out seven days earlier. When compared to cultivars of a comparable maturity, Neepawa out-yielded Marquis by 16%, Thatcher by 12%, Selkirk by 22% and Manitou by 12%. Those yield differentials were achieved in the absence of disease pressure. Hucl and Baker concluded that yield increases in our red spring wheats were achieved by increases in harvest index and kernels per spike but that this was achieved at the expense of earlier maturity.

The objective of the current study was to examine a larger array of red spring wheats over a wider range of environments not only for agronomic performance, but also for end-use quality.

MATERIALS AND METHODS

The following red spring wheat cultivars were studied: Red Fife, Early Red Fife, Preston, Huron, Marquis, Stanley, Ruby, Garnet, Red Bobs 222, Ceres, Thatcher, Apex, Regent, Rexcue, Redman, Saunders, Selkirk, Lake, Canthatch, Pembina, Manitou, Neepawa, Napayo, Sinton, Chester, Katepwa, Roblin and Laura. Field experiments were conducted at Watrous (1989-1992) and Saskatoon (1990-1992). The 1991 experiment at Watrous was destroyed by hail and the 1992 experiment at that site was abandoned. A randomized complete block design with four (1989) or three (1990-1992) replications was used. At Watrous, each plot consisted of four spring wheat rows 22 cm apart and 5 m long. A single row of winter wheat was seeded between each plot. At Saskatoon, each plot consisted of four 3.7 m-long rows spaced 30 cm apart (1990, 1991) or five rows spaced 20 cm apart (1992). Fertilizer (11-51-0) was drilled in with the seed at a rate of approximately 50 kg ha^{-1}. With the exception of the 1989 experiment, which was seeded on a plough-down green manure lentil crop from the previous year, all experiments were established on fallow land. Seeding rates of 290 and 250 seeds m^{-2} were used at Watrous and Saskatoon, respectively.

The following traits were measured on two replications: days to spike emergence, days to maturity, plant height (excluding awns), degree of lodging (Belgian scoring system) and leaf rust severity index (CIMMYT system). At maturity, plots were harvested with a plot combine and the grain was dried down to a moisture content of 10±1% in forced air driers. Kernel weights were determined from a 500-kernel subsample and test weights were measured using a 0.5 hL cup.

The following quality parameters were measured in 1990 and 1991: flour yield (Brabender mill), flour protein (Udy method (1990), NIR method (1991)), sedimentation value (SDS method (1990), Zeleny method (1991)), and loaf volume using the GRL remix method (Irvine and McMullan 1960) with 0 and 15 ppm potassium bromate added to the flour. In 1990 mixograph data (MDT, MPKH) were obtained while in 1991 farinograph data (FAbs, DDT, MTI) were obtained instead. Additional laboratory tests conducted in 1991 included flour ash content and colour (Kent-Jones scale) determinations.

Analyses of variance were performed for each experiment A combined ANOVA was performed for the 1990 experiments. Where significant (P=0.05) cultivar effects were detected, cultivar means were regressed against the relative time of cultivar release. The year 1860, when Red Fife is thought to have been introduced to Western Canada (DePauw and Thomas 1986), was considered year zero. The function providing the best significant fit was used to descibe the relationship between an individual trait and the time of cultivar release. Rates of trait improvement were obtained from the regression coefficients of linear functions and from the first derivative of quadratic and cubic functions at four points in time corresponding to the release of Marquis, Thatcher, Selkirk and Neepawa.

RESULTS AND DISCUSSION

With the exception of plant height in 1989 and flour yield in 1991, cultivar differences for the traits measured in each experiment were statistically significant (data not presented). A majority (83%) of the agronomic traits exhibited a significant response to time of cultivar release while approximately half of the quality attributes exhibited a significant response to time of cultivar release (Tables 1 to 3). These results indicate that plant breeding efforts have had an effect on both the agronomic performance and quality attributes of our red spring wheats.

Table 1. Coefficients of determination for functions describing the effect of cultivar age on agronomic performance.

Year	Grain yield	Days to Heading	Days to Maturity	Plant height	Lodging	Leaf rust infection
1989	NS	20.0 **	22.6 **	NS		
1990	20.0 **	21.9 **	35.1 **	42.3 **		
1991	37.5 **	NS	29.9 **	35.0 **	NS	51.4 **
1992	49.1 **	12.3 **	38.8 **	63.9 **	18.7 *	

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.

Table 2. Coefficients of determination for functions describing the effect of cultivar age on quality attributes.

Year	Test weight	Kernel weight	Flour yield	Flour protein	Sedim.	Mixograph DT	Mixograph PKH	Loaf vol. 0ppm	Loaf vol. 15ppm
1989	NS	NS							
1990	38.5 **	NS	NS	NS	20.4 **	NS	NS	26.5 **	10.7 *
1991	NS	18.7 *	NS	33.0 **	32.7 **			19.7 *	10.6 *
1992	37.6 **	NS							

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.

Table 3. Coefficients of determination for functions describing the effect of cultivar age on quality attributes.

	Farinograph absorption	Farinograph DDT	Farinograph MTI	Ash	Kent Jones Colour
1991	61.7 **	48.5 **	34.2 **	NS	NS

** Significant at the 0.01 probability level.

When cultivar means are grouped by era of release a number of obvious trends are apparent. In the case of grain yield (Table 4), there has been, on average, an 18% increase since the turn of the century. Under leaf rust (Puccinia recondita) pressure, as was the case in 1991, the yield advantage of more recent cultivars over pre-1928 cultivars increased to 22-31% (Table 4).

Table 4. Mean agronomic performance of wheat cultivars released during five eras.

		Grain yield (kg/ha)					
Era	N	1989	1990	1991	1992	AVERAGE	(% of most recent era)
1860-1900	4	1108	2628	2794	3272	2451	81.9
1909-1928	6	844	2530	3175	3304	2463	82.3
1935-1947	6	827	2426	3332	3502	2522	84.2
1953-1965	5	918	2617	3528	3753	2704	90.3
1970-1986	7	975	2822	4035	4142	2994	100.0

N = number of cultivars per era.

Based on Cooperative Test data from outside the rust prone areas of western Canada, the cultivar Neepawa yielded approximately 13% more than Marquis and 7% more than Thatcher (DePauw and Thomas 1986). Hucl and Baker (1987) determined that Neepawa out-yielded Marquis and Thatcher by 14 and 10%, respectively, in the absence of foliar disease pressure. In the rust-prone portion of the prairies (eastern Saskatchewan, Manitoba) Neepawa out-yielded Marquis by approximately 19% (1971-1983 Central Bread Wheat Coop Tests). It would appear, based on the figures cited above, that in the absence of obvious disease pressure grain yields have increased by roughly 15% over an 80 year period. Yield protection due to introduced resistance to leaf rust is responsible for an extra 5%, or more, increase in grain yield.

The yield gains in cultivar era 5 (1970-1986) were achieved with only a slight delay in maturity (+1 day) relative to the cultivars released in eras 2 to 4 (Table 5). The post-Neepawa cultivars are, however, still four days earlier maturing than the pre-Marquis era cultivars. DePauw and Thomas (1986) reported that, based on Coop Test data, Neepawa matured 2-4 days earlier than Marquis. Hucl and Baker (1987) found that Marquis reached the heading stage 2.5 days later than Neepawa. Consequently, on average, yield gains have been achieved with little or no loss (i.e. delay) in maturity.

Table 5. Mean agronomic performance of wheat cultivars released during five eras.

		Maturity (days)				
Era	N	1989	1990	1991	1992	AVERAGE
1860-1900	4	77.6	93.4	91.7	102.3	91.3
1909-1928	6	74.1	90.1	86.7	95.1	86.5
1935-1947	6	74.5	90.0	86.3	94.1	86.1
1953-1965	5	75.0	90.2	87.7	94.7	86.9
1970-1986	7	76.1	90.6	86.2	96.8	87.4

N = number of cultivars per era.

On average, plant height was reduced by approximately 12 cm by the 1930's and has remained rather stable since that era (Table 6).

Table 6. Mean agronomic performance of wheat cultivars released during five eras.

		Height (cm)			
Era	N	1990	1991	1992	AVERAGE
1860-1900	4	69.5	118.8	109.7	99.3
1909-1928	6	64.6	113.1	101.2	92.7
1935-1947	6	61.5	105.7	94.1	87.1
1953-1965	5	60.2	108.5	97.1	88.6
1970-1986	7	60.8	108.9	94.1	87.9

N = number of cultivars per era.

Protein content has risen, on average, from 14.6% (pre-Marquis era) to 15.7% in the most recent era (Table 7). Era differences in protein content were small in 1990 but large in 1991, likely reflecting varietal differences in leaf rust resistance. Moderate to high levels of leaf and/or stem rust infection have been shown to significantly reduce protein content (Greaney et al. 1941). Protein yield (kg/ha) has increased by 40% over time (data not presented). Sedimentation values have risen from 44.4 up to 52.4 cc over the same period of time (Table 7).

Table 7. Mean quality performance of wheat cultivars released during five eras.

		Protein content (%)			Sedimentation (cc)		
Era	N	1990	1991	AVG	1990	1991	AVG
1860-1900	4	16.2	13.0	14.6	52.3	36.5	44.4
1909-1928	6	16.1	14.0	15.1	50.4	37.9	44.2
1935-1947	6	16.2	14.1	15.2	55.7	41.0	48.4
1953-1965	5	16.2	14.4	15.3	58.3	43.6	51.0
1970-1986	7	16.3	15.0	15.7	57.7	47.1	52.4

N = number of cultivars per era.

Farinograph absorption, dough stength and mixing stability have all increased over time (Table 8). One of the more important measures of final end-use product quality, loaf volume, has increased by approximately 10% (Table 9).

Table 8. Mean quality performance of wheat cultivars released during five eras.

Era	N	Farinograph absorption (%)	DDT (min)	MTI (BU)
1860-1900	4	62.8	5.2	35.6
1909-1928	6	63.0	6.0	30.0
1935-1947	6	62.7	5.6	33.8
1953-1965	5	64.4	7.1	24.5
1970-1986	7	66.8	13.4	13.4

N = number of cultivars per era.

Table 9. Mean quality performance of wheat cultivars released during five eras.

		Loaf volume (cc) 0 ppm			15 ppm $KBrO_3$		
Era	N	1990	1991	AVG	1990	1991	AVG
1860-1900	4	694	631	663	912	726	819
1909-1928	6	708	675	692	832	695	764
1935-1947	6	735	674	705	947	728	838
1953-1965	5	737	685	711	970	814	892
1970-1986	7	754	718	736	940	788	864

N = number of cultivars per era.

Quadratic functions provide the best fit when grain yield is regressed on time of cultivar release. Based on the first derivative of those quadratic functions (Table 10) it is apparent that the rate of yield improvement has increased with time. Following the release of Marquis there was actually a decrease in the yielding ability of spring wheats relative to pre-Marquis cultivars. This decrease in yield potential is associated with earlier maturity as indicated by a decrease in maturity requirement of 0.04 to 0.1 days per year (Table 10). High rainfall and cooler temperatures during the first two decades of this century accentuated maturity differences among cultivars and resulted in the release of primarily early maturing cultivars during the 1920's. With increasing temperatures from the 1930's onwards we have seen the introduction of higher yielding but slightly later maturing cultivars relative to those released in the 1920's. Average rates of grain yield improvement (average of 1954 and 1970 estimates = 17.1 kg/ha/yr) in this study are consistent with estimates derived, largely, from the analysis of spring wheat regional cultivar evaluation trials in the northern Great Plain states of the USA from 1954 to 1984 (Feyerherm et al. 1984, 1989). Feyerherm et al. estimated that red spring and durum wheat yields increased by approximately 17.3 kg/ha/yr during that period in North Dakota and 10.4 kg/ha/yr in Montana. It is interesting that our yield gain estimates obtained using a regression analysis approach are of a similar magnitude to the estimates obtained from the temporal differential yielding ability (DYA) analysis approach of Feyerherm et al. (1984). The above yield gains are a result of genetic improvement as opposed to a combination of management and cultivar improvements. Based on statistical data presented by DePauw and Thomas (1986), spring wheat yield gains between 1960 and 1985 on fallowed dark brown soils were approximately 23.2 kg/ha/yr compared to 16.7 kg/ha/yr on stubble. On brown soils, estimates of 26.6 and 17.2 kg/ha/yr were obtained for fallow and stubble-seeded spring wheat crops, respectively. These estimates combine gains due to improvements in cultivar yield potential and management practices. Based on our results it would appear that roughly 70-75% of yield gains are due to cultivar improvement while 25-30% are due to improved crop management approaches.

Table 10. Rates of improvement over time for selected agronomic traits.

	Grain yield (kg/ha/yr)				Maturity (days/yr)			
	1909	1935	1954	1970	1909	1935	1954	1970
1990	-1.2	2.8	5.7	8.1	-0.05	-0.02	0.00	0.02
1991	3.5	12.5	19.1	24.7	-------- -0.04 --------			
1992	-2.9	9.6	18.6	26.3	-0.10	-0.03	0.02	0.10

Linear functions provid the best fit when sedimentation volume and loaf volume are regressed on time of cultivar release (Table 11). Sedimentation volume has increased by approximately 0.1 cc per year while loaf volume has been increasing at a rate of approximately 1.0 cc/yr. The rate of loaf volume improvement with the addition of potassium bromate is roughly twice that obtained without flour oxidation (Table 11).

Table 11. Rates of improvement over time for selected quality traits.

	Sedimentation (cc/yr)	Loaf volume (cc/yr)	
		0	15 ppm
1990	0.09	0.59	0.91
1991	0.12	0.68	1.03

It is apparent from this study that CWRS wheat breeders have been able to improve both the agronomic and value-added performance of our cultivars. Using 1970 estimated rates of yield improvement (ca. 20 kg/ha/yr) we are increasing provincial production, on average, by 4.6 million bushels of CWRS wheat (worth $17 million, avg. of 1986-1990 prices) each year through plant breeding improvements. Increases in protein content and quality also add to the marketability of our wheats as do improvements in sprouting tolerance, and resistance to pests. Spring wheat breeding in Canada has proven to be a lucrative public investment opportunity. In the longer term, Zentner and Peterson (1984) estimated that the internal rate of return was 44%. Finn (1987) calculated that the internal rate of investment was 29%. For higher-yielding spring wheat growing environments, Araji (1989) estimated that the return on investment was 71.3%. The latter two authors calculated that for every extra dollar invested in wheat breeding an extra $77.80 or $142.90 was generated in marginal value product.

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