Hardness of Winter Wheats Grown Under Widely Different Climatic Conditions[1]

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ABSTRACT

Fifteen winter wheat cultivars or selections from the 15th International Winter Wheat Performance Nursery grown at 11 locations in the USA, Europe, and Asia, were analyzed for protein content, kernel weight, and hardness. A total of 161 samples were evaluated. Hardness was determined by four methods: time to grind, resistance to grinding, particle size index (PSI), and near-infrared reflectance (NIR) of ground wheat. The effects of location were larger than those for variety on protein content and 1,000-kernel weight. Variety had a much larger effect than location on wheat hardness as determined by all four methods. All hardness parameters were significantly correlated ($r = 0.67$ to 0.85). Low, significant correlations were found between 1,000-kernel weight and PSI ($r = 0.27$**) and resistance to grinding ($r = -0.35$**) and between NIR at 1,680 nm and protein content ($r = 0.19$*). Variance component ratios (σ_g^2/σ_e^2 and σ_g^2/σ_{ge}^2) were much higher for hardness parameters than for 1,000-kernel weight or protein content. This indicates the relatively large and stable genetic, as contrasted to environmental, influence on hardness characteristics and variability. It is concluded that hardness of winter wheat is governed mainly by genotype and that some methods of measuring hardness may be influenced by kernel size. Grain protein content was not correlated with hardness when it was calculated for all varieties across all locations. Some varieties, however, showed significant (negative or positive) relationships between protein content and hardness. Those effects were expressed primarily in the two hardness methods based on particle size determination (PSI and NIR).

The effects of protein content on wheat hardness have been the subject of numerous investigations, with various and often conflicting results. These were summarized by Pomeranz and Miller (1983) and are listed in Table I. Similarly, the effects of kernel size (weight) and growth conditions on wheat hardness are of considerable interest (Miller et al 1984, Pomeranz and Afework 1984).

This study reports on hardness, as determined by four methods, of 15 wheat cultivars and selections grown at 11 locations in the USA, Europe, and Asia. The wheats varied widely in 1,000-kernel weight and protein content. The objective of the study was to determine to what extent varietal hardness characteristics are influenced by environment, kernel weight, and protein content.

MATERIALS AND METHODS

Origins and pedigrees of the 15 varieties or selections from the 15th International Winter Wheat Performance Nursery are listed in Table II. Grain samples were provided by cooperating nurseries from 11 locations reported in Table III. A total of 161 samples were evaluated for protein content, 1,000-kernel weight, moisture, and grain hardness characteristics. The selections TAW 12399-75 and Quilamapu 25-77 are soft wheats, and the others are intermediate hard wheats. Lasko is a winter triticale.

Whole kernels were analyzed for moisture by ASAE method S352 (American Society of Agricultural Engineers 1980). Protein was determined by AACC method 46-10 (1983).

Wheat hardness was measured by the time to grind 4 g of wheat with a Brabender automated microhardness tester (Miller et al 1981a), by particle-size index (PSI) (Miller et al 1982), by near-infrared reflectance (NIR) at 1,680 nm (Bruinsma and Rubenthaler 1978), and by resistance to grinding by the Stenvert mill (Pomeranz et al 1985). All hardness measurements reported represent means for duplicate subsamples. All determinations were made on an as is moisture basis, which ranged from 12.1 to 13.0% (average 12.6%). Procedures from the Statistical Analysis System (Helwig and Council 1979) were used for all data analyses and calculations of variance components.

RESULTS AND DISCUSSION

One-thousand-kernel weights, protein contents, and hardness parameters of the 15 cultivars or selections (across locations) are summarized in Table IV, and data for the 11 locations (across cultivars) are presented in Table V. The locations in this study are environmentally diverse for wheat production, which is indicated by the wider range in protein contents and 1,000-kernel weights over locations means than among varietal means. The varieties examined are diverse in origin and genetic makeup. The varieties Feng Kong 15 and Arina were significantly (at the 0.05 level) above the mean in protein. The varieties Bounty Hybrid 100, Ogosta, and Feng Kong 15 were significantly (at the 0.05 level) above the mean in 1,000-kernel weight. There were large significant differences in wheat hardness, as determined by the four methods, for the 15 cultivars. The conclusions about the hardness of the cultivars were reached, primarily, on the basis of average ranking by the four methods. The ranges of hardness values (for the 15 varieties, across locations) divided by the LSD values (0.05) were 12.28 for time to grind, 9.37 for resistance to grinding, 7.71 for PSI, and 16.78 for NIR. The higher the range/LSD ratio the more sensitive and powerful the predictive test. Whereas the NIR reflectance values show the highest ratio, measurement by NIR at several wavelengths, or especially at one wavelength (1680 nm), is affected by several compositional factors in addition to particle size of the ground material and therefore limits this measurement as an index of hardness.

Based on the results in Table IV, the varieties Super X and Arina are hard; Saliente, Ogosta, WWP4258, and Bounty Hybrid 200 are medium hard; Lasko, Bezostaya, Katya A1, Bounty Hybrid 100, NS 1589A, CA 8055, and Feng Kong are medium soft; and TAW 12399-75 and Quilamapu 25-77 are soft.

Correlation coefficients among 1,000-kernel weight, protein content, and four hardness parameters are summarized in Table VI. The correlation coefficient between 1,000-kernel weight and protein content was not significant. In agreement with the findings of Pomeranz and Afework (1984), 1,000-kernel weight was related to resistance to grinding and PSI (probably through the effect of kernel shape and ratio of starchy endosperm to outer kernel layers).

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TABLE I
Wheat Protein and Hardness

Investigator(s)	Method(s)	Results
Newton et al (1927)	Cracking	No relation
Worzella (1942)	Particle size	No relation
Berg (1947)	Particle size	Varietal character, uninfluenced by protein
Fajerson (1950)	Particle size	Varietal character, influenced by protein
Symes (1961)	Particle size	Protein effect varies among varieties
Williams (1967)	Particle size index, starch damage	No relation
Symes (1969)	Particle size	No relation
Greenaway (1969)	Wheat hardness index	Relation with protein/m^2 of flour and protein
Seckinger and Wolf (1970)	Microscopy of endosperm particles	Protein particles for hard (unlike soft) wheat compact and hard to disrupt
Barlow et al (1973)	Penetrometer-starch granules and storage protein fragments	No varietal differences
Moss et al (1973)	Pearling resistance, particle size index	Negative relation for single cultivar
Trupp (1976)	Particle size index (protein by dye binding)	Very low relation, affected by variety and environment
Stenvert and Kingwood (1977)	Time to produce a fixed volume of ground wheat	Positive relation with protein content and formation of a continuous phase, cultivar dependent
Moss (1978)	Starch damage, particle size, resistance to abrasion, specific volume of wholemeal	Optimum hardness and starch damage related to minimum protein
Obuchowski and Bushuk (1980a,b)	Miscellaneous	No relation
Miller et al (1981a, 1982)	Time to grind, work to grind, particle size, NIR	No relation
Miller et al (1981b)	Work required to grind	No relation

TABLE II
Cultivars in the 15th International
Winter Wheat Performance Nursery, 1983

Cultivar	Origin	Pedigree
Bezostaya 1	USSR	Lutescens 17/Skorospelka 2
CA 8055	China	Jing Shuang 2/Lovrin 13//Jing Shaung 3
Ogosta	Bulgaria	234/S-13//Bezostaya 1
TAW 12399-75	E. Germany	Atlas 66/Kavkaz//Alcedo
Arina	Switzerland	Moisson/Zenith
Super X	Mexico (CIMMYT)	Penjamo 62 "S"-Gabo 55 II 8156
Lasko (LT 176-73)	Poland	Triticale 57 (Hungary)// Bezostaya 1/Dankowska Polnocna//6TA 206 (Jenkins)
Bounty Hybrid 200	USA (Cargill)	Unavailable
Bounty Hybrid 100	USA (Cargill)	Unavailable
NS 15-89A	Yugoslavia	Aurora/NS 845
Katya A-1	Bulgaria	Fortunato/No. 301 (Bulgaria)/ Bezostaya 1
Quilamapu 25-77	Chile	(MD-Nor 10/B × PQQ × Sup. F_2 (Kw-F_2 Kans. 1111/Neb) Trumb 3.-H/Hussar
WWP 4258	Austria	(Record × Mexico 40) × Record × (Bezostaya 1 × Accord)
Fenz Kang 15	China	You Mang Hong 7/Lovrin 10
Saliente	Italy	Bezostaya 1/Marimp 3

TABLE III
Latitude, Longitude, and Elevation of Nursery Sites in the
15th International Winter Wheat Performance Nursery in 1983

Country	Station	Latitude	Longitude	Elevation (m)
France	Orgerus	48°40′ N	02°20′ E	90
Hungary	Martonvasar	47°21′ N	18°49′ E	150
Italy	Milano	45°13′ N	09°05′ E	70
Switzerland	Zurich	47°29′ N	08°32′ E	445
USA	Davis, CA	38°32′ N	121°46′ W	18
	Billings, MT	45°38′ N	108°30′ W	923
	Ithaca, NY	42°30′ N	76°30′ W	335
	Pullman, WA	46°42′ N	117°08′ W	768
USSR	Krasnodar	45°00′ N	38°55′ E	37
West Germany	Monsheim	49°35′ N	08°20′ E	160
Yugoslavia	Zagreb	45°49′ N	15°59′ E	177

The correlations were statistically significant but small and explained only 7 and 12% of the variability, respectively ($r^2 = 0.071$ and 0.121). When it was calculated for all varieties across all locations, protein content was not significantly correlated to three of the hardness parameters (time to grind, grinding resistance, or PSI). The low correlation ($r^2 = 0.035$) between Kjeldahl protein content and NIR probably reflects the lack of specificity of the measurement at 1,680 nm. The correlation coefficients among the hardness parameters (0.492–0.845) were all highly significant; yet, they explain only 24 to 71% of the variability. These coefficients are much lower than the values ($r = 0.923$–0.967) reported for a wide range of Australian wheats grown at one location (Pomeranz and Miller 1983). In the Australian wheats, the correlation coefficients between hardness parameters and end-use properties (starch damage and flour density) were very high. The results of this study emphasize the empirical nature of the hardness determinations that measure specific—and probably single and different—characteristics of the overall grain texture and hardness. Those properties relate to functional end properties of wheat in processing, including milling.

Some varieties in this study showed significant (negative or positive) relationships between protein content and hardness (Table VII). Those effects were expressed primarily in the two methods based on particle size determination: NIR (nine out of 15) and PSI (five out of 15). The two varieties which showed the most consistent (for the four methods) relationships between protein content and hardness were the medium-soft triticale Lasko and the soft wheat Quilamapu 25-77.

The estimate of the variance component ratio σ_g^2/σ_e^2 denotes the relative influence of genetic and environmental effects on variability. The higher the ratio, the greater the influence of genetic (cultivar) factors on variability. The ratios (Table VIII) of the estimates of the variance components are small for 1,000-kernel weight and for protein content, especially, indicating the larger influence of environment on variability of these traits. The influence of genotype (cultivar) is greater on variability of hardness measurements. In agreement with previous data (Miller et al 1984), the ratio is highest for time to grind and rather low for grinding resistance. The variance component ratio σ_g^2/σ_{ge}^2 denotes the relative influence of genetic effects and effects of the interaction of genotype with environment on variability. The higher the ratio, the more stable the genotypic effect and the less that effect is influenced by the environment. The ratios of the estimates of variance components for protein and 1,000-kernel weight are low. The ratios for the four hardness parameters are relatively high and indicate the greater stability of hardness characteristics among varieties than among locations.

TABLE IV
Wheat Variety Means and Ranks for Kernel Weight, Protein Content, and Hardness Parameters Averaged Over 11 Locations

Variety	1,000-Kernel Weight (g)		Protein[a] (N × 5.7, %)		Time to Grind (sec)		Grinding Resistance (sec)		Particle Index (%)		Near-Infrared Reflectance at 1,680 nm (arbitrary units)	
	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank
Super X	37.4	11	11.2	12	28.2	15	57.2	14	27.2	15	337.3	15
Arina	38.1	10	12.6	2	32.4	9	55.2	13	27.9	14	327.7	14
WWP4258	33.4	15	11.4	9	32.9	6	61.5	15	28.8	13	315.4	11
Lasko	36.5	13	11.3	10	34.7	5	36.2	3	30.8	12	266.2	3
Bounty Hybrid 200	39.0	8	11.3	11	31.1	14	49.6	12	31.1	11	309.9	7
Saliente	36.5	14	11.0	15	31.7	11	49.3	11	31.2	10	313.2	10
Ogosta	44.3	2	11.5	8	31.3	12	45.7	7	32.0	9	317.4	13
Bezostaya	41.6	4	12.0	6	32.5	8	45.6	5	32.2	8	312.5	9
Katya A1	37.3	12	11.2	13	31.2	3	47.8	9	32.5	7	316.6	12
Bounty Hybrid 100	44.9	1	12.1	5	32.6	7	47.2	8	32.5	6	312.3	8
NS 1589A	41.5	5	11.8	7	32.1	10	45.6	6	32.8	5	296.4	6
CA 8055	40.6	6	12.4	3	37.7	3	48.1	10	33.3	4	280.6	4
Feng Kong 15	43.2	3	14.0	1	37.6	4	40.9	4	34.3	3	283.2	5
TAW 12399-75	40.1	7	12.3	4	89.6	1	34.7	2	39.5	2	176.2	1
Quilamapu 25-77	38.3	9	11.2	14	62.6	2	28.7	1	40.3	1	208.4	2
Mean	39.5		11.8		38.4		46.1		32.4		291.7	
Range												
Minimum	33.4		11.0		28.2		28.7		27.2		176.2	
Maximum	44.9		14.0		89.6		61.5		40.3		337.3	
LSD (0.05)	2.9		.08		5.0		3.5		1.7		9.6	
C.V.	7.8		8.0		3.6		1.6		1.5		0.9	

[a] 14% moisture basis.

TABLE V
Location Means and Ranks for Kernel Weight, Protein Content, and Hardness Parameters Averaged Over 15 Wheat Cultivars

Location	1,000-Kernel Weight (g)		Protein[a] (N × 5.7, %)		Time to Grind (sec)		Grinding Resistance (sec)		Particle Size Index (%)		Near-Infrared Reflectance at 1,680 nm (arbitrary units)	
	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank
Krasnodar, USSR	35.8	8	12.5	5	34.5	9	51.5	10	30.9	11	307.4	10
Zurich, Switzerland	36.7	7	12.8	3	36.7	7	48.0	8	31.0	10	293.9	6
Billings, MT	···	···	14.6	1	34.1	10	40.8	2	31.1	9	307.2	9
Davis, CA	37.7	5	10.5	9	41.1	4	56.8	11	31.2	8	288.2	4
Zagreb, Yugoslavia	41.9	4	10.8	8	35.3	8	45.0	6	31.2	7	295.0	7
Martonvasar, Hungary	37.1	6	12.1	6	33.9	11	46.5	7	32.2	6	322.4	11
Milano, Italy	···	···	10.4	10	36.7	6	38.3	1	32.5	5	276.7	3
Orgerus, France	43.1	3	11.7	7	39.8	5	44.4	5	33.7	4	272.1	2
Pullman, WA	43.6	2	9.6	11	44.3	1	41.4	3	33.9	3	254.6	1
Ithaca, NY	32.5	9	12.5	4	44.0	2	48.6	9	34.5	2	293.0	5
Monsheim, West Germany	46.5	1	12.8	2	41.2	3	44.2	4	34.7	1	300.5	8
Mean	39.5		11.8		38.4		46.1		32.5		291.7	
Range												
Minimum	32.5		9.6		33.9		38.3		30.9		254.6	
Maximum	46.5		14.6		44.3		56.8		34.7		322.4	

[a] 14% moisture basis.

TABLE VI
Correlation Coefficients Among 1,000-Kernel Weight, Protein Content, and Hardness Parameters for all Samples

	1,000-Kernel Weight	Protein Content	Time to Grind	Grinding Resistance	Particle Size Index
Protein content	−0.011	···			
Time to grind	0.049	−0.047	···		
Grinding resistance	−0.348**[a]	−0.037	−0.492**	···	
Particle size index	0.266**	−0.020	0.728**	−0.717	···
Near-infrared reflectance	−0.108	0.186*	−0.845**	0.671**	−0.758**

[a] * and ** = Significance at the 0.05 and 0.01 levels, respectively.

TABLE VII
Correlation Coefficients Between Protein Content and 1,000-Kernel Weight or Hardness for Individual Varieties

Variety	1,000-Kernel Weight	Time to Grind	Grinding Resistance	Particle Size Index	Near-Infrared Reflectance
Super X	0.266	−0.330	0.003	0.178	0.478
Arina	−0.301	−0.194	0.205	0.678*[a]	0.686*
WWP4258	−0.475	0.007	0.397	−0.388	0.253
Lasko	−0.262	−0.798**	0.653*	−0.891**	0.908**
Bounty Hybrid 200	−0.277	−0.590	0.486	−0.739**	0.700*
Saliente	−0.421	−0.300	0.140	−0.506	0.726*
Ogosta	−0.207	−0.485	−0.061	−0.061	0.812**
Bezostaya	−0.409	−0.047	−0.057	0.268	0.693*
Katya A1	0.027	0.051	−0.171	0.270	0.682*
Bounty Hybrid 100	0.332	−0.197	−0.111	−0.154	0.468
NS 1589A	0.215	−0.189	0.033	−0.176	0.616*
CA 8055	−0.176	0.373	−0.278	0.605*	0.266
Feng Kong 15	−0.161	0.075	−0.598	0.438	0.344
TAW 12399-75	−0.456	−0.199	−0.075	0.343	0.237
Quilamapu 25-77	−0.708*	−0.766**	0.509	−0.802**	0.861**

[a]* and ** = Significance at the 0.05 and 0.01 levels, respectively.

TABLE VIII
Ratios of Estimates of Genetic and Environmental, and Genetic by Environmental Interaction Variance Components for Kernel Weight, Protein Content, and Hardness Parameters

Ratio	1,000-Kernel Weight	Protein Content	Time to Grind	Grinding Resistance	Particle Size Index	Near-Infrared Reflectance
σ_g^2/σ_e^2	0.5	0.3	21.0	2.6	6.1	5.6
σ_g^2/σ_{ge}^2	1.0	1.0	5.5	3.9	2.8	11.8

In summary, variation in hardness of winter wheat grown under widely different environmental conditions was found to be affected mainly by genotype and to a small extent by growth conditions. Thus, wheat hardness can be considered to denote a characteristic of wheat class and variety and may be modified by environmental factors (Symes 1965). Kernel size may modify hardness characteristics to a limited extent. Protein content affected hardness within a variety, rather than across all varieties.

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