Wheat Hardness: Comparison of Methods of Its Evaluation[1]

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ABSTRACT

Twelve measurements obtained with two different models of the Brabender Hardness Tester, two (new and used) Strong Scott Barley Pearlers, and a Brabender Quadrumat Junior mill, were assessed for their potential as indices of wheat grain hardness and for their ability to differentiate cultivars within a wheat class. The wheat hardness index, flour yield, and grinding torque, all obtained with the two-step Brabender Hardness Tester, gave the same ranking of the cultivars examined. Particle size index, obtained with the Quadrumat mill, also ranked the cultivars in the same order except that the differences between samples were, in some cases, smaller than the experimental error. Pearling resistance index, obtained with the Strong Scott barley pearler, did not give the same ranking as the other methods did. This discrepancy was attributed to differences in bran properties rather than in endosperm hardness. The results of all methods of hardness evaluation were dependent on moisture content. The moisture content of maximum discrimination varied somewhat among the methods investigated.

Grain kernel hardness is a characteristic very often used in wheat classification (Meppelink 1974, Symes 1961). The miller knows that harder wheat usually produces a higher extraction of flour of suitable color. Hard wheat mills to a flour with a higher percentage of damaged starch. In bread making, the higher starch damage results in higher water absorption of the dough and, subsequently, higher bread yield (Stenvert 1974).

The methods of wheat kernel hardness evaluation have been the subject of many studies (Blum et al 1960, Simmonds 1974). Different laboratories have used many different methods, often based on different principles, to measure kernel hardness. Hardness of individual kernels can be measured by penetrometers (Grosh and Milner 1959, Khusid 1959) or defined as the force required to crack the kernel (Meppelink 1974, Newton et al 1927). The practical application of these methods is limited by the low reproducibility of results, due to variability among kernels (Blum et al 1960) and among various parts of the endosperm of a single kernel (Khusid 1959).

The magnitude of interkernel variation can be decreased to some extent by making measurements on bulk grain samples. Methods that use bulk samples measure either the grinding or pearling resistance (Anderson et al 1966, Chesterfield 1971, Chung et al 1975) or the nature of the ground product (Meppelink 1974, Symes 1961). Some have used a combination of the two measurements to obtain a more accurate estimate of hardness (Greenaway 1969). Others have used indirect techniques such as the determination of grain density (Gasiorowski and Poliszko 1977), vitreosity (Gasiorowski and Poliszko 1977, Simmonds 1974), or amount of damaged starch in a ground product (Flour Milling and Baking Research Association 1976).

Some of these methods measure different properties of the grain. Particularly great differences could be expected, for instance, between methods based on pearling the grain, which depend strongly on bran properties, and methods based on milling properties, which depend on endosperm characteristics.

Interlaboratory comparison of published wheat hardness results is difficult because very few workers have used more than one method on similar samples. In an attempt to alleviate this shortcoming, this article reports hardness measurements made with a number of commonly used methods on a series of samples covering a range of grain hardness.

MATERIALS AND METHODS

Twelve wheat cultivars of various classes were selected to cover the range of hardness from soft to very hard. All but one sample were of the 1977 crop grown at Agriculture Canada Research Stations. Glenlea I was grown in 1976 at the University of Manitoba. The cultivars and some of their physical, chemical, and technological characteristics are listed in Table I.

The evaluation of kernel hardness was performed at five moisture contents: 9.5, 11.0, 12.5, 14.0, and 15.5%. The samples were first dried to about 8% moisture in a laboratory dryer at 60° C and then tempered to the required moisture level by pouring the appropriate amount of water over the samples and allowing them to equilibrate for 24 hr. All measurements of hardness were made in triplicate; average results are reported.

Brabender Hardness Tester

Two different models of the Brabender Hardness Tester (BHT), a one-step and a two-step, were used. In the two-step tester, the first burr mill is used to produce a cracked grain product of fairly uniform particle size for the measuring (second) grinder, which is connected to a farinograph torque measuring and recording device. The levers were set as for the 50-g dough mixing bowl. The damper was set to allow the pen to come down from 1,000 to 100 BU in 4 sec, and the chart paper was run at a constant speed of 3.3 cm/min.

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With the two-step tester, varying the gap between the grinding surfaces was not possible.

In the one-step BHT, the grinder was connected to the farinograph dynamometer with the levers set as for the 300-g dough mixing bowl. The speed of the chart paper was 40 cm/min. The damper was set to allow the pen to come down from 1,000 to 100 BU in 1.5 sec. The gap between grinding surfaces was set on position 4-10.

With each model of the BHT, several different variables were investigated as possible indices of kernel hardness. With the two-step BHT, the following were used: 1) torque during grinding (BU); 2) time taken to grind a given sample of wheat (sec); 3) energy input for grinding calculated as the area under curve (cm^2); 4) flour produced during grinding, expressed as material passing through a 177-μm sieve (%); 5) average particle size (APS) in μm of ground product obtained by sieve analysis on an Endecott shaker (7 min on sieves with openings starting from 88 μm and increasing to 840 μm); and 6) wheat hardness index (WHI), calculated according to Greenaway (1969). This index is the maximum torque (BU) produced during grinding, divided by yield (%) of flour.

With the one-step BHT, only the torque and WHI were used as indices of hardness.

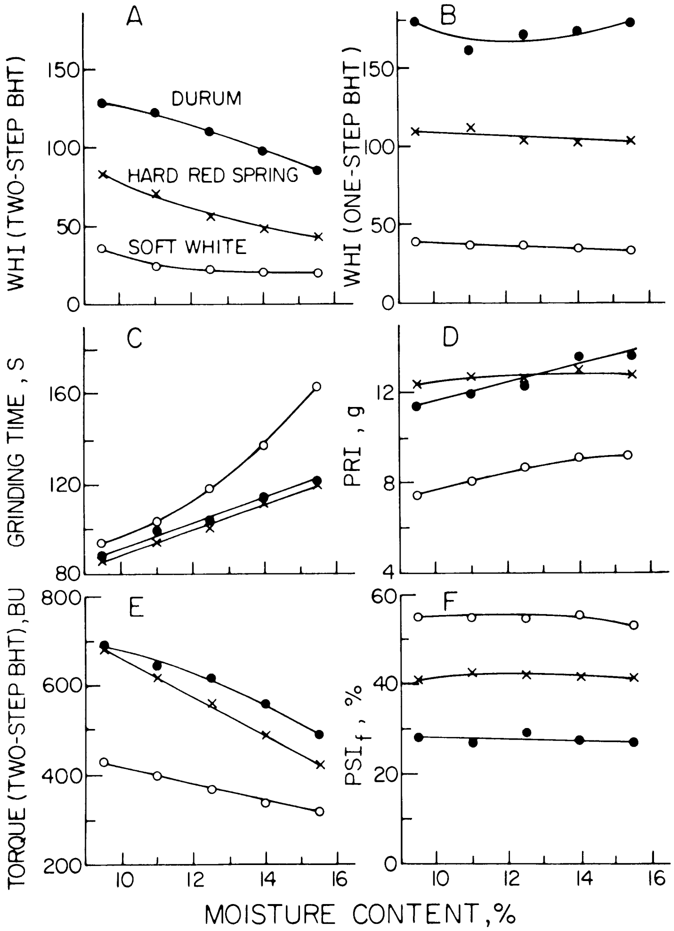

Fig. 1. Hardness indices for three classes of wheat as a function of moisture content, **A,** two-step Brabender Hardness Tester (BHT) wheat hardness index (WHI); **B,** one-step BHT WHI; **C,** grinding time; **D,** pearling resistance index (PRI); **E,** two-step BHT torque; **F,** particle size index of flour (PSI_f).

Strong Scott Barley Pearler

Two pearlers of different ages were used in this study. With the new model, 20 g of wheat was pearled for 20 sec. With the older model, the same amount of grain was pearled for 60 sec. For both machines, the weight of pearled grain in grams was the pearling resistance index (PRI). The new model was used in this study except in the experiment comparing the two pearlers.

Brabender Quadrumat Junior Mill

Twenty grams of wheat were milled on a Brabender Quadrumat Junior mill, and the product obtained was sieved for 7 min on an Endecott laboratory sieve shaker with 125-μm sieve openings. Two particle size indices were determined from the results: 1) the percentage of the total sample of wheat, in grams, passing through a 125-μm sieve (PSI_w) and 2) the amount of product passing through the 125-μm sieve divided by the amount of flour obtained with the same mill for the same size sample (20-g) multiplied by 100 (PSI_f, %).

Statistical Analysis of Results

The results from the various methods on samples of different moisture content were analyzed by the analysis of variance in order to determine optimum moisture for best discrimination between cultivar samples. The significance of differences among samples was determined by Duncan's multiple range test. The relationships of results from different methods were evaluated by coefficients of linear correlation.

TABLE I
Physical, Chemical and Technological Characteristics of Wheat Samples[a]

Cultivars	Hectoliter Weight (kg/hl)	1,000-Kernel Weight (g)	Grain Ash (%)	Grain Protein[b] (%)	Flour Yield[c] (%)	Flour Ash (%)	Farinograph Absorption (%)
Durum							
Hercules	79.9	52.8	1.42	14.5	61.0	0.66	64.8
Stewart 63	84.3	45.6	1.33	14.5	58.5	0.57	61.2
Hard red							
Glenlea 1	79.5	43.4	1.73	12.0	71.0	0.44	59.0
Glenlea 2	79.4	43.2	1.44	12.3	71.5	0.43	59.4
Neepawa	80.8	31.6	1.60	10.8	67.0	0.43	60.4
Sundance	77.4	33.6	1.58	10.0	72.0	0.43	58.0
Chester	80.4	35.7	1.63	12.7	70.7	0.40	59.8
Manitou	79.4	31.9	1.58	14.2	67.5	0.45	60.6
Soft white							
Talbot	76.9	37.2	1.40	12.0	70.5	0.38	53.4
Fielder	78.7	37.2	1.58	10.4	60.5	0.36	53.0
Pitic	74.8	36.4	1.51	9.6	55.0	0.41	53.8
Fredrick	79.4	38.0	1.39	11.7	67.0	0.34	50.8

[a] All on a 14% moisture basis.
[b] N × 5.7.
[c] Buhler experimental mill.

RESULTS AND DISCUSSION

The usefulness of the methods used in this study was assessed by evaluating their relative precision, based on differences between samples relative to differences among triplicates. If the number of replicates is the same, a measure of the usefulness of a method can be obtained from the F ratio in the analysis of variance, which tests for any differences among samples compared to differences among repeated measurements on each sample. For each method compared, the highest F ratio for the same number of degrees of freedom identifies the most discriminating method. Duncan's test was used to determine which cultivar samples were significantly different by a particular method for the determined "optimum" moisture level.

The compared methods of grain hardness evaluation showed different sensitivity to moisture content of grain (Figs. 1 and 2). Different classes of wheat showed different sensitivity to moisture, but the direction of the changes with moisture was the same for all classes of wheat investigated. The only exception was energy input (Fig. 2), in which with increasing moisture content, values for durum and hard red spring wheat classes decreased whereas values for soft wheat increased. In some methods of hardness evaluation, eg, average particle size (two-step BHT) and flour yield (two-step BHT), only one class of wheats (soft white) showed sensitivity to moisture content, probably because of bran characteristics.

Some of the hardness indices were extremely sensitive to moisture content, especially the torque, grinding time, and energy input from two-step BHT. Increasing moisture content decreased WHI and torque and increased grinding time. Moisture content had only a slight influence on PSI_f and a somewhat greater influence on PSI_w, especially for durum and hard red spring classes. In the case of PSI_f and PSI_w, the results are similar to those of Symes (1961), which showed large differences between wheat classes and a nonlinear relationship with moisture content for all samples. The PRI values increased slightly with moisture for all classes of wheat except for the hard red spring class in the moisture content range 14.0–15.5%, where it decreased slightly. Chesterfield (1971) obtained similar results for hard and soft Australian wheats.

An analysis of variance (one way) was made for each of the five levels of moisture to determine the moisture at which each hardness index showed the widest resolution of samples (Table II).

The BHT torque and PSI gave the best discrimination in the 9.5–11.0% moisture region. The optimum moistures for other methods were as follows: PRI and energy input, 11.0–12.5%; flour yield, APS, and WHI, 12.5–14.0%; and grinding time, 15.5%. Obviously, moisture content is an important factor in grain hardness. Furthermore, it affects different methods of hardness evaluation to a different extent.

The usefulness of the methods of wheat hardness evaluation, at the optimum moisture level of each method, was evaluated with Duncan's test (Table III). The best differentiation of the wheat cultivar samples was obtained by the flour yield and WHI measured with the two-step BHT. On the basis of these two indices, significant ($P = 0.05$) differentiation of all cultivars was obtained. Also, the range of values for the samples was exceptionally wide; WHI from 105 to 14 and flour yield from 5.5 to 22.6%. In order of decreasing hardness, the ranking of the cultivars on the basis of these two indices was as follows: durum wheat cultivars, hard red cultivars, and soft cultivars. Essentially the same ranking of wheat

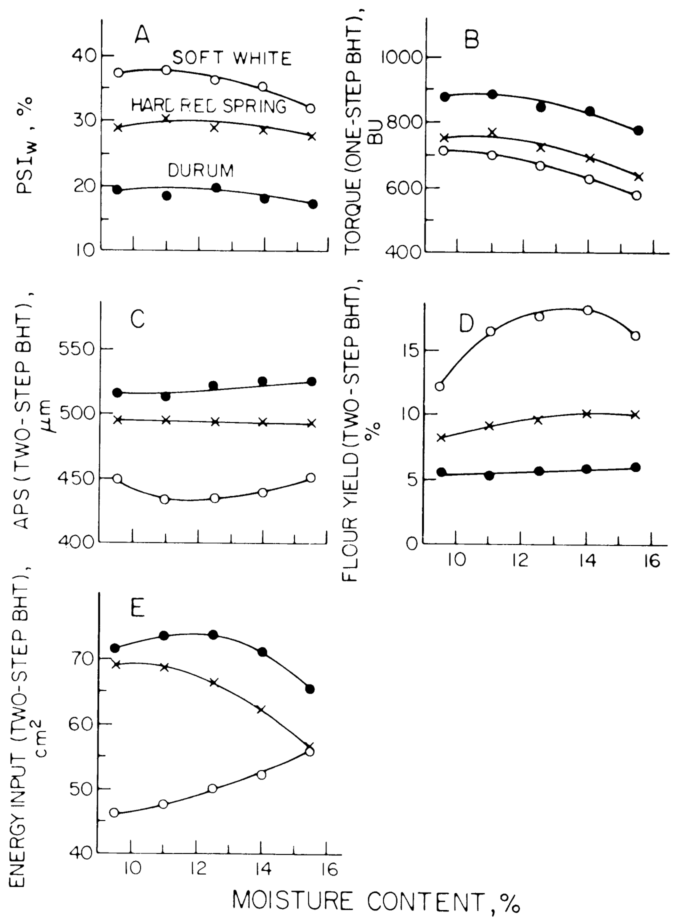

Fig. 2. Hardness indices for three classes of wheat as a function of moisture content. **A,** particle size index of wheat (PSI_w) from the Brabender Quadrumat mill; **B,** one-step Brabender Hardness Tester (BHT) torque; **C,** two-step BHT average particle size (APS); **D,** two-step BHT flour yield; **E,** two-step BHT energy input.

TABLE II
Analysis of Variance[a] Within Cultivars and Among Cultivars at Five Levels of Moisture[b]

Methods of Grain Kernel Hardness Evaluation	F Ratio at Moisture Level, % 9.5	11.0	12.5	14.0	15.5	Error Mean Square[c]
Torque (two-step BHT[d])	800.8*	500.7	311.3	355.2	164.4	35.28
Pearling resistance index	247.6	986.1*	517.6	257.9	319.4	0.020
Particle size index						
Flour	245.7	357.7*	123.9	288.4	69.0	0.820
Wheat	122.5	160.3*	66.2	120.2	82.7	0.444
Torque (one-step BHT)	88.6	128.4*	111.6	89.0	61.1	111.1
Average particle size	161.3	518.7	1,066.9*	856.4	342.6	2.573
Energy input	214.4	189.4	371.9*	162.6	199.9	0.513
Flour yield	161.7	510.4	1,009.1	2,950.2*	186.5	0.0286
Wheat hardness index						
Two-step BHT	384.2	410.3	1,009.3	2,254.6*	421.8	1.044
One-step BHT	38.4	158.0	208.9	391.1*	107.4	19.89
Grinding time	53.1	38.4	105.4	193.7	435.3*	2.95

[a] Degrees of freedom: for cultivar, 11; for error, 24; total, 35. $F_{0.01}$ for cultivars = 3.09.
[b] Moisture levels with the highest F ratio are starred.
[c] For the highest F ratio starred.
[d] Brabender Hardness Tester.

classes was obtained on the basis of two other indices obtained with two other apparatuses: PSI_f (Quadrumat Junior mill) and WHI (one-step BHT). The sensitivity of these two indices to hardness was lower. Minor variations in the ranking were obtained on the basis of torque and energy input from the two-step BHT. The rankings according to PRI and grinding time were quite different from that based on WHI. According to the PRI, durum wheats ranked between hard red and soft wheats. By grinding time, one durum cultivar, Stewart 63, was placed between the hard red and the soft cultivars, and one soft cultivar, Talbot, between the hard ones. The discordance of the results of PRI and grinding time with those of other methods is probably caused by differences in the amount and properties of the bran. Nevertheless, the high sensitivity of PRI suggests that it should be useful as a screening method for breeding programs.

A highly significant linear correlation was obtained between the results from the two different Strong Scott barley pearlers (Fig. 3). Although the intensity of pearling by the two machines is obviously different (the old machine required three times as much time to produce the same degree of debranning as the new one), either machine can be used for wheat hardness evaluation.

The high coefficients of correlation (Table IV) for WHI from the two-step BHT, PSI_f from the Quadrumat mill, and WHI from the one-step BHT indicate that direct comparison of results obtained by these methods is justified. The high resolution of the cultivars on the basis of WHI and the fact that this method combines two distinctly different kernel properties, resistance to grinding (expressed by torque) and endosperm structure (expressed by flour yield), suggests that this method has definite advantages over the other methods that were investigated.

In comparison with the one-step BHT, the two-step BHT has two basic advantages: 1) higher sensitivity (Tables II and III) and 2) elimination (by first grinding and uniform feeding rates) of the influence of kernel size on the hardness evaluation. The high coefficient of correlation between the results from this instrument for the 50-g and 20-g samples (Table V) shows that the instrument can be used effectively on a smaller grain sample than the 50 g recommended by the manufacturer. Classification of wheat cultivar samples with the Quadrumat Junior mill indicates that this mill can also be used effectively for grain hardness evaluation.

SUMMARY

Comparison of a number of methods of wheat hardness evaluation showed that the WHI and flour yield obtained on the two-step BHT and WHI from the one-step BHT provide a rapid and sensitive measure of physicomechanical properties of wheat related to hardness. On the basis of these results, the cultivars were

TABLE III

Usefulness of Hardness Methods (at Optimum Moisture) for Differentiation of Wheat Cultivars,[a] Using Duncan's Multiple Range Test at $P = 0.05$[b]

Two-Step BHT[c]						Strong Scott Barley Pearler	Quadrumat Junior Mill		One-Step BHT[c]	
Wheat Hardness Index (14.0)[d]	Flour Yield (14.0)	Average Particle Size (12.5)	Torque (9.5)	Energy Input (12.5)	Grinding Time (15.5)	Pearling Resistance Index (11.0)	PSI_f[e] (11.0)	PSI_w[e] (11.0)	Wheat Hardness Index (14.0)	Torque (11.0)
A 105	A 5.5	A 527	D 745	B 74.7	C 108 a	H 13.53	A 26.1	A 18.5 a	B 190	B 900 a
B 87	B 6.2	B 518	A 712 a	A 72.8	A 111 a	F 13.17	B 27.9	B 19.5 a	A 166	E 890 ab
C 66	C 8.2	C 500 a	F 693 a	C 70.3	H 114	G 12.63 a	C 37.8 a	C 26.0	F 128	A 880 b
D 56	D 8.7	F 500 a	H 687 ab	D 68.5 a	E 119	C 12.42 ab	D 38.8 a	D 28.8 b	E 117	G 840
E 48 a	F 9.9	E 499 a	C 680 b	E 67.6 a	G 124 b	D 12.35 ab	E 41.8	E 29.7 b	C 109	L 790 c
F 47 a	E 10.3	D 496	B 667 c	F 66.3	J 125 b	E 12.23 b	F 44.1	F 31.5	H 100 a	H 780 c
G 41	G 11.2	H 483 b	E 661 c	H 62.7 b	D 127 bc	A 12.21 b	G 46.1 b	G 32.8 c	D 97 a	C 730 d
H 37	H 12.5	G 482 b	G 627	G 62.0 b	F 127 bc	B 11.73	H 47.0 b	H 33.5 c	G 80	J 720 d
J 25	J 13.3	J 450	K 483	L 57.5	B 130 c	L 10.27	J 52.9	J 36.2 d	K 44 a	D 700
K 21	K 17.8	L 444	J 453 d	K 50.1 c	K 139	K 9.23	L 54.9 c	K 36.8 d	J 42 a	K 680
L 19	L 19.3	K 436	L 443 d	M 49.0 c	L 184	J 8.34	K 55.8 c	L 37.3 d	L 31	F 640 e
M 14	M 22.6	M 411	M 342	J 43.7	M 203	M 5.07	M 58.4	M 42.2	M 19	M 630 e

[a] A, Hercules; B, Stewart 63; C, Glenlea 1; D, Glenlea 2; E, Neepawa; F, Sundance; G, Chester; H, Manitou; J, Talbot; K, Fielder; L, Pitic; M, Fredrick.

[b] Within each column, values with the same letter are not significantly different.

[c] Brabender Hardness Tester.

[d] Optimum moisture content (%) for each parameter shown in parentheses.

[e] Particle size index. f = flour, w = wheat.

TABLE IV

Correlations[a] Between Results of Various Tests of Grain Hardness Evaluation, Based on Average Results from Moisture Range 9.5–15.5% of 12 Wheat Cultivar Samples

Method of Grain Kernel Hardness Evaluation	Flour Yield	Average Particle Size	Torque	Energy Input	Grinding Time	Pearling Resistance Index	Particle Size Index: Wheat	Particle Size Index: Flour	Torque[b]	Wheat Hardness Index[b]
Wheat Hardness Index	−0.870[c]	0.835[c]	0.872[c]	0.778[c]	−0.526	0.365	−0.800[c]	−0.890[c]	0.256	0.843[c]
Flour yield		−0.942[c]	−0.774[c]	−0.649	0.581	−0.473	0.774[c]	0.879[c]	−0.260	−0.849[c]
Average particle size			0.734[c]	0.760[c]	−0.411	0.658	−0.873[c]	−0.934[c]	0.449	0.913[c]
Torque				0.794[c]	−0.706	0.436	−0.557	−0.690	0.089	0.726[c]
Energy input					−0.180	0.687	−0.758[c]	−0.778[c]	0.383	0.756[c]
Grinding time						−0.059	0.121	0.303	0.160	−0.406
Pearling resistance index							−0.595	−0.554	0.548	0.570
Particle size index										
Wheat								0.955[c]	−0.600	−0.849[c]
Flour									−0.491	−0.916[c]
Torque[b]										0.493

[a] $r_{0.01} = 0.708$.

[b] One-step Brabender Hardness Tester.

[c] Significant at $P = 0.01$.

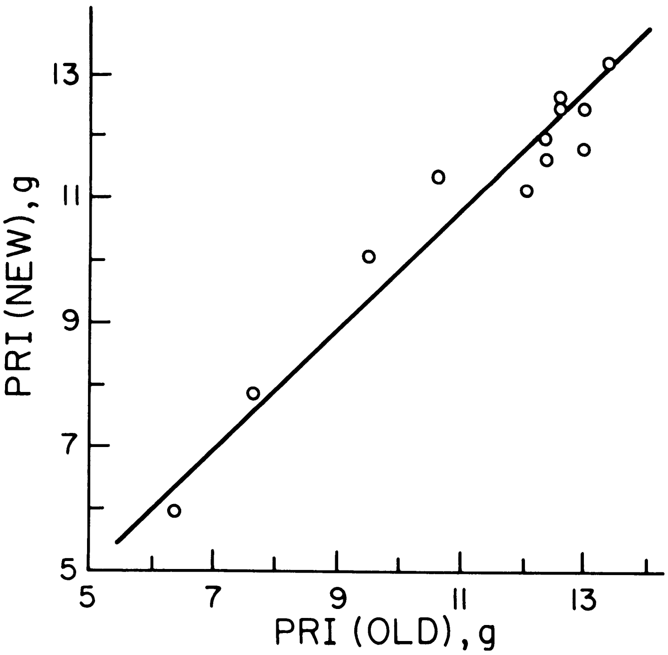

Fig. 3. Relationship between pearling resistance indices (PRI) obtained with new and old models of the Strong Scott pearler (r = 0.964, $P = 0.01$). Each point is the average of 15 results (three replicates and five moisture contents).

properly grouped in wheat classes of known hardness (ie, durum cultivars harder than hard red spring cultivars, which were harder than soft wheats). Several other methods (eg, PSI_w, PSI_f, APS, and energy input on the two-step BHT) ranked wheat classes in the proper order, but these indices were either less sensitive or more time-consuming. PRI did not rank the wheat classes in the same order as the other methods investigated. This discrepancy is presumed to be the result of differences in bran properties. Results of some of the methods investigated were strongly affected by moisture content; they gave the best discrimination at a characteristic "optimum" moisture content.

TABLE V
Comparison of Results[a] for the Same Factors for 50-Gram and 20-Gram Samples[b] of Seven Wheat Cultivars

Grain Hardness Evaluation Factor	Coefficient of Correlation of Samples	Relative Precision	
		50-g (%)	20-g (%)
Torque	0.986	2.2	2.8
Grinding time	0.975	2.8	3.7
Energy input	0.986	4.3	1.5
Average particle size	0.968	...	...
Flour yield	0.994	...	...
Wheat hardness index	0.990	...	...

[a] With two-step Brabender Hardness Tester; $r_{0.01} = 0.430$.
[b] Five levels of moisture for each sample.

LITERATURE CITED

ANDERSON, R. A., PREIFER, V. F., and PEPLINSKI, A. J. 1966. Measuring wheat kernel hardness by standardized grinding procedures. Cereal Sci. Today 11:204.

BLUM, P. H., PANOS, G., and SMITH, R. J. 1960. Measurement of hardness of barley and malt with the Brabender Hardness Tester. II. Modification during malting. Am. Soc. Brew. Chem., Proc. 18:95.

CHESTERFIELD, R. S. 1971. A modified barely pearler for measuring hardness of Australian wheats. J. Aust. Inst. Agric. Sci. 37:148.

CHUNG, C. H., CLARK, S. J., LINDHOLM, J. C., McGINTY, R. J., and WATSON, C. A. 1975. The Pearlograph technique for measuring wheat hardness. Trans. ASAE. 18:185.

FLOUR MILLING AND BAKING RESEARCH ASSOCIATION. 1976. Milling Quality. Flour Milling Baking Res. Assoc. Bull. 2:38.

GASIOROWSKI, H., and POLISZKO, S. A. 1977. Wheat endosperm microhardness index. Acta Alim. 6:113.

GREENAWAY, W. T. 1969. A wheat hardness index. Cereal Sci. Today 14:6.

GROSH, G. M., and MILNER, M. 1959. Water penetration and internal cracking in tempered wheat grains. Cereal Chem. 36:260.

KHUSID, S. D. 1959. Grain Milling (Theory and Practice). Moscow.

MEPPELINK, E. K. 1974. Untersuchungen über die methodik der kornhärtebestimmung bei Weizen. Getreide, Mehl Brot 28:142.

NEWTON, R., COOK, W. H., and MALLOCH, J. G. 1927. The hardness of the wheat kernel in relation to protein content. Sci. Agric. 8:205.

SIMMONDS, D. H. 1974. Chemical basis of hardness and vitreosity in the wheat kernel. Bakers Dig. 48:16.

STENVERT, N. L. 1974. Grinding resistance. A simple measure of wheat hardness. Flour Anim. Feed Milling 7:24.

SYMES, K. J. 1961. Classification of Australian wheat varieties based on the granularity of their whole meal. Aust. J. Exp. Agric. Anim. Husb. 1:18.

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