Relationship of Kernel Size to Flour Water Absorption for Canada Western Red Spring Wheat

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ABSTRACT

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Canada Western Red Spring (CWRS) wheat exhibits consistent positive relationships between kernel weight and farinograph and baking water absorption. These relationships are sufficiently robust to be statistically significant ($P < 0.05$) for historical Canadian Grain Commission harvest survey data generated one year apart for 17 years, and for historical data on individual cultivars in advanced Canadian wheat breeding trials, also generated annually. Verification of the relationships were obtained by analyzing different kernel size fractions obtained by sieving CWRS harvest survey samples and pure CWRS cultivars from various origins. In all cases, highly significant positive relationships were observed between kernel size and water absorption. The relationships were evident for individual streams from pilot-scale millings of sized fractions from CWRS harvested in two different years. Strong correlations of kernel weight to farinograph and baking absorption also were shown for sized fractions from commercial samples of American Dark Northern Spring and Australian Prime Hard wheat. The strong statistical association between kernel size and water absorption could not be explained on the basis of wheat hardness (flour starch damage), protein content, or dough strength. In view of the importance of flour water absorption to bakers, further investigation is warranted to identify the cause for the association between large kernel size and high water absorption.

There have been many studies that have demonstrated that wheat kernel size is related to milling potential. The relationship is complex and appears to vary among wheats of different classes and origin (Dexter et al 1987). Marshall et al (1984, 1986) attempted to relate wheat flour yield to kernel size and shape with limited success. However, in general, as kernel size declines, flour yield and flour refinement (ash and color) are adversely affected (Shuey 1960, Shuey and Gilles 1969, Li and Posner 1987). Kernel size and kernel diameter determinations using the single-kernel characterization system (SKCS) (Martin et al 1993) have been useful in predicting wheat milling yield (Satumbaga et al 1995, Osborne et al 1997, Deyoe et al 1998, Gibson et al 1998, Ohm et al 1998).

There are conflicting reports in the literature on the relationship between wheat kernel size and end-use quality. It is important to distinguish between plump small kernels and shriveled kernels. Kernels that are shriveled due to frost, immaturity, heat stress, Fusarium damage, and other environmental factors clearly have serious deleterious effects on wheat milling and end-product quality (Watson et al 1977, Tkachuk et al 1990, Gaines et al 1992, Dexter et al 1996, Dexter and Edwards 1998, Gibson et al 1998).

Sutton et al (1992) reported that kernel weight is positively correlated to breadbaking performance for New Zealand wheat. Other studies have suggested that large kernel size is not necessarily an asset. Miller et al (1997) presented evidence that for UK wheat, large kernel size is associated with inferior quality due to low falling number. Gaines et al (1997) found that small plump soft wheat kernels did not have diminished flour milling potential and exhibited slightly superior cookie baking quality (larger cookie diameter) than large kernels.

Analysis of Canadian Grain Commission wheat harvest survey data suggests that there is a consistent positive relationship between kernel weight and water absorption for Canada Western Red Spring (CWRS), a hard red spring common wheat class. In this article, we report on the relationship between kernel weight and water absorption and on the results of investigations to determine robustness across cultivars and environments.

MATERIALS AND METHODS

Wheat

All CWRS wheat samples used in this study met the visual and physical specifications for the No. 1 grade and thus were sound and essentially free of damaged kernels.

Harvest survey data are generated each year for CWRS wheat by grade, protein content (for the top two grades), and province or region at the Grain Research Laboratory (GRL) using samples provided by producers and grain companies operating primary elevators. Each year, over 10,000 individual samples of CWRS wheat are available to prepare composite samples for quality testing. Historical data analyzed in this study were from annual No. 1 CWRS composites harvested from 1983 to 1999.

Historical data from advanced wheat breeder trials were derived from reports of the Prairie Regional Recommending Committee for Grains (PRRCG) on Cooperative Tests (C-Tests). C-Test material is grown in numerous locations across western Canada, and composite samples from ≈10 replicate sites each year are prepared for quality testing. Samples of the hard red spring wheat cultivars Katepwa and Roblin from 1995 C-Test trials were sieved to give a range of kernel sizes.

Commercial samples of CWRS sieved to give a range of kernel sizes were composites of No. 1 CWRS harvested in 1995 in Alberta and Manitoba, respectively, and a composite of No. 1 CWRS cargoes exported from Canadian Pacific ports from February 1, 1996 to July 31, 1996. Samples of Dark Northern Spring (DNS) and Australian Prime Hard (APH) wheat were composites of samples supplied by milling companies around the world in 1994 and 1995.

Sizing of Wheat by Sieving

Samples were cleaned free of broken and severely damaged kernels and then fractionated over slotted sieves to yield three portions: held on a 2.78 mm (7/64 in.) sieve, held on a 2.38 mm (6/64 in.) sieve, and passing through a 2.38 mm sieve. The sieve-sized fractions from Manitoba, Alberta, Roblin, Katepwa, CWRS cargo, DNS cargo, and APH cargo composites were blended in various amounts to give 10 or more samples with a wide range of kernel weight. For pilot millings of 1995 and 1997 CWRS harvest survey composites, only three sieve-sized fractions were milled due to limited sample size.

Milling

For laboratory-scale millings, samples were cleaned and conditioned as described by Dexter and Tipples (1987) and milled into straight-grade flour with an Allis-Chalmers mill using the GRL sifter

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flow described by Black et al (1980). Flour yields were expressed on the basis of clean wheat on a constant moisture basis.

Unless otherwise stated, samples were milled in duplicate to determine average yield, and the resulting flours were combined before further analysis. Where sample size was limiting, as for laboratory-scale millings of sized samples, only a single milling was performed.

According to standard practice at the GRL, the mill was monitored by milling a standard wheat sample at least once every day. All check samples were evaluated for flour yield, color, and farinograph absorption. Farinograph absorption of control samples deviated <0.5% from the overall mean. Typical ranges and standard deviations of all quality tests discussed in this article for repeated millings on the GRL Allis-Chalmers mill were documented by Black et al (1983).

For pilot-scale millings, sized fractions from the 1995 and 1997 CWRS harvest were cleaned and conditioned, then milled on the GRL pilot mill as described by Black (1980) using the mill flow of Fajardo et al (1995). Due to limited sample size, each sieved sample was milled singly. To verify consistent mill performance, a control wheat was milled before the first sized wheat sample and after the last sized wheat sample. Farinograph absorption of straight-grade flour from pilot mill control millings exhibited a range of <0.5%.

Wheat and Flour Tests

Analytical test results for wheat and flour are expressed on a 13.5 and 14.0% moisture basis, respectively. Wheat test weight and kernel weight were determined as described by Dexter and Tipples (1987). Particle size index and falling number were determined by AACC Approved Methods 55-30 and 56-81B, respectively (AACC 2000).

Protein content (N × 5.7) was determined by the Kjeldahl procedure as modified by Williams (1973) until 1997, when the Canadian Grain Commission (CGC) adopted Combustion Nitrogen Analysis (CNA) (LECO model FP-428 Dumas CNA analyzer). The Dumas test extracts ≈2% more nitrogen than the Kjeldahl test; consequently, protein content results are higher by 0.2–0.3 percentage units, the discrepancy being higher at higher protein content. For continuity of historical data sets in this study, all protein values determined by CNA were converted to equivalent Kjeldahl values using the conversion chart established by the CGC (1997).

Flour starch damage was determined by the Farrand (1964) method until 1996 when the MegaZyme method was adopted according to AACC Approved Method 76-31 (AACC 2000). For continuity of historical data sets in this study, starch damage values determined by the MegaZyme method were converted to Farrand units (FU) using the conversion formula developed by the CGC (1997).

AACC Approved Method 08-01 was used to determine ash content (AACC 2000). Flour grade color values were determined using a Colour Grader Series IV (Satake UK, Stockport, UK) by flour testing panel method No. 007/4 (FMBRA 1991) and were expressed in Satake international color grade units. Total and water-soluble pentosan content were determined by the phloroglucinol method as described by Douglas (1981). Farinograph and extensigraph characteristics were obtained using AACC Approved Methods 54-21 and 54-10, respectively (AACC 2000).

Baking

The remix-to-peak baking procedure has been described in detail by Kilborn and Tipples (1981). A lean formula (no fat) dough was subjected to 160 min of initial fermentation, after which the dough was remixed to 10% past peak consistency before makeup and final proof before baking. The Canadian short process (CSP), a mechanical no-time dough procedure similar to that used by many Canadian commercial bakeries, was described in detail by Preston et al (1982). A dough containing all ingredients was mixed to 10% past peak consistency, rounded by hand, rested 15 min, sheeted, molded, and panned, proofed, and baked.

Baking absorptions for both baking procedures were determined by an expert baker at the panning stage. Loaf volumes were determined by rapeseed displacement; bread scoring was conducted as described by Preston et al (1982).

TABLE I
Mean, Range, and Standard Deviation for Farinograph Absorption, Kernel Weight, Flour Protein, and Starch Damage for CWRS Cultivars in Canadian Cooperative Test Breeding Program Trials[a]

		Farinograph Absorption, %				Kernel Weight, mg				Flour Protein, %				Starch Damage, FU			
Cultivar (test)	Yr	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD
Neepawa (CBW)	24	63.9	67.2	65.5	0.8	31.6	37.2	34.3	1.7	12.4	15.1	14.0	0.8	22	37	28.1	4.1
Neepawa (WBW)	24	63.0	67.6	65.0	1.1	28.9	36.9	33.3	2.0	12.3	14.7	13.4	0.6	22	41	28.7	4.7
Marquis (CBW)	13	60.3	64.4	62.9	1.1	28.6	36.6	33.9	2.5	11.0	14.8	13.2	0.9	16	27	21.7	3.6
Marquis (WBW)	13	61.4	64.6	63.0	0.9	28.8	35.7	33.2	1.8	11.8	13.7	13.0	0.5	17	28	22.0	3.7
Columbus (CBW)	11	65.4	68.8	67.2	1.0	33.3	40.0	37.2	2.4	13.4	15.0	14.1	0.6	27	36	31.0	3.0
Roblin (CBW)	14	65.1	68.3	66.4	0.9	34.5	38.7	36.9	1.4	13.7	15.6	14.6	0.7	18	28	23.9	3.0
Laura (WBW)	14	63.7	66.4	65.2	1.0	28.6	37.3	33.7	2.9	12.1	14.8	13.3	0.7	21	31	26.6	3.5
Katepwa (WBW)	11	62.8	66.6	64.7	1.0	28.7	37.2	34.0	2.8	12.3	14.9	13.3	0.7	26	39	31.6	4.4

[a] CBW = Central Bread-wheat C-Test; WBW = Western Bread-wheat C-Test; FU = Farrand units; Min = minimum value; Max = maximum value; SD = standard deviation.

TABLE II
Coefficients of Determination (r^2) for Relationships Between Farinograph Absorption, Kernel Weight, Flour Protein, and Starch Damage for CWRS Cultivars in Canadian Cooperative Test Breeding Program Trials[a]

Cultivar (test)	Years	KW vs. FA	KW vs. FP	KW vs. SDM	FP vs. FA	FP vs. SDM	SDM vs. FA
Neepawa (CBW)	24	0.37**[b]	0.00	–0.00	0.11	–0.32**	0.00
Neepawa (WBW)	24	0.38**	–0.16	0.16	–0.04	–0.19*	0.31**
Marquis (CBW)	13	0.67***	0.22	–0.17	0.43*	–0.27	–0.05
Marquis (WBW)	13	0.54**	–0.10	0.11	0.00	–0.00	0.20
Columbus (CBW)	11	0.53*	–0.21	0.50*	–0.20	–0.23	0.35
Roblin (CBW)	14	0.44*	–0.00	0.08	0.38*	–0.00	0.17
Laura (WBW)	14	0.85****	–0.04	0.61**	–0.00	–0.47**	0.45*
Katepwa (WBW)	11	0.68**	0.00	–0.35	0.00	0.36	0.63**

[a] KW = kernel weight; FA = farinograph absorption; FP = flour protein; SDM = starch damage; CBW = Central Bread-wheat C-Test, WBW = Western Bread-wheat C-Test.

[b] *, **, ***, **** = $P < 0.05$, 0.01, 0.001, 0.0001; no label = $P > 0.05$.

Experimental Design

All quality tests used in the current study were routine test procedures used by the GRL to monitor Canadian wheat quality, and, hence, were well standardized and precise (CGC 1997). With the exception of farinograph and extensigraph results, which represent single tests, all quality tests were performed in duplicate and results reported as averages unless otherwise noted. Statistics were calculated using the procedures of the software system v6.08 for Windows (SAS Institute, Cary NC).

RESULTS AND DISCUSSION

CWRS Wheat Harvest Survey Data

The possibility that kernel weight and water absorption were related for CWRS wheat first became evident from analyses of historical CGC wheat harvest survey data. From 1983 until 1999, procedures used to create harvest composite samples and the main quality testing procedures have been similar. As seen in Fig. 1, during that 17 year period the two CWRS protein segregate levels tested every year (12.5 and 13.5%) demonstrated strong positive relationships between kernel weight and water absorption. Significant ($P < 0.05$) coefficients of determination (r^2 0.59–0.70) between kernel weight and farinograph absorption (Fig. 1A) and between kernel weight and CSP baking absorption (Fig. 1B) were evident with both sample sets. The relationships were very strong considering that each data point for each protein segregate represents test results performed immediately following harvest each year over a 17-year period. Farinograph absorption is continually monitored through daily check samples, but one would still expect that accuracy and precision of farinograph absorption would be less than if samples were tested at the same time. In addition, variation from year to year in growing conditions and cultivar distribution would also potentially weaken the relationships.

It is well established that protein content and starch damage levels are primary factors influencing CWRS flour water absorption (Holas and Tipples 1978, Tipples et al 1978). Examining CWRS-12.5 and CWRS-13.5 protein segregates individually eliminated the influence of protein content on water absorption within each segregate. At a given kernel weight, CWRS-13.5 exhibited, on average, farinograph and CSP water absorptions ≈0.5% higher than for CWRS-12.5. The higher water absorption of CWRS-13.5 was consistent with higher protein content.

Flour starch damage was positively correlated ($P < 0.05$) to farinograph absorption for each protein segregate ($r^2 = 0.40$ for CWRS-12.5; $r^2 = 0.43$ for CWRS-13.5), but the relationship was weaker than that observed for kernel weight. Stepwise regression analysis showed that addition of starch damage as a second variable did not significantly ($P > 0.05$) improve the ability to predict farinograph absorption by kernel weight alone ($r^2 = 0.59$–0.66 for CWRS-12.5; $r^2 = 0.66$–0.71 for CWRS-13.5).

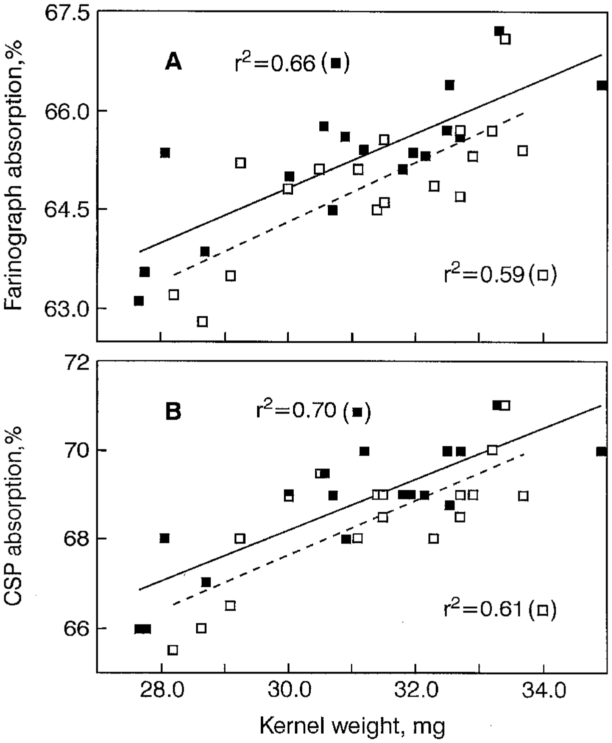

Fig. 1. Relationship of kernel weight to farinograph absorption (**A**) and Canadian Short Process baking absorption (**B**) for Canadian Grain Commission harvest survey composites from 1983 to 1999 for No. 1 CWRS protein segregate levels of 12.5% (□) and 13.5% (■).

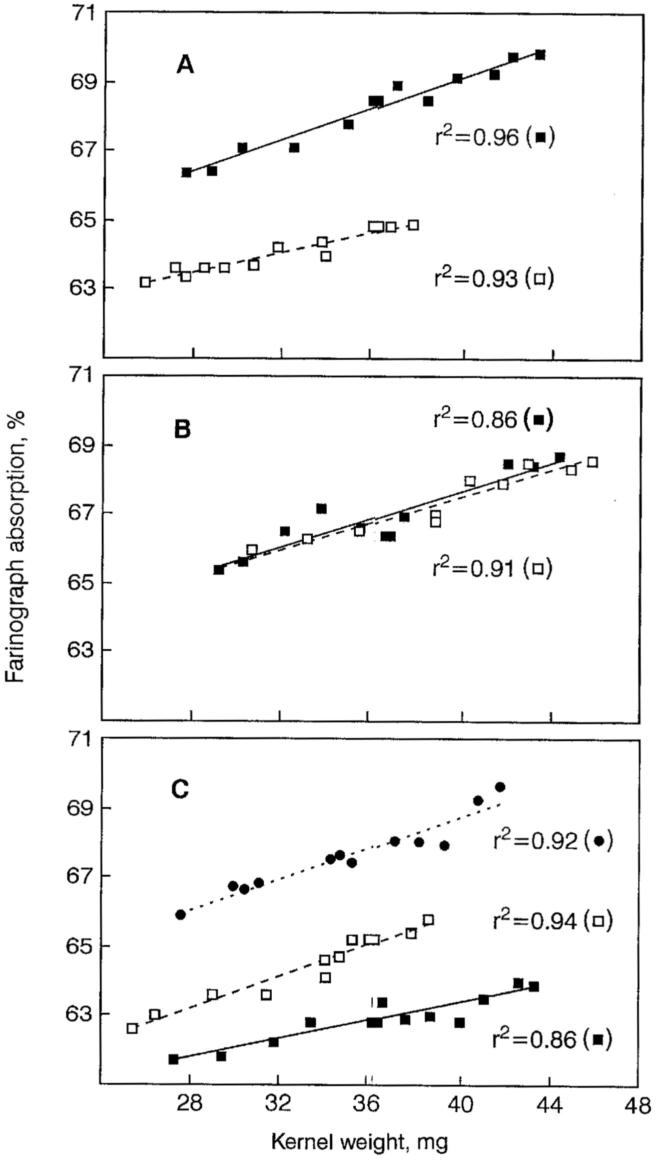

Fig. 2. Relationship between farinograph absorption and kernel weight for samples of variable kernel size derived by sieving. **A,** Canada Western Red Spring (CWRS) harvested in 1995 from Manitoba (□) and Alberta (■); **B,** samples of CWRS harvested in 1995 exclusively containing cultivars Roblin (□) or Katepwa (■); **C,** composites of export cargoes of CWRS (●), Dark Northern Spring (□), and Australian Prime Hard (■) exported during 1994 and 1995.

CWRS-12.5 exhibited slightly higher starch damage (1–2 FU for most years) despite having lower water absorption. Starch damage was not correlated ($P > 0.05$) to CSP baking absorption for either protein segregate. These results, and the relatively weak relationships between flour starch damage and kernel weight ($r^2 = 0.31$ for CWRS-12.5; $r^2 = 0.25$ for CWRS-13.5) suggest that the much stronger relationship between kernel weight and water absorption parameters cannot be adequately explained on the basis of flour starch damage differences.

With the exception of flour grade color, year-to-year variability in test weight, flour yield, flour ash content, and dough strength properties (farinograph and extensigraph properties) did not show significant correlations ($P > 0.05$) to kernel weight (data not shown). Flour grade color exhibited significant ($P < 0.05$) negative relationships to both kernel weight ($r^2 = 0.34$; improved color with increasing kernel weight) and to CSP absorption ($r^2 = 0.28$) but no significant relationship ($P > 0.05$) to farinograph absorption (data not shown).

C-Test Data

Further analysis was conducted on historical data from C-Tests to assess these relationships using cultivar information obtained over 11–24 years (Tables I and II). Two cultivars, Marquis and Neepawa, were grown as controls in both the Central Breadwheat (CBW) and Western Breadwheat (WBW) C-Tests, and the other four cultivars were grown as controls in only one of these tests.

The relationship between kernel weight and farinograph absorption was significant ($P < 0.05$–0.0001) and positive for all eight cultivar data sets (Table II). Considering that the data were generated annually over a period of many years, growing conditions varied widely, and different growing locations were used from year to year, the relationship is surprisingly robust. In five of the eight samples sets, >50% of the variance (r^2) in absorption could be accounted for solely by kernel weight. In spite of a relatively wide variation in protein content and starch damage in all sample sets (Table I), these parameters showed significant ($P < 0.05$) relationships to farinograph absorption in only two of eight and three of eight sample sets, respectively (Table II). No consistent relationship was evident between kernel weight and either flour protein content or starch damage. Stepwise regression analysis using starch damage or protein content as dependent variables in addition to kernel weight resulted in little improvement in the ability to predict farinograph absorption ($P \geq 0.05$) (data not shown).

These results were consistent with the CWRS harvest survey data, confirming that protein content had little influence on this relationship and that the magnitude of the water absorption effect cannot be explained adequately on the basis of starch damage differences.

Kernel weight showed no consistent relationship to test weight, flour yield, flour ash content, flour color, or dough strength properties (data not shown). It was not possible to investigate the relationship to baking absorption because of changes in bake testing protocols over the period covered.

All recently released CWRS cultivars that have been included in either regional C-Test for at least four years since 1991 show the same strong positive relationship between kernel weight and farinograph absorption: AC Majestic ($r^2 = 0.63$), AC Barrie ($r^2 = 0.96$), AC Domain ($r^2 = 0.90$), Invader ($r^2 = 0.95$), CDC Merlin ($r^2 = 0.77$), and CDC Teal ($r^2 = 0.98$).

CWRS Sieved Sample Sets

The relationships between kernel weight and water absorption parameters, including farinograph absorption and remix-to-peak baking absorption, were examined further by sieving and blending individual CWRS samples to give a series of subsamples covering a wide range of kernel weight at uniform intervals. Samples included a composite of CWRS export cargoes shipped from Canadian Pacific ports, regional (provincial) 1995 harvest survey samples, and pure cultivars obtained from C-Tests (Fig. 2, Table III). In addition, export cargo samples of DNS wheat from the United States and APH wheat from Australia were included to determine whether this relationship was robust among hard common wheat other than CWRS.

Sieving had no effect on visual grade (all samples met the physical condition requirements for No. 1 CWRS) nor on cultivar composition, as determined by electrophoretic analysis (data not shown). For the Canadian CWRS wheat samples, increasing kernel weight was strongly associated ($P < 0.001$) with increases in farinograph absorption and remix-to-peak baking absorption. Kernel weight alone accounted for 86–96% of the variance in farinograph absorption (Fig. 2) and 76–92% of the variance in baking absorption (Table III). The fact that the non-Canadian wheat samples gave similar r^2 values suggests that these relationships may be present for other hard common wheat genotypes and environments.

The much stronger relationship between kernel weight and water absorption parameters observed for the sieved samples when compared with the historical data would be expected because the samples were tested simultaneously rather than a year apart. Another possible factor is that the influence of environment and cultivar composition would be less evident. Whereas the historical data span a number of years with different growing and harvesting conditions, each sieved sample represents wheat harvested in a single season and, in some cases, are also selected by shipping port, growing region, or cultivar.

TABLE III
Mean, Range, Standard Deviation, and Coefficient of Determination to Kernel Weight for Remix-to-Peak Water Absorption, Flour Protein, and Starch Damage for Sieved Sample Sets[a,b]

Sample	RA	FP	SDM
CWRS Pacific Cargoes			
Mean	65.0	13.0	37.3
Range	63–68	12.8–13.3	35–39
SD	1.6	0.2	1.4
r^2	0.76***[c]	0.57**	0.05
CWRS Alberta HS			
Mean	67.3	12.3	38.3
Range	64–70	11.9–12.6	36–39
SD	1.9	0.2	0.9
r^2	0.79****	0.90****	0.19
CWRS Manitoba HS			
Mean	63.3	13.3	23.3
Range	62–65	13.1–13.6	22–24
SD	1.3	0.2	0.7
r^2	0.83****	0.55**	0.14
CWRS Katepwa			
Mean	63.7	13.3	34.1
Range	61–67	13–13.9	31–38
SD	2.0	0.4	2.2
r^2	0.83****	0.81***	0.43*
CWRS Roblin			
Mean	64.9	14.0	25.5
Range	62–67	13.4–14.6	23–27
SD	1.7	0.5	1.2
r^2	0.92****	0.83***	0.08
DNS			
Mean	62.4	13.3	30.5
Range	61–64	13.1–13.4	28–32
SD	0.9	0.1	1.1
r^2	0.78***	0.06	0.57**
APH			
Mean	63.0	12.1	30.6
Range	62–64	12–12.2	29–32
SD	0.7	0.1	1.0
r^2	0.85****	0.00	0.17

[a] RA = remix to peak baking absorption; FP = flour protein; SDM = starch damage; SD = standard deviation; r^2 = coefficient of determination; CWRS = Canada Western Red Spring; HS = harvest survey; DNS = Dark Northern Spring; APH = Australian Prime Hard.

[b] $n = 12$, except $n = 10$ for Roblin and $n = 11$ for Katepwa and DNS.

[c] *, **, ***, **** = P <0.05, 0.01, 0.001, 0.0001; no label = $P > 0.05$.

The increase in farinograph and baking absorption with kernel weight cannot be adequately explained on the basis of protein content or starch damage. There were significant positive relationships ($P < 0.05$) of protein content to farinograph and baking absorption (data not shown) and of protein content to kernel weight for some of the CWRS sieved sample sets (Table III). However, within each sample set, the protein content range was <1%, which, as established from the historical CWRS harvest survey data (Fig. 1), would account for <0.5% of the farinograph water absorption range. The DNS and APH sample sets also demonstrated strong relationships between kernel weight and water absorption (Fig. 2C and Table II) despite a narrow protein content range.

For some sample sets, starch damage had a positive correlation to farinograph water absorption (data not shown), but there was no consistency in the relationship across sample sets. Except for the Katepwa CWRS sample set, starch damage range was ≤4 FU (Table III) and thus insufficient to account for the relatively large variability observed for farinograph absorption for all sample sets (Fig. 2).

Baking absorption differences also cannot be adequately explained by starch damage. Remix-to-peak baking absorption is less influenced by starch damage than short baking processes because long fermentation (almost 4 hr including initial fermentation and final proof) induces greater fermentation loss at higher starch damage levels (Tipples et al 1978, Dexter et al 1994). Remix-to-peak baking absorption was strongly associated with kernel weight in all cases and exhibited a range of ≥5 for several sample sets that had a starch damage range of ≤4 FU.

In agreement with numerous previous reports, for most sieved sample sets, flour yield increased and flour color decreased (improved) with increasing kernel weight (data not shown). There was no evidence that protein quality was a factor in determining farinograph or baking absorption because kernel weight was not related ($P > 0.05$) to farinograph dough development time and stability, remix energy and mixing time, or loaf volume potential when expressed on a constant protein basis for any of the sample sets (data not shown).

Pilot Milling Results

Large residues from the 1995 and 1997 No. 1 CWRS harvest were sieved and pilot-milled, and straight-grade flours were evaluated for farinograph and remix-to-peak baking performance (Table IV). Results confirmed previous results from laboratory-scale milling. Farinograph and baking absorption were higher for the largest kernel sample and lowest for the smallest kernel sample in both years. It is also noteworthy that smaller kernel size for the 1997 harvest was associated with lower farinograph and remix-to-peak water absorption than for the larger kernel size 1995 harvest. For both crop years, starch damage, protein content, and protein quality variations were either not evident or too small to account for water absorption differences. Flour yield and flour color were better for the larger kernel size fractions for both harvests.

As described previously (Symons and Dexter 1991, Preston and Dexter 1994), individual streams from milling of CWRS by the GRL pilot mill have a wide range in protein content (break flours highest), starch damage (break flours lowest), ash, and color due to variable degrees of contamination by nonendosperm components. When flour streams were evaluated for farinograph water absorption individually and in blends with streams of similar quality (Table V),

TABLE IV
Quality Characteristics of Pilot-Milled Sieved Fractions from the 1995 and 1997 No. 1 CWRS Harvest[a]

	1995			1997		
Property	**Held on 2.78 mm**	**Held on 2.38 mm**	**Through 2.38 mm**	**Held on 2.78 mm**	**Held on 2.38 mm**	**Through 2.38 mm**
Wheat						
Test weight, kg/hL	83.3	82.7	81.5	82.4	81.7	78.8
Kernel weight, mg	42.4	34.4	27.4	36.8	33.7	23.4
Protein, %	13.4	12.9	12.9	13.4	13.0	13.6
Flour yield, %	76.7	76.0	75.5	74.5	74.5	72.9
Flour						
Protein, %	13.0	12.6	12.7	12.7	12.6	12.9
Ash, %	0.54	0.56	0.54	0.45	0.45	0.47
Color, Satake units	–0.4	–0.2	0.2	–1.2	–1.1	–0.1
Starch damage, Farrand units	28	28	28	26	28	26
Farinograph						
Absorption, %	66.2	64.1	63.1	63.1	62.9	60.8
Development time, min	5.25	4.50	4.75	4.25	4.75	5.25
Stability, min	7.50	7.50	7.50	7.00	8.00	8.50
Remix-to-peak						
Baking absorption, %	66	64	63	65	64	63
Time, min	1.7	1.7	1.8	2.6	2.3	2.3
Loaf volume, cm^3	860	840	850	880	890	940

[a] Standard deviation of flour, rheological, and baking tests (Black et al 1983): protein 0.15%; ash 0.009%; color 0.08 units; starch damage 1.4 Farrand units; farinograh absorption 0.38%; development time 0.22 min; baking absorption <0.1%; loaf volume 7 cm^3.

TABLE V
Farinograph Absorption (%) of Selected Flour Streams and Combinations from Pilot-Milled Sieved Fractions of No. 1 CWRS-13.0 Harvest Survey Samples from 1995 and 1997

	1995			1997		
Sample[a]	**Held on 2.78 mm**	**Held on 2.38 mm**	**Through 2.38 mm**	**Held on 2.78 mm**	**Held on 2.38 mm**	**Through 2.38 mm**
B1, B2, and B3	64.5	62.4	61.4	63.1	61.9	59.5
B4 coarse and bran finisher flour	75.2	70.8	70.2	69.8	68.9	66.9
S1 and S2	63.6	61.2	60.9	62.5	60.7	59.3
M1	64.7	63.0	62.1	63.0	62.2	60.5
M2	65.6	63.1	62.4	62.9	62.1	59.6
M3 and M4	69.5	69.1	69.1	69.0	68.6	66.2
M5 and B4 fine	65.7	63.8	63.4	62.8	62.2	60.9

[a] B = break flour, S = sizing flour, M = middling flour. Standard deviation for determination of farinograph absorption on replicate millings of the same sample is 0.38% (Black et al 1983).

without exception, for both harvest years each stream or group of streams examined clearly showed a trend to higher water absorption with increasing kernel weight. This relationship would suggest that the factor associated with higher water absorption was not confined to a specific region of the wheat kernel.

CONCLUSIONS

The data presented here provide convincing evidence for a robust relationship between water absorption and kernel weight for CWRS wheat, and possibly for some other hard common wheats. The effect of kernel weight on water absorption is more than just a curiosity. Water absorption is a primary quality determinant for bread wheat. It is well established that starch damage (wheat hardness) and protein content are the main factors associated with water absorption (Holas and Tipples 1978, Tipples et al 1978). However, breeding lines of comparable hardness and comparable protein content often exhibit a commercially relevant range in baking absorption.

The reason for the strong positive relationships of kernel weight to farinograph and baking absorption is not clear. As expected, some trends between starch damage and protein content and kernel weight and water absorption are evident within some of the sample sets examined in this study, but the trends are not consistent, and the magnitude of the variations are not sufficient to adequately explain water absorption differences. Stepwise linear regression analysis using starch damage or protein as additional dependent variables does not result in significantly better ($P > 0.05$) prediction of water absorption than for kernel weight alone. In addition, on the basis of farinograph properties, bread dough mixing requirements, and loaf volume, there is no evidence that dough strength, which could also affect water absorption, particularly baking absorption, is influenced by kernel weight. GRL pilot mill results demonstrate that the influence of kernel weight on water absorption properties is apparent for individual millstreams of variable composition.

Pentosans can also play an important role in determining water absorption (Kulp 1968). The differences in water absorption among flour streams derived from pilot-milled CWRS are consistent with other studies that have shown that pentosan content increases toward the outer layers of the wheat kernel (Ciacco and D’Appolonia 1982, Delcour et al 1999). For example, the high water absorption of break flours and bran finisher flour is partially attributable to relatively high aleurone content (Symons and Dexter 1991) where pentosans are known to concentrate. However, the effect of kernel weight on water absorption also is evident for the most refined reduction streams (sizing and early middling flours) which would have low pentosan content because they are derived primarily from the center of the endosperm. One sample set from this study (Alberta CWRS 1995 harvest survey) was analyzed for pentosan content, and the larger kernel size fractions actually exhibited slightly lower soluble pentosan content (0.23%) and total pentosan content (1.8%) when compared with smaller sieved fractions (0.25 and 2.0%, respectively) (results not shown).

Starch is the largest component in wheat flour, so differences in starch properties cannot be excluded as a possible factor associated with water absorption differences. D’Appolonia and Gilles (1971) were unable to relate any bread properties, including baking absorption, to starch granule size distribution for isolated wheat starch. However, Sahlström et al (1998) reported that higher bread weight (due to higher water absorption) may be associated with a greater proportion of small A-type granules for wheats of diverse origin.

In this study, one probable cause of the effect of kernel weight on water absorption is stress during the growing season. For historic data, years of low kernel weight correspond to years when growing conditions were generally hotter and drier than normal. Smaller kernels in sieved composite samples grown in a single year may also be derived preferentially from grain grown in locations of higher stress. Another factor that could be influencing the water absorption of sieved samples is kernel position in the spike. Further studies on pure cultivars to establish the effect of environment and spike position on kernel weight and water absorption, and factors that could affect water absorption (hardness, protein composition, carbohydrate composition) are warranted.

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LITERATURE CITED

American Association of Cereal Chemists. 2000. Approved Methods of the AACC, 10th ed. Methods 08-01, 54-10, 54-21, 55-30, 56-81B, and 76-31. The Association: St. Paul, MN.

Black, H. C. 1980. The GRL pilot mill. Assoc. Operative Millers Bull. (Sept.) 3834-3837.

Black, H. C., Hsieh, F.-H., Tipples, K. H., and Irvine, G. N. 1980. The GRL sifter for laboratory flour milling. Cereal Foods World 12:757-760.

Black, H. C., Preston, K. R., and Dexter, J. E. 1983. Modifications to the Bühler laboratory mill to produce a flour comparable in yield and quality to the Allis-Chalmers mill. Can. Inst. Food Sci. Technol. J. 16:191-195.

CGC. 1997. Methods and definitions. Pages 22–26 in: Quality of Western Canadian Wheat Exports. February 1, 1997 to July 31, 1997. Crop Bulletin No. 282. Grain Research Laboratory, Canadian Grain Commission: Winnipeg, MB.

Ciacco, C. F., and D’Appolonia, B. L. 1982. Characterization and gelling capacity of water-soluble pentosans isolated from different mill streams. Cereal Chem. 59:163-166.

D’Appolonia, B. L., and Gilles, K. A. 1971. Effect of various starches in baking. Cereal Chem. 48:625-636.

Delcour, J. A., Van Win, H., and Grobet, P. J. 1999. Distribution and structural variation of arabinoxylans in common wheat mill streams. J. Agric. Food Chem. 47:271-275.

Dexter, J. E., and Edwards, N. M. 1998. The implications of frequently encountered grading factors on the processing quality of common wheat. Assoc. Operative Millers Bull. (June) 7115-7122.

Dexter, J. E., and Tipples, K. H. 1987. Wheat milling at the Grain Research Laboratory. 2. Milling 180(7):16,18-20.

Dexter, J. E., Matsuo, R. R., and Martin, D. G. 1987. The relationship of durum wheat test weight to milling performance and spaghetti quality. Cereal Foods World 32:772-777.

Dexter, J. E., Preston, K. R., Martin, D. G., and Gander, E. J. 1994. The effects of protein content and starch damage on the physical dough properties and bread-making quality of Canadian durum wheat. J. Cereal Sci. 20:139-151.

Dexter, J. E., Clear, R. M., and Preston, K. R. 1996. Fusarium head blight: Effect on the milling and baking of some Canadian wheats. Cereal Chem. 73:695-701.

Deyoe, C., Chen, Y., Reddy, P. V., McCluskey, P., Gwirtz, J., and Eustace, D. 1998. Utilization of the SKWCS information in hard red winter surveys for quality evaluations. Assoc. Operative Millers Bull. (July) 7131-7140.

Douglas, S. G. 1981. A rapid method for the determination of pentosans in wheat flour. Food Chem. 7:139-145

Fajardo, J. E., Dexter, J. E., Roscoe, M. M., and Nowicki, T. W. 1995. Retention of ergot alkaloids in wheat during processing. Cereal Chem. 72:291-298.

Farrand, E. A. 1964. Flour properties in relation to the modern bread process in the United Kingdom, with special reference to α-amylase and starch damage. Cereal Chem. 41:98-111.

FMBRA. 1991. Flour testing panel method No. 007/4. Determination of grade colour. Flour Milling and Baking Research Association: Chorleywood, UK.

Gaines, C. S., Kassuba, A., Finney, P. L., and Donelson, J. R. 1992. Instrumental measurement of cookie hardness. II. Application to product quality variables. Cereal Chem. 69:120-125.

Gaines, C. S., Finney, P. L., and Andrews, L. C. 1997. Influence of kernel size and shrivelling on soft wheat milling and baking quality. Cereal Chem. 74:700-704.

Gibson, L. R., McCluskey, P. J., Tilley, K. A., and Paulsen, G. M. 1998.

Quality of hard red winter wheat grown under high temperature conditions during maturation and ripening. Cereal Chem. 75:421-427.

Holas, J., and Tipples, K. H. 1978. Factors affecting farinograph and baking absorption. I. Quality characteristics of flour streams. Cereal Chem. 55:637-652.

Kilborn, R. H., and Tipples, K. R. 1981. Canadian test baking procedures. I. GRL remix method and variations. Cereal Foods World 26:624-628.

Kulp, K. 1968. Pentosans of wheat endosperm. Cereal Sci. Today 13:414-417, 426.

Li, Y. Z., and Posner, E. S. 1987. The influence of kernel size on wheat millability. Assoc. Operative Millers Bull. (Nov.) 5089-5098.

Marshall, D. R., Ellison, F. W., and Mares, D. J. 1984. Effects of grain shape and size on milling yields in wheat. I. Theoretical analysis based on simple geometric models. Aust. J. Agric. Res. 35:619-630.

Marshall, D. R., Mares, D. J., Moss, H. J., and Ellison, F. W. 1986. Effects of grain shape and size on milling yields in wheat. II. Experimental studies. Aust. J. Agric. Res. 37:331-342.

Martin, C. R., Rousser, R., and Brabec, D. L. 1993. Development of single-kernel wheat characterization system. Trans. ASAE 36:1399-1404.

Miller, S. J., Whitworth, M. B., and Evers, A. D. 1997. Image analysis—The prediction and assessment of wheat quality and milling properties. Pages 141-151 in: Proc. Int. Wheat Quality Conf. J. L. Steele and O. K. Chung, eds. Grain Industry Alliance: Manhattan, KS.

Ohm, J. B., Chung, O. K., and Deyoe, C. W. 1998. Single-kernel characteristics of hard winter wheats in relation to milling and baking quality. Cereal Chem. 75:156-161.

Osborne, B. G., Zotwal, Z., Blakeney, A. B., O'Brien, L., Shah, S., and Fearn, T. 1997. Application of the single-kernel characterization system to wheat receiving testing and quality prediction. Cereal Chem. 74:467-470.

Preston, K. R., and Dexter, J. E. 1994. Canadian short process bread: Potassium bromate response of flour streams and divide flours milled from Canadian red spring wheat. Can. J. Plant Sci. 74:71-78.

Preston, K. R., Kilborn, R. H., and Black, H. C. 1982. The GRL pilot mill. II. Physical dough and baking properties of flour streams milled from Canadian hard red spring wheat. Can. Inst. Food Sci. Technol. J. 15:29-36.

Sahlström, S., Bråthen, E., Lea, P., and Autio, K. 1998. Influence of starch granule size distribution on bread characteristics. J. Cereal Sci. 28:157-164.

Satumbaga, R., Martin, C., Eustace, D., and Deyoe, C. W. 1995. Relationship of physical and milling properties of hard red winter wheat using the single kernel wheat characterization system. Assoc. Operative Millers Bull. (Jan.) 6487-6496.

Shuey, W. C. 1960. A wheat sizing technique for predicting wheat flour yield. Cereal Sci. Today 5:71,72,75.

Shuey, W. C., and Gilles, K. A. 1969. Experimental milling of sized wheat. Northwestern Miller 276(3):9-13.

Sutton, K. H., Hay, R. L., and Mouat, C. H. 1992. The effect of kernel weight on the assessment of baking performance of wheats by RP-HPLC of glutenin subunits from single grains. J. Cereal Sci. 15:253-265.

Symons, S. J., and Dexter, J. E. 1991. Computer analysis of fluorescence for the measurement of flour refinement as determined by flour ash content, flour grade color, and tristimulus color measurements. Cereal Chem. 68:454-460.

Tipples, K. H., Meredith, J. O., and Holas, J. 1978. Factors affecting farinograph and baking absorption. II. Relative influence of flour components. Cereal Chem. 55:652-660.

Tkachuk, R., Dexter, J. E., and Tipples, K. H. 1990. Wheat fractionation on a specific gravity table. J. Cereal Sci. 11:213-223.

Watson, C. A., Sibbitt, L. D., and Banasik, O. J. 1977. Relation of grading and wheat quality factors to end-use quality characteristics for hard red spring wheat. Baker's Dig. 51(3):38-41.

Williams, P. C. 1973. The use of titanium dioxide as a catalyst for large-scale Kjeldahl determination of total nitrogen content of cereal grains. J. Sci. Food Agric. 24:343-348.

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