Determination of Hardness in Mixtures of Hard Red Winter and Soft Red Winter Wheats. I. Bulk Samples[1]

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ABSTRACT

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Four methods were used to determine wheat hardness: time to grind and resistance to grinding wheat, and particle size index and near infrared reflectance (NIR) at 1,680 nm of ground wheat. The methods were used to evaluate 12 soft red winter (SRW) and 12 hard red winter (HRW) wheats that differed widely in hardness. Coefficients of variation were much higher for the four hardness measurments in the SRW than in the HRW wheats. There was little overlap in hardness parameters between the HRW and SRW wheats. Hardness in blends of HRW and SRW wheats was determined in four groups of samples: mixtures of Arkan (HRW) and Arthur (SRW) prepared in the laboratory; four sets of coded mixtures of Arkan and Arthur prepared by the Federal Grain Inspection Service (FGIS), U.S. Department of Agriculture; eight coded blends of eight different HRW and eight different SRW wheat varieties or selections prepared by the FGIS; and five blends of five commercial samples, each, of HRW and SRW wheats provided by FGIS and mixed in the laboratory. Generally, NIR reflectance was linearly related and effective in determining the HRW:SRW wheat ratios in blends. The standard errors of estimate for the four methods varied and depended, among others, on the percent of admixed wheat. The hardness methods were most powerful in determining admixtures of large amounts of one class of wheat to another, especially, if the hardness of the individual wheats used for blending was known.

High yields and double-cropping of soft wheats make the production of soft wheats economically attractive. When soft wheats contain large amounts of vitreous kernels, there is a temptation to blend soft wheat into shipments of hard wheat. Soft wheats that appear vitreous may be unacceptable to mills that produce flours for the manufacture of cookies and cakes. Because color, kernel characteristics, test weight, and protein content are similar in soft and hard red wheats, distinguishing between the two wheat classes can be difficult.

Determination of wheat hardness has been the subject of many investigations. Some of them were listed by Miller et al (1982, 1984). We know of no reports, however, on determination of hardness in mixtures of hard and soft wheats. Studies on determining the composition of such mixtures are described for bulk samples in Part I and for individual kernels in Part II of this investigation.

MATERIALS AND METHODS

Materials

Twelve hard red winter (HRW) and 12 soft red winter (SRW) wheat cultivars or breeding lines harvested in 1982 were selected to cover a wide range in hardness.

The soft wheat cultivars or lines from Wooster, OH, were: Ciba Geigy-62511, Ciba Geigy S-19-102, Ill. 77-2656, Logan, McNair 1003, McNair 3271, NY 6120-10, Pioneer 689D, Ruler, Severn, Stacy, and Ticonderaga.

The hard wheat cultivars or selections from Manhattan, KS, were: Arkan, Bennett, Buckskin, Centurk, Eagle, Hawk, Larned, Newton, Rocky, Scout 66, Vona and Wings.

A HRW wheat, Arkan (cross between HRW Sage and SRW Arthur), was obtained from the Seed Foundation of Kansas State University and a SRW wheat, Arthur, from the Soft Wheat Quality Laboratory, ARS, USDA, Wooster, OH. The wheat samples contained 12.4 and 12.6% moisture and their protein contents were 10.1 and 10.6%, respectively. Blends of the two wheats were prepared in our laboratory.

Twenty-one samples of wheat mixtures were obtained from the Federal Grain Inspection Service (FGIS), U.S. Department of Agriculture, Kansas City, MO. The 21 mixtures comprised four sets of Arthur and Arkan blends; the sets were identified by FGIS after completion of the hardness tests. Protein contents were 12.0, 9.8, 10.4, and 10.1% in the Arkan wheat in sample sets 1, 2, 3, and 4, respectively. Protein contents of the Arkan and Arthur wheats were approximately the same in sample sets 1, 2, and 3; in sample set 4, the protein content of Arthur was considerably higher than in Arkan (FGIS, *private communication*).

Eight sample blends of eight different HRW and eight SRW wheat cultivars were obtained from FGIS. They are listed in Table I.

Five commercial samples each of HRW and SRW wheats were obtained from FGIS from various locations in the country. The protein contents of the HRW wheat samples ranged from 9.5 to 12.5% (average 11.2%) and of the SRW wheat samples from 10.2 to 10.7% (average 10.5%). Blends of the wheats were prepared in our laboratory (samples A–E).

Methods

Whole kernels were analyzed for moisture by the ASAE method S352 (Agricultural Engineers Yearbook 1980). Protein was determined by AACC method 46-10 (1961). All protein results are expressed in percentages as N × 5.7, 14% mb.

Hardness determinations were made on wheat samples as obtained, without equilibration to a constant moisture level. It is not likely that enough time (at least 3 days) would be available to equilibrate the moisture content in marketing channels. Small differences in moisture content, as found among the samples used

TABLE I
Blends of Hard Red Winter (HRW) and Soft Red Winter (SRW) Wheats

HRW Variety or Selection	SRW Variety or Selection	SRW (%) in the Blend
Tam 105	Abe	4
Larned	Pike	4
Newton	Arthur 71	8
Triumph 64	Hart	8
Eagle	S-76	12
Scout 66	Pioneer 2550	12
Centurk	S-78	15
Wings	Beau	15

[1]Cooperative investigations between USDA/ARS and the Kansas Agricultural Experiment Station, Kansas State University, Contribution 84-515-J of the Kansas Agricultural Experiment Station.

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in this study, had insignificant effects on hardness parameters. Large differences in moisture, however, may affect hardness values.

Wheat hardness was measured by the time to grind 4 g of wheat with a Brabender automatic microhardness tester (BMHT), by the particle-size index (PSI) (Miller et al 1982), by the near infrared reflectance (NIR) method at 1,680 nm (Bruinsma and Rubenthaler 1978) and by the Stenvert Hardness Tester (SHT) (Lai et al 1983). Unless specified otherwise, PSI and NIR were determined on samples ground on the BMHT. All determinations were made in triplicate.

TABLE II
Hardness Characteristics of 12 Hard Red Winter and 12 Soft Red Winter Wheats

Wheat Class and Statistical Parameter	Brabender Microhardness Tester			Stenvert Hardness Tester		
	Grinding Time (sec)	PSI[a] (%)	NIR[b] at 1,680 nm	Grinding Time (sec)	PSI (%)	NIR at 1,680 nm
Soft Winter						
Range	44.8–383.0	41.3–56.7	120–252	23.6–44.2	14.9–32.9	163–338
Mean	157.6	48.2	178.1	30.5	21.7	260.0
C.V.[c] (%)	74.9	10.6	22.9	18.3	28.1	19.8
Hard Winter						
Range	32.6–38.3	34.3–39.5	248–294	43.0–54.5	8.2–11.8	386–466
Mean	35.6	36.5	271.4	49.5	9.6	427.7
C.V.[c] (%)	5.9	4.7	4.9	7.3	11.5	5.1

[a] Particle size index.
[b] Near-infrared reflectance.
[c] Coefficient of variation.

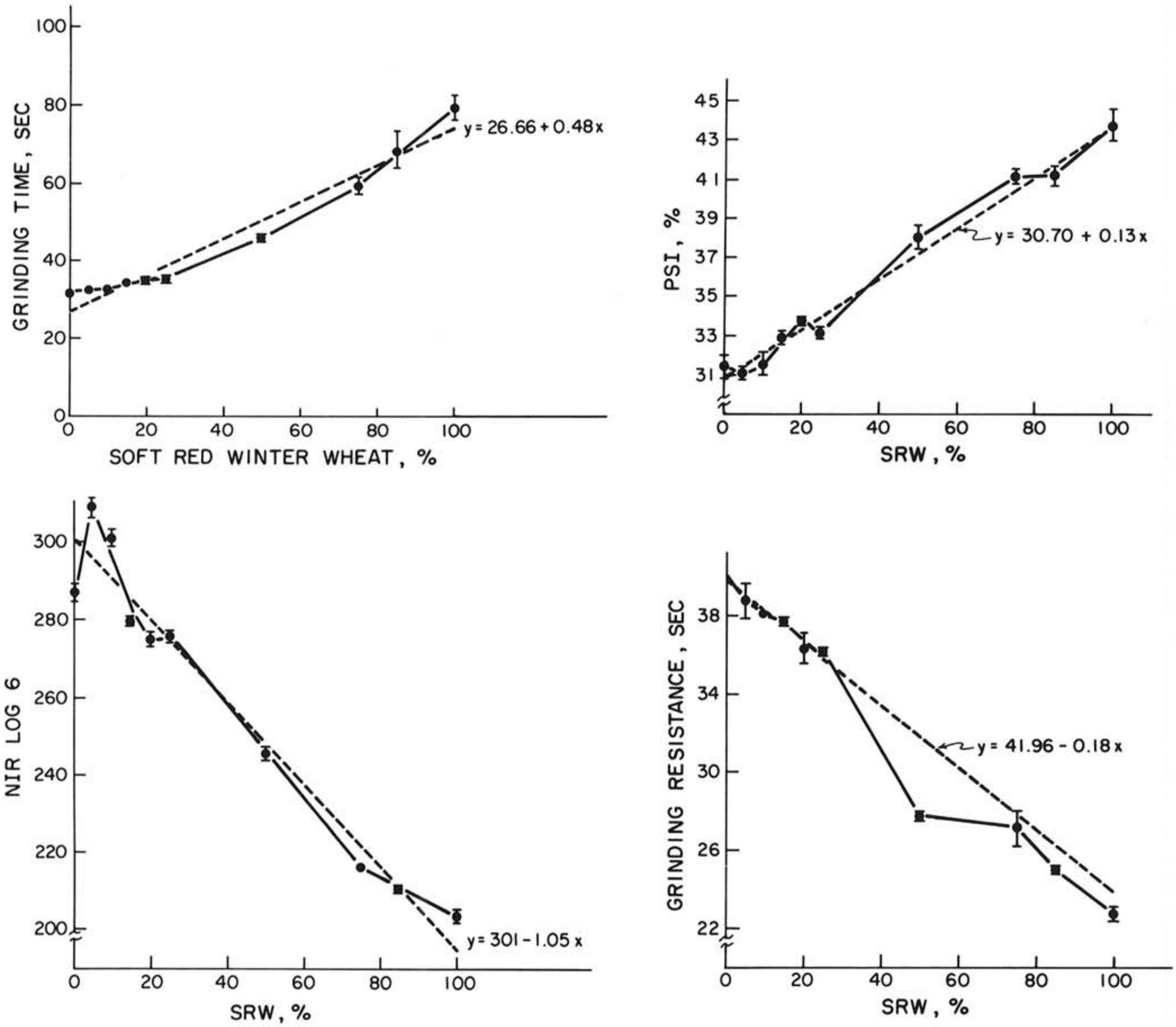

Fig. 1. Grinding time (Brabender automatic microhardness tester, sec), particle size index (PSI, %), near infrared reflectance (NIR) at 1,680 nm, and grinding resistance (Stenvert Hardness Tester, sec) of Arthur-Arkan wheat mixtures prepared in the laboratory.

We used the method of Zar (1974) for inverse prediction of the value of the independent variable (the percent of SRW) that is to be expected in a population at a specific value of the dependent variable (BMHT, PSI, NIR, or SHT).

RESULTS AND DISCUSSION

Hardness characteristics of the 12 HRW wheats and 12 SRW wheats are summarized in Table II and the correlation coefficients are listed in Table III. Ranges and coefficients of variation for all hardness measurements were much higher for the soft than for the hard wheats. There was little overlap in extremes of NIR measurements of the BMHT ground wheat and resistance determined by the SHT and no overlap for any of the other methods. Different PSI and NIR ranges and mean values were obtained, however, for samples ground on the BMHT and SHT (Table II). All correlation coefficients for the combined samples were significant at the 0.1% level. For both the HRW and SRW wheat groups, the more significant correlations were between BMHT grinding time and NIR, PSI and NIR from BMHT ground wheat, and PSI from BMHT and SHT ground wheat.

The results of determining hardness in mixtures of Arthur and Arkan wheats prepared in the laboratory are shown in Figure 1. Whereas the relations between hardness measurement and percent SRW are basically linear for PSI, NIR, and grinding resistance, a curvilinear relation seems indicated for grinding time. The broken lines in Figure 1 are for the respective linear regression equations for each group of measurements. Results of the Duncan multiple range test (Table IV) indicate that NIR measurements of hardness were the most powerful in determining the composition of mixtures prepared from two samples of known hardness. All correlation coefficients were high, and the standard errors of estimate ($S_{x \cdot y}$) to predict the percent of Arthur wheat in a mixture from the results of a hardness test were lowest for PSI and highest for NIR. Simple correlation coefficients among the four methods of hardness determination were all very high and significant (0.95–0.99).

The 95% confidence limits of the predicted values are given in Table IV. Of the four hardness tests, PSI predicted best the difference for each group of samples. This observation is also consistent with the highest correlation coefficient (r = 0.99) between PSI and percent of Arthur wheat in the mixture.

When sets of Arthur-Arkan mixtures covering a more narrow range than in Figure 1 were prepared by the FGIS and evaluated, the results shown in Figure 2 were obtained. The correlation coefficients, linear regression equations (to calculate hardness parameters y from percent of SRW x in the mixture), and corresponding standard errors of estimate for the four sets of samples are given in Table V. The correlation coefficients for hardness determination and percent of SRW wheat in the four small sets were comparable, with three exceptions, to those in Table IV. The correlation coefficients were insignificant for the relation between percent of SRW wheat and resistance to grinding in set 3 and for the relation between percent of SRW and NIR reflectance in sets 1 and 3. When calculated for combined samples in the four sets (Table VI), the low correlation coefficients, apparently, reflect the effects of a narrow range in composition of wheat mixtures and the fact that several samples of Arkan and Arthur were used to prepare the mixtures. Any combination of two hardness tests increased the multiple correlation coefficient to 0.91–0.93; the multiple correlation coefficient for all three hardness tests and percent of SRW wheat in a blend was 0.93. The standard errors of estimate in Table VI were smaller than those in Table IV.

The 95% confidence limits for the four small sets of samples with narrow ranges of SRW-HRW mixtures are given in Table V. The percent of SRW wheat in the mixture was predicted best by the BMHT method in sets 1 and 4 and by NIR in set 2. In set 3, NIR and SHT methods provided no meaningful confidence limits due to the poor correlation between the independent and dependent variables. In the combined four sets of samples (Table VI), BHMT provided the best prediction, and NIR no meaningful prediction, of percent SRW in the mixture.

The effects of blending eight different HRW wheats with relatively small amounts of eight different SRW wheats on hardness determination by four methods are summarized and evaluated statistically in Table VII. The 15% blends differed consistently from the 4% blends; grinding times and PSI values were higher and grinding resistance and NIR values were lower for the blends containing 15% SRW in the HRW-SRW blend. The

TABLE III
Correlation Coefficients[a] Between Various Hardness Parameters of 12 Hard Red Winter and 12 Soft Red Winter Wheats

Correlation Between[b]	Soft Wheat (n = 12)	Hard Wheat (n = 12)	Combined (n = 24)
BMHT vs.			
PSI-BMHT	0.65*	0.79**	0.78***
NIR-BMHT	−0.78**	−0.76**	−0.83***
SHT	−0.55	−0.39	−0.71***
PSI-SHT	0.86**	0.64*	0.88***
NIR-SHT	−0.67*	−0.67*	−0.76***
PSI-BMHT vs.			
NIR-BMHT	−0.72**	−0.71**	−0.92***
SHT	−0.79**	−0.59	−0.93***
PSI-SHT	0.70	0.83***	0.91***
NIR-SHT	−0.37	−0.65*	−0.86***
NIR-BMHT vs.			
SHT	0.78**	0.24	0.92***
PSI-SHT	−0.74**	−0.46	−0.91***
NIR-SHT	0.49	0.73**	0.89***
SHT vs.			
PSI-SHT	−0.46	−0.81**	−0.85***
NIR-SHT	0.44	0.30	0.90***
PSI-SHT vs.			
NIR-SHT	−0.52	−0.56	−0.87***

[a] *, **, *** = significant at the 5%, 1%, and 0.1% levels, respectively.
[b] BMHT = Brabender microhardness tester. PSI = Particle size index. NIR = Near-infrared reflectance at 1,680 nm. SHT = Stenvert hardness tester.

TABLE IV
Significant Differences[a] in Mixtures of Arthur and Arkan Wheats Prepared in the Laboratory

Hardness Test	% Arthur Wheat in a Mixture										Correlation Coefficient[b]	$Sy \cdot x$[c]	$Sx \cdot y$[d]	Range of 95% Confidence Limits[d]
	0	5	10	15	20	25	50	75	85	100				
Grinding						x	x	x	x	x				
time (sec)	x—	x—	x—	x—	x—	x					0.98	3.62	7.44	0.170–0.202
PSI (%)	x—	x—	x	x—	x—	x	x	x—	x	x	0.99	0.59	4.47	0.101–0.114
NIR at														
1,680 nm	x	x	x	x	x—	x	x	x	x	x	0.98	8.91	8.34	0.194–0.214
Grinding														
resistance	x	x—	x		x—	x	x—	x	x	x				
(sec)			x—	x							0.98	1.22	6.80	0.157–0.174

[a] Based on Duncan's multiple range test.
[b] Between percent Arthur wheat in a mixture and results of a hardness test.
[c] To predict hardness from percent Arthur wheat in a mixture.
[d] To predict percent Arthur wheat in a mixture from results of a hardness test.

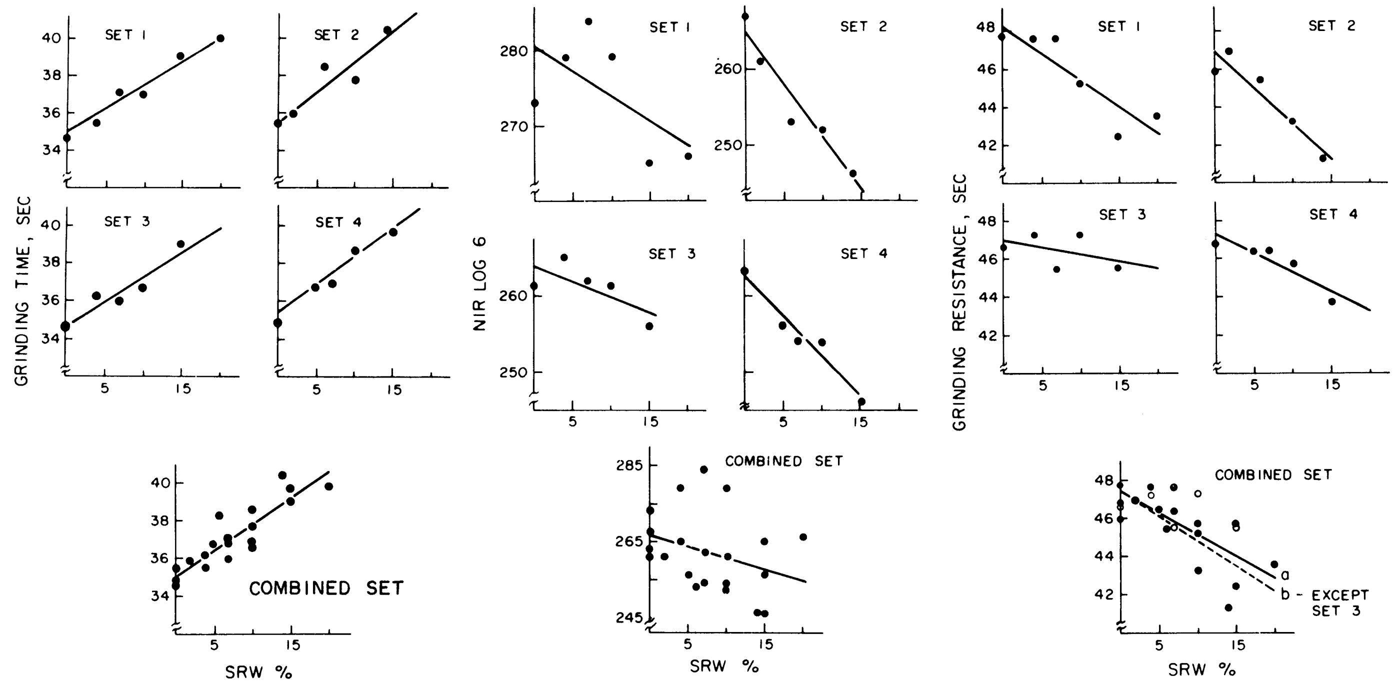

Fig. 2. Grinding time (Brabender automatic microhardness tester, sec), near infrared reflectance (NIR) at 1,680 nm, and grinding resistance (Stenvert Hardness Tester, sec) of Arthur-Arkan wheat mixtures prepared by the Federal Grain Inspection Service.

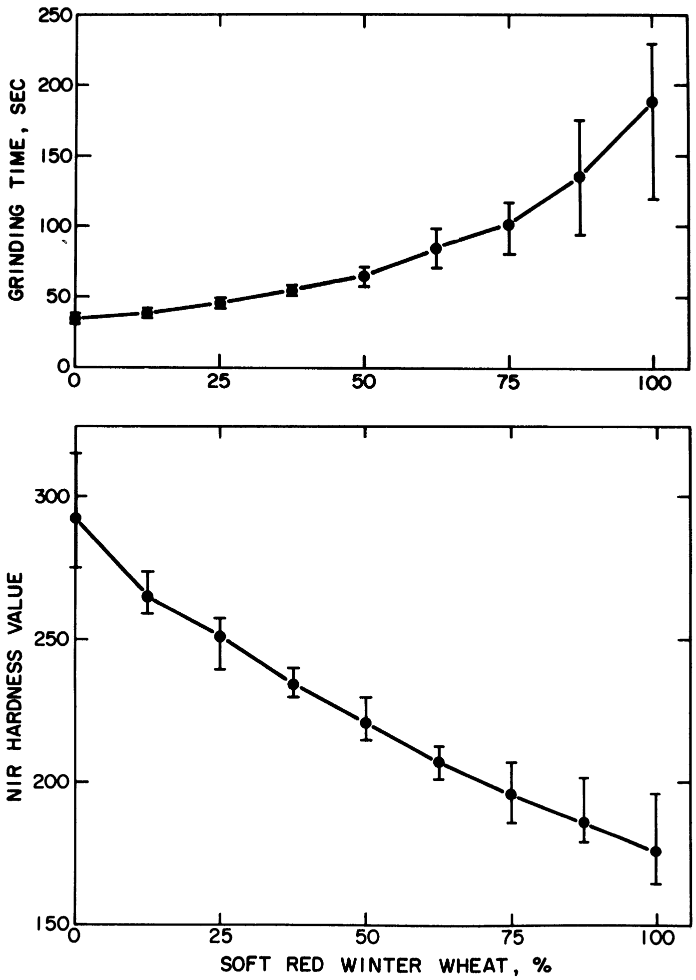

Fig. 3. Ranges and averages of grinding time (Brabender automatic microhardness tester) and near infrared reflectance (NIR) at 1,680 nm (for five) blends of five commercial HRW and SRW wheats.

TABLE V
Correlation Coefficients, Linear Regressions, and Standard Errors of Estimate for Determination of Hardness in Mixtures of Arthur and Arkan Wheats

Samples and Determinations	Correlation Coefficient (r)[a]	Linear Regression ($y = \beta + \alpha x$)	Standard Error of Estimate $Sy \cdot x$	Range of 95% Confidence Limits[b]
Set 1				
Grinding time	0.98***	$34.67 + 0.26x$	0.39	0.279–0.324
NIR	0.62	$280.40 - 0.65x$	6.75	···
Resistance	0.89*	$48.31 - 0.28x$	1.20	1.13–1.54
Set 2				
Grinding time	0.93*	$35.50 + 0.32x$	0.82	1.09–1.53
NIR	0.96**	$264.66 - 1.38x$	2.55	0.664–0.816
Resistance	0.94*	$46.92 - 0.37x$	0.86	0.919–1.25
Set 3				
Grinding time	0.94*	$34.60 + 0.26x$	0.60	0.909–1.28
NIR	0.70	$263.86 - 0.40x$	2.67	···
Resistance	0.41	$46.88 - 0.06x$	0.93	···
Set 4				
Grinding time	0.99***	$34.85 + 0.33x$	0.36	0.350–0.413
NIR	0.97**	$262.41 - 1.06x$	1.59	0.524–0.650
Resistance	0.91*	$47.30 - 0.20x$	0.59	1.58–2.83

[a] *, **, *** = significant at the 5%, 1%, and 0.1% levels, respectively.
[b] To predict percent of Arthur wheat in a mixture from results of a hardness test.

differences were not uniform, however, for the various high percentage blends and insignificant for the intermediate percentage blends (data not shown). Consequently, the correlation coefficients are low and insignificant. It is therefore obvious that the methods tested on bulk sample are not satisfactory for determining, on the basis of hardness measurements, small differences in the composition of blends of wheats that vary widely in grain texture.

The eight samples, each, of HRW and SRW wheats (described in Tables I and VII) were selected to cover a very wide range of hardness among wheat cultivars of the two classes. Such a wide range is possible but not likely in wheat blends in commercial channels. Hardness results of blends that varied widely in ratios of

TABLE VI
Statistical Evaluation of Hardness Tests of Mixtures (Combined Samples) of Arthur and Arkan Wheats

Evaluation	Grinding Time (sec)	NIR at 1,680 nm	Grinding Resistance
Correlation coefficient[a]	0.91***	0.30	0.72***
Linear regression line for			
Hardness (y) on % SRW (x)	$y = 35.01 + 0.28x$	$y = 266.15 - 0.54x$	$47.33 - 0.22x$
% SRW (y) from hardness (x)	$y = -103.74 + 3.00x$	$y = 52.34 - 0.17x$	$113.26 - 2.32x$
Standard error of estimate for			
Hardness (y) on % SRW (x)	0.75	10.11	1.29
% SRW (y) from hardness (x)	2.48	5.71	4.14
Range of 95% confidence limits[b]	0.230–0.253	···	0.533–0.685

[a]Between percent Arthur wheat in the mixture and results of the hardness test. *** = significant at the 0.1% level.
[b]To predict percent of Arthur wheat in a mixture from the results of a hardness test.

TABLE VII
Statistical Evaluation of Hardness Tests of Mixtures of Eight Hard Red Winter (HRW) and Eight Soft Red Winter (SRW) Wheats

Evaluation	Grinding Time (sec)	Particle Size Index (%)	NIR at 1,680 nm	Grinding Resistance
Correlation coefficient[a]	0.17	0.66	0.45	0.33
Linear regression line for				
Hardness (y) on % SRW (x)	$26.81 + 0.12x$	$26.0 + 0.37x$	$322.18 - 2.98x$	$46.17 - 0.30x$
% SRW (y) from hardness (x)	$2.88 + 0.25x$	$-25.32 + 1.19x$	$29.93 - 0.07x$	$25.29 - 0.36x$
Standard error of estimate for				
Hardness (y) on % SRW (x)	3.36	2.00	28.08	4.14
% SRW (y) from hardness (x)	4.71	3.60	4.27	4.52

[a]Between % SRW wheat in the mixture and results of the hardness test.

TABLE VIII
Significant Difference[a] in Mixtures of Commercial (Five Soft Red Winter and Five Hard Red Winter) Wheats

Sample and Hardness Test	Soft Red Winter Wheat (%) 0.0	12.5	25.0	37.5	50.0	62.5	75.0	87.5	100.0
Grinding time									
A	x---	------	x		x	x---	x	x	x
B	x---	x---	x---	x					
			x---	x---	x				
				x---	x---	x			
						x---	x	x	x
C	x---	x							
		x---	x	x	x	x	x	x	x
D	x---	x	x---	x	x	x	x	x	x
E	x		x		x		x		x
Combined	x---	x---	x---	x					
		x---	x---	x---	x				
					x---	x			
						x---	x	x	x
Near infrared reflectance at 1,680 nm									
A	x		x		x	x	x	x	x
B	x	x	x	x	x	x	x	x	x
C	x	x	x	x	x	x	x	x	x
D	x	x	x	x	x	x	x	x	x
E	x		x		x		x		x
Combined	x	x	x	x	x	x---	x		
							x---	x	
								x---	x

[a]Based on the Duncan's multiple range test.

commercial HRW-SRW wheats are shown in Figure 3 and Table VIII.

As in Table IV, for Arthur-Arkan mixtures prepared in our laboratory, the NIR method was more effective than the BMHT method in differentiating among various levels of SRW admixture. In addition, whereas a curvilinear relation was established for hardness determined by the BMHT method, a linear relation was established between percent of SRW and NIR. Consequently, the data for the mixtures of commercial wheats were evaluated for the ranges between 0 and 50% SRW, 62.5 and 100% SRW, and the total range (0 to 100% SRW). The statistical evaluation is summarized in Table IX. All correlation coefficients were highly significant, but the correlation coefficient for the total range for the grinding time method was only 0.93, compared to 0.99 for the NIR method. Similarly, standard errors of estimate (to predict percent of soft wheat in a mixture from hardness determination) were 13.05 and 5.37 for the BMHT and NIR methods, respectively.

According to the 95% confidence limits for the wide range of mixtures of commercial SRW and HRW wheats, the NIR method was better than the other methods for the 62.5–100% range; this observation is consistent with the correlation coefficient of 1.00. For any given set of samples, the percent of SRW wheat was predicted better by the NIR method than by the BHMT method.

Testing bulk samples of wheat mixtures is rapid and simple and eliminates or averages kernel-to-kernel variability and reduces sampling error. Testing bulk samples, on the other hand, makes determining the composition of mixtures very difficult, especially when hardness values of the wheats (at times, more than two) are unknown and when small amounts of a wheat type are admixed. If a specific limit or range of useful hardness values can be established by actual performance tests (i.e., wheat conditioning, milling, and baking), the need to determine the actual HRW:SRW wheat ratios may not be necessary. Such a limit or range would be especially appropriate when hardness varies considerably among wheats in the two classes that were studied in this investigation (see Table II). The other alternative is to determine hardness in individual kernels rather than in a bulk sample.

CONCLUSIONS

There is little, if any, overlap in analytical hardness parameters (time to grind, resistance to grinding wheat, particle size index, and NIR) between hard and soft red winter wheats. None of the methods, however, can be used to determine precisely the admixture of small amounts of soft to hard wheats or hard to soft wheats. The estimation of the amount of admixed wheat depends on the hard:soft wheat ratio, the hardness characteristics and numbers of wheats in the blend, and the hardness method used in the assay.

TABLE IX
Statistical Evaluation of Hardness Tests on Mixtures of Commercial Wheats (Five Soft Red Winter [SRW] and Five Hard Red Winter [HRW])

Evaluation	Grinding Time (sec)			NIR at 1,680 nm		
	0–50% SRW	62.5–100% SRW	0–100% SRW	0–50% SRW	62.5–100% SRW	0–100% SRW
Correlation coefficient[a]	0.97	0.98	0.93	0.99	1.00	0.99
Linear regression						
Hardness (y) on % SRW (x)	$y = 31.88 + 0.61x$	$y = -92.68 + 2.70x$	$y = 13.20 + 1.38x$	$y = 287.47 - 1.38x$	$y = 258.20 - 0.82x$	$y = 281.57 - 1.12x$
% SRW (y) from hardness (x)	$y = 50.48 + 1.61x$	$y = 36.6 + 0.35x$	$y = -2.01 + 0.63x$	$y = 203.1 - 0.71x$	$y = 313.2 - 1.21x$	$y = 246.74 - 0.87x$
Standard error of estimate						
Hardness (y) on % SRW (x)	3.21	11.94	19.32	5.04	0.39	6.09
% SRW (y) from hardness (x)	3.87	4.32	13.05	3.60	0.47	5.37
Range of 95% confidence limits[b]	0.383–0.422	1.05–1.44	0.370–0.463	0.334–0.407	0.082–0.095	0.191–1.223

[a]Between percent of soft wheat in the mixture and results of the hardness test.
[b]To predict percent of soft wheat in a mixture from the results of a hardness test.

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