Int. Agrophysics, 2001, 15, 191-195

INTERNATIONAL
Agrophysics
www.ipan.lublin.pl/int-agrophysics

Variability in the mechanical properties of Polish wheat cultivars from various regions

J. Sadowska[1]*, J. Budny[1], T. Jeliński[1], J. Fornal[1], and S. Grundas[2]

[1]Institute of Animal Reproduction and Food Research, Polish Academy of Sciences, Tuwima 10, 10-748 Olsztyn, Poland
[2]Institute of Agrophysics, Polish Academy of Sciences, Doświadczalna 4, P.O. Box 201, 20-290 Lublin 27, Poland

Received November 22, 2000; accepted February 6, 2001

A b s t r a c t. Although multi-factorial variance analysis for examined samples showed significant influence of variety and cultivation year on wheat hardness and mechanical resistance only, effect of cultivation region was also confirmed by variance analysis calculated separately for spring and winter wheat. Despite these strong variability in obtained values the cultivar order in homogenous Duncan's groups was constant (except cv. Begra and Jasna) what indicated a strong influence of genetic traits on mechanical resistance. It has been confirmed in results of discriminant analysis which showed good recognition of cultivars according to hardness independently of cultivar and cultivation region and year (Wilks' coefficient = 0.0547). Close correlation (R = 0.7275 at $p \leq 0.05$) between hardness determined in Single Kernel Characteristics System and mechanical resistance expressed by relative fracture force was established.

K e y w o r d s: hardness, mechanical resistance, wheat

INTRODUCTION

Hardness of wheat (*Triticum aestivum*) and durum (*Triticum durum*) grain is still the subject of numerous investigations because of its profound influence on wheat milling properties and end-use. Although the genetic basis for the two major hardness classes (soft and hard) is well known, variability of texture in grain of these groups is relatively large. Although loss of puroindoline *a* or point mutation in puroindoline *b* is found to be conferred hard phenotype [3,7], it has been known that other factors or components must also modify wheat grain hardness. Among these parameters chemical compounds such as lipids [7] or pentosans [3], and endosperm microstructure [2,12], as well as environmental effects [4] are often mentioned. Many methods of hardness determination have been based on grinding or milling resistance of grain and obtained results depended on both rheological properties and basic physical properties such as kernel size and shape and vitreosity. These kernel physical properties differ significantly for particular cultivars in various environmental and cultivation conditions. Mechanical properties of grain have been used in other popular methods for hardness classification but the complex geometric shapes of wheat grains and the presence of a deep crease have complicated the study of their mechanical and rheological properties [8]. Haddad *et al*. [8] suggested that different mechanical behaviour of wheat grain should be interpreted in terms of microstructure and binding between starch granule and protein matrix in wheat endosperm. Therefore, the aim of the present work was to examine variability of grain mechanical properties, and hardness, and interrelations between them for Polish wheat cultivars during two-year cultivation in 8 typical regions.

MATERIAL AND METHODS

Material

Polish cultivars of winter (Begra, Juma, Sakwa, MIB-496) and spring (Torka, Jasna, Santa) wheat (*T. aestivum*) were collected in 1997 and 1998 and classified in the Research Centre for Cultivar Testing in Słupia Wielka in 9-score scale according to Klockiewicz-Kamińska and Brzeziński [9]. Samples collected by the Research Centre for Cultivar Testing contained grain of genetically pure cultivars (confirmed by electrophoresis method), without contaminants, screanings and cereal insects. Among examined cultivars Begra, Jasna, and Torka were classified into A class of quality, Juma, Sakwa, Santa into B class, and MIB-496 into C class. All cultivars were grown in 8 regions of Poland (but not always in the same locations) of different soil-climate conditions and agrotechnical treatment was adjusted to

*Corresponding author's e-mail: jaga@pan.olsztyn.pl

conditions of particular regions. Water content in grain examined ranged from 12 to 13%.

Methods

Resistance for compression was measured with a compression device of Instron 1011 (Instron Ltd, England) at the crosshead speed of 20 mm min^{-1}. Kernels were compressed along width axis and the directions of force action were perpendicular to kernel crease. Fracture force, F (N), and relative force, F_{rel} (N mm^{-1}) at first fracture were accepted as kernel resistance measures. The determinations were made in 30 repetitions.

Technological hardness was measured using Single Kernel Characterization System 4100 (Perten Instruments, USA). About 300 single kernels were individually weighed and crushed during sample measurement. Mean hardness index, weight, size, moisture and their standard deviations were automatically calculated from the single kernel data. Hardness classification was determined from the average hardness of sample and the distribution of single kernel hardness.

The statistical analysis of results was carried out with a Statistica ver. 5 (StatSoft, USA) programme using: variance analysis (Anova), multifactorial analysis of variance (Manova) and discriminant function analysis [5].

RESULTS

Mean values of mechanical resistance parameters of wheat kernels and grain hardness of spring and winter wheat cultivars collected in 8 typical Polish regions (but not always the same location) are presented in Table 1. Results of multifactorial variance analysis (Manova), in which all affecting factors were considered, showed statistically significant influence of cultivar and cultivation year on mechanical properties of grain and hardness of all wheat samples (Table 2). Despite strong varietal and environmental variability, results of Duncan Multiple Range Test (DMRT), used as the final calculation in Anova analysis, allowed finding the same order of homogenous groups of hardness indices in both years (Table 1). Hardness indices were lower in 1997 than in 1998 but always all spring wheat cultivars were classified as very hard, winter wheat cultivars Juma and Begra as hard, and MIB-496 as soft wheat in both years. Similar results were obtained for compression resistance of kernels (fracture, F, and relative, F_{rel}, forces) except those for Begra wheat. Begra was always SKCS classified as hard wheat but

Table 1. Mechanical resistance and hardness of grain of cultivars harvested in 1997 and 1998

Cultivars	F (N)	F_{rel} (N mm^{-1})	Hardness index	F (N)	F_{rel} (N mm^{-1})	Hardness index
		1997			1998	
			Spring wheat			
Jasna	238.9^{b}	69.94^{b}	75.4^{c}	249.9^{d}	55.10^{bc}	75.4^{c}
Torka	253.0^{c}	73.40^{b}	72.8^{c}	217.9^{c}	59.94^{c}	71.4^{c}
Santa	261.5^{c}	75.80^{b}	73.7^{c}	265.8^{d}	52.76^{b}	74.3^{c}
			Winter wheat			
Begra	256.5^{c}	71.89^{b}	64.7^{b}	221.0^{c}	60.25^{c}	58.6^{b}
Juma	221.3^{b}	64.08^{b}	72.6^{c}	185.8^{b}	51.22^{b}	64.4^{b}
Sakwa	230.7^{b}	67.01^{b}	64.1^{b}	186.4^{b}	63.30^{c}	60.9^{b}
MIB-496	162.0^{a}	46.56^{a}	21.2^{a}	155.3^{a}	42.07^{a}	24.2^{a}

Values are means of 8 samples (each sample in 30 determinations) from various Polish regions. The same superscripts in the column denote homogenous groups from DMRT.

Table 2. Variability of grain mechanical resistance in all the examined wheat cultivars estimated with Manova

Factors	Wilks' λ	Rao's R	Degree of freedom 1	Degree of freedom 2	Probability level
Year (I)	0.8389*	28.5392*	3*	446*	0.0000*
Cultivar (II)	0.5723*	15.2935*	18*	1261*	0.0000*
Interaction:					
(I) × (II)	0.8651*	3.6852*	18*	1261*	0.0000*

* statistically significant at $p \leq 0.05$.

kernel compression resistance was considerably lower in 1998 than in 1997, what resulted in its different position in homogenous group in the Duncan's test.

Samples of these cultivars in both years were collected in 8 regions of Poland but not always in the same locations. Then, the next statistical analysis of hardness and mechanical resistance variability has been limited for samples of spring wheat (Table 3) from 4 and winter wheat (Table 4) from 2 the same locations, i.e., cultivated at the same environmental conditions. Variance analysis (Manova) was done in separated groups of spring and winter cultivars because of traditional differences of quality parameter values between both wheat forms. Results of Manova, confirmed influence of both above-mentioned factors and showed statistically significant effect of cultivation region on kernel fracture forces, F and F_{rel}, and wheat hardness (Tables 5 and 6). Despite strong environmental effect which has been manifested by significant differences in determined values

T a b l e 3. Mechanical resistance and hardness of wheat grain of spring cultivars harvested in 1997 and 1998 in the same locations

Location	F (N)	F_{rel} (N mm^{-1})	Hardness index	F (N)	F_{rel} (N mm^{-1})	Hardness index
	1997			1998		
			Jasna			
Bezek	221.4	65.4	74.6	221.4	65.4	74.3
Przecław	209.4	62.2	72.9	209.4	62.2	71.7
Rychliki	232.6	69.1	77.3	232.6	69.1	76.3
Seroczyn	232.2	67.7	76.1	232.2	67.7	78.5
			Torka			
Bezek	242.1	69.8	72.4	242.1	69.8	72.1
Przecław	252.9	73.1	69.2	252.9	73.1	80.3
Rychliki	245.0	71.1	71.5	245.0	71.1	70.0
Seroczyn	248.0	71.8	72.3	248.0	71.8	73.1
			Santa			
Bezek	263.4	76.5	76.5	263.4	76.5	75.3
Przecław	215.2	63.3	72.0	215.2	63.3	73.6
Rychliki	261.7	75.6	68.5	261.7	75.6	76.3
Seroczyn	274.0	79.5	72.2	274.0	79.4	79.6

Values are means of respective number of determinations (see Material and Methods).

T a b l e 4. Mechanical resistance and hardness of wheat grain of winter cultivars harvested in 1997 and 1998 in the same locations

Location	F (N)	F_{rel} (N mm^{-1})	Hardness index	F (N)	F_{rel} (N mm^{-1})	Hardness index
	1997			1998		
			Begra			
Krzyżewo	240.6	68.9	65.9	206.8	57.1	62.7
Słupia Wlk.	281.8	77.3	64.2	223.7	61.3	64.1
			Juma			
Krzyżewo	208.0	60.1	71.9	173.9	47.4	68.6
Słupia Wlk.	234.5	67.6	72.8	194.7	54.2	72.7
			Sakwa			
Krzyżewo	232.0	67.4	65.1	182.7	50.0	66.7
Słupia Wlk.	249.8	72.1	68.8	218.0	58.1	69.3
			MIB-496			
Krzyżewo	148.0	43.5	20.6	136.5	40.3	31.6
Słupia Wlk.	154.1	44.0	21.0	155.3	41.3	32.5

Explanations as in Table 3.

T a b l e 5. Variability of grain mechanical resistance for spring wheat cultivars estimated with Manova

Factors	Wilks' λ	Rao's R	Degree of freedom 1	Degree of freedom 2	Probability level
Year (I)	0.4913*	85.5866*	3*	248*	0.0000*
Place (II)	0.9134*	2.5444*	9*	603*	0.0071*
Cultivar (III)	0.8580*	6.5765*	6*	496*	0.0000*
Interactions:					
(I) × (II)	0.8748*	3.7895*	9*	603*	0.0001*
(I) × (III)	0.8820*	5.3556*	6*	496*	0.0000*
(II) × (III)	0.8917	1.6125	18	701	0.0513
(I) × (II)×(III)	0.8528*	2.2576*	18*	701*	0.0021*

* statistically significant at $p \leq 0.05$.

T a b l e 6. Variability of grain mechanical resistance for winter wheat cultivars estimated with Manova

Factors	Wilks' λ	Rao's R	Degree of freedom 1	Degree of freedom 2	Probability level
Year (I)	0.7872*	15.3156*	3*	170*	0.0000*
Place (II)	0.9157*	5.2124*	9*	170*	0.0018*
Cultivar (III)	0.5104*	14.6342*	6*	413*	0.0000*
Interactions:					
(I) × (II)	0.9749	1.4589	3	170	0.2276
(I) × (III)	0.8631*	2.8678*	9*	413*	0.0027*
(II) × (III)	0.9315	1.3597	9	413	0.2044
(I) × (II)×(III)	0.9635	0.7071	9	413	0.7024

* statistically significant at $p \leq 0.05$.

of examined parameters, strong and independent genetic effect on hardness and mechanical properties of wheat grain was confirmed.

Because mechanical properties and hardness were influenced by many factors (cultivar, region, location, and year of cultivation, and different market class) discriminant analysis with canonical analysis, using of which allows easy and simultaneously present multifactorial effects on few parameters, was also used for separation of the samples into discrete hard and soft classes. In this analysis cultivar as grouping variable and mechanical resistance parameters and hardness index as independent variables were accepted. Discrimination of different hardness cultivars (with very low Wilks' coefficient, i.e., 0.0547) was presented in Fig. 1. Extremely soft cultivar MIB-469 is clearly separated but other cultivars, which are hard and very hard, are gathered into one common group. Accurate discrimination of hard and very hard cultivars examined was very difficult despite statistically significant differences in final average hardness indices. Statistically confirmed high diversification of cultivar samples from various locations, such as hardness indices for Torka (Table 3) from Przecław and Bezek (69.2 and 72.8, respectively) or Santa (Table 3) from Rychliki and Bezek (68.5 and 76.5, respectively), was probably the main reason of such result.

The knowledge of environmental variability range of mechanical properties allowed predicting milling behaviour and, consequently, end-use of particular cultivars in respective hardness wheat group because of relationships between hardness indices and same breadmaking quality traits such as flour yield and farinograph water absorption [13]. Good correlations between both hardness index and compression resistance measures and some grain quality parameters such

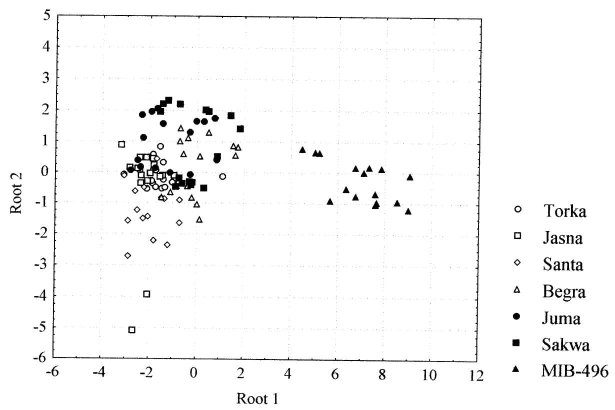

Fig. 1. Discrimination of SKCS hardness groups among the examined wheat cultivars (Wilks' coefficient = 0.0547).

as sedimentation ($R^2 = 0.6371$) and farinograph water absorption (R^2=0.7298) for examined Polish cultivars were also confirmed. Ohm *et al*. [11] found also for USA hard winter wheat cultivars that SKCS data were significantly correlated to some conventional wheat quality parameters such as test weight, kernel density, kernel sizing and flour yield.

Despite wide spreading of such popular method as NIR or SKCS the relations between wheat hardness and grain mechanical properties are still studied and results obtained are used for developing or/and improving of new methods of hardness recognition [1]. Results of mechanical or milling properties determination are often compared to results of NIR or SKCS methods. While Glenn *et al*. [6] established good correlation between NIR reflectance values and stress -strain properties in compression for soft, hard and durum wheat endosperm then Morris *et al*. [10] presented good correlation between milling properties and NIR- and SKSC -determined hardness. Also in the present work accuracy of relation between results of used compression test and SKCS hardness indices was controlled. Close correlations between hardness index and both mechanical resistance measures, i.e., fracture force, F, and relative fracture force, F_{rel}, were found. Correlation coefficients for the relationship between hardness index and F_{rel} were 0.8314, 0.7230, and 0.7275 (at $p \leq 0.05$) in groups of all examined wheat samples from 1997, 1998, and both years, respectively. Also good correlation, expressed by $R^2 = 0.7183$ at $p \leq 0.05$, for the relationship between fracture force and hardness index was obtained in group of all samples from both years. These values of coefficients confirmed very close relation between accepted measures of compression resistance and hardness in grain, independently of wheat cultivar and form. Then, obtained correlations showed the used method of compression resistance determination to be useful for recognition of grain mechanical properties diversification in wheat cultivars of the same hardness classification.

CONCLUSIONS

Statistical analysis of obtained results allowed confirming dominant effect of genetic traits of Polish wheat cultivars on their hardness, independently of statistically significant influences of region and year of cultivation. Yet, location and year of cultivation region influence strongly mechanical properties of grain resistance of cultivars of the same hardness.

REFERENCES

1. **Anjum F.M. and Walker C.E., 1991.** Review on the significance of starch and protein to wheat kernel hardness. J. Sci. Food Agric., 56, 1-13.
2. **Bechtel D.B. and Wilson J.D., 1997.** Ultrastructure of developing hard and soft red winter wheats as after air- and freeze -drying and its relation to endosperm texture. Cereal.Chem., 74, 235-241.
3. **Bedge A.D. and Morris C.F., 2000.** Relationship among grain hardness, pentosan fractions, and end-use quality of wheat. Cereal Chem., 77, 241-247.
4. **Bergman C.J., Gualberto D.G., Campbell K.G., Sorrels M.E., and Finney P.L., 1998.** Genotype and environmental effects on wheat quality traits in a population derived from a soft by hard cross. Cereal Chem., 75, 729-737.
5. General Convention and Statistics, **1995.** In: Statistica for Windows (Ed. Statsoft Inc.). I, III, 2nd edition.
6. **Glenn G.M., Younce F.L., and Pitts M.J., 1991**. Fundamental physical properties characterizing the hardness of wheat endosperm. J. Cereal Sci., 13, 179-194.
7. **Greenblatt G.A., Bettge A.D., and Morris C.F., 1995**. Relationship between endosperm texture and the occurrence of friabilin and bound polar lipids on wheat starch. Cereal Chem., 72, 172-176.
8. **Haddad Y., Benet J.C., and Abecassis J., 1998.** A rapid general method for appraising the rheological properties of starchy endosperm of cereal grain. Cereal Chem., 75, 673-676.
9. **Klockiewicz-Kamińska E. and Brzeziński J.W., 1998**. Method of evaluation and quality classification of wheat cultivars (in Polish). Przegląd Zbożowo-Młynarski, XLII(1), 2-6.
10. **Morris C.F., DeMacon V.L., and Giroux M.J., 1999.** Wheat grain hardness among chromosome 5D homozygous recombinant substitution lines using different methods of measurement. Cereal Chem., 76, 249-254.
11. **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, 151-161.
12. **Sadowska J., Jeliński T., and Fornal J., 1999**. Comparison of microstructure of vitreous and mealy kernels of hard and soft wheat. Polish J. Food Nutr. Sci., 8/49, 3-15.
13. **Vida G. and Bedö Z., 1999.** Use of principal component analysis in correlation studies between kernel hardness and other breadmaking quality traits in winter aestivum and durum wheat genotypes. Növénytermelés, 48, 33-42.