INTERRELATIONS BETWEEN SELECTED PHYSICAL AND TECHNOLOGICAL PROPERTIES OF WHEAT GRAIN

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A b s t r a c t

The aim of this work was to determine selected physical properties of wheat grain which are of significance in transport, separation and storage processes as well as to assess the correlations between them and the technological properties of wheat.

The grain of two wheat varieties (Eta and Banti) which are popular in Poland was used as research material. The tested properties included: vitreousness, test weight, thousand kernel weight, true density, geometric parameters (thickness, width, length), static friction coefficient of wheat kernels against steel and glass, protein and gluten content and the Zeleny sedimentation value.

The grain of the investigated wheat varieties differed in most physical and technological properties. The average length, width and thickness kernels were 6.31 mm, 3.31 mm and 3.03 mm for vr. Banti and 6.05 mm, 3.33 mm, 2.97 mm for vr. Eta. The test weight ranged from 75.68 (Banti) to 78.29 kg · hl^{-1} (Eta), the thousand kernel weight from 36.3 (Eta) to 39.2 g (Banti) and vitreousness was from 13 (Banti) to 81% (Eta).

A correlation between the physical and technological properties of wheat was found. The vitreousness of the wheat grain was positively correlated with protein content (the correlation indices were 0.58 for Banti variety and 0.67 for Eta) and the volume was positively correlated with the true density of grain (r = -0.69 Eta, r = -0.64 Banti). The static coefficient of the friction of wheat grains of two structural materials (metal or glass) is insufficient to predict its technological properties.

Symbol list
m_1 – pycnometer mass with toluene [g],
m_2 – pycnometer mass with toluene and grain on a scale [g],
m_3 – pycnometer mass with toluene and grain in pycnometer [g],
ρ_{tl} – toluene density [g · cm^{-3}],
ρ_g – single grain specific mass [g · cm^{-3}],
V_g – grain volume [mm^3],
V – variability [%],

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L   – length [mm],
W   – width [mm],
T   – thickness [mm],
TW   – test weight [kg · hl^{-3}],
TKW– thousand kernel weight [g],
KV   – kernel virtuousness [%],
PC   – protein content [%],
TD   – true density [g · cm^{-3}],
GC   – gluten content [%],
SV   – Zeleny sedimentation value [ml].

Introduction

In transport, the separation and storage processes of the physical properties of grain mass and single kernels are of great significance. Knowledge of important physical properties such as mass density, test weight, internal angle of friction and static coefficient of friction is necessary to design various separating, handling, storing systems (HORABIK 2001). The static coefficient of friction is used to determine the angle at which chutes must be positioned in order to achieve a consistent flow of materials through the chute. Single grain properties, such as shape, linear sizes and volume, should also be considered for optimizing technological processes (GRUNDAS 2004, KHEIRALIPOUR et al. 2008, MOHSENIN 1986). Grain geometrical properties are of special significance during the separation and removal of impurities. Cereal transport, purification, drying and storage are operations in which grain quality changes may occur (MARKOWSKI et al. 2006, AL-MAHASNEH, RABABAH 2007, MARKOWSKI et al. 2007, SYPUŁA, DADRZYŃSKA 2008).

Grain quality is characterized based on indicators of storage durability and technological value such as: moisture, falling number, gluten and protein content and the Zeleny sedimentation value (DELWICHE 1998, RACHOŃ et al. 2011). Since grain processing requires increasingly stringent standards for raw material quality, it has become imperative to identify the correlations between physical and technological properties to develop better methods for grain quality assessment (ZAPOTOCZNY 2009). Knowledge of these correlations may find application in designing and monitoring technological processes in the cereal-milling industry (DZIKI, LASKOWSKI 2005).

The physical properties of wheat grain at different moisture levels were tested by TABATABAEEFAR (2003), AL-MAHASNEH, RABABAH (2007), KARIMI et al. (2009). An increasing moisture content was found to increase axial dimensions, mass of 1000 kernels, kernel volume and static friction coefficient, while decreasing bulk density, true density and porosity.

The correlation between the physical and technological properties of cereal grain was tested by DZIKI, LASKOWSKI (2002), who found a significant correla-

tion between the test weight and grain shape factor. The correlations between physical and technological properties were also investigated by RÓŻYŁO, LASKOWSKI (2007a, 2007b), who found correlations between hardness index and grain squeeze strength for durability threshold and Zeleny sedimentation value, protein and gluten content. The protein content of the grain was significantly correlated to the hardness of the grain. Thus, vitreous kernels are usually harder and have a higher protein content than the non-vitreous (starchy) kernels (SYMONS et al. 2003). A positive correlation between hardness index and protein content was also observed by RÓŻYŁO et al. (2003) and KONOPKA et al. (2005).

Wheat grain physical properties are essential in transport, separation and storage processes. These properties include specific density, bulk density and friction angle against construction materials. Knowledge of the correlations between physical and technological properties of wheat grain is important for designing and optimizing the processing stages. There is insufficient information on this subject in the literature.

The aim of the study was to determine selected physical and technological properties of wheat grain and investigate the correlations between them.

Materials and Methods

The kernels of spring wheat varieties (Eta and Banti) used in this study were procured from the Experimental Station of the University of Warmia and Mazury in Olsztyn, in north- eastern Poland (Tomaszkowo; 53°73'N 20°41'E).

The sample was cleaned and pooled together to obtain approximately 20 kg samples of each variety. The initial moisture content of seeds was determined by ICC Standard No. 110/1. The physical properties of wheat grain were determined with a moisture content in the range of 8.2–9.9%. All measurements were taken using at least 30 replications.

Thousand kernel weight (TKW) was measured for each variety using an electronic kernel counter (Kernel Counter LN S 50A, UNITRA CEMI) and an electronic balance WPE 120 Radwag (PN-68/R-74017). The grain test weight was also determined (PN-ISO 7971-2:1998). The vitreousness of grain was evaluated based on an analysis of the cross-sections of kernels and expressed as the percentage of vitreous kernels in a sample of 50 elements. The partially vitreous kernels were classified as semi-vitreous kernels and their number in the sample was multiplied by 0.5 (PN-70/R-74008). The static friction coefficient was determined with respect to different surfaces: steel and glass. The sample was then placed on a slab and the inclination angle was slowly increased. At the moment of movement, the angle was read from the scale and

the friction coefficient was calculated according to the following formula (SHARMA et al. 2011):

$$\mu = \tan(\alpha) \tag{1}$$

where μ is the coefficient of friction and α is the angle of tilt in degrees.

The kernels were measured along the three principal axial dimensions, i.e. length (L), width (W) and thickness (T), using an electronic caliper (Limit company) ($\Delta = \pm 0.05$ mm). True density and volume were measured for singular kernels using a 25 cm^3 volume pycnometer and an analytical balance (AS 110/C/2 Radwag). The true density was determined using the toluene displacement method in order to avoid absorption of water during the experiment (JHA 1999, COSKUNER, KARABABA 2007). The true density and volume measurements were taken at 20°C. The results of measurements of pycnometer mass with toluene (m_1), pycnometer mass with toluene and grain on a weighing pan (m_2), and pycnometer mass with toluene and grain in pycnometer (m_3) were used to calculate the grain true density according to the following formula (2):

$$\rho_z = \frac{m_2 - m_1}{m_2 - m_3} \tag{2}$$

Grain volume was calculated as:

$$V = \frac{m_2 - m_3}{\rho_{tl}} \tag{3}$$

Kernel density measurement was performed in 100 replications for each variety and the technological properties of the grain were also determined. Protein and gluten content and Zeleny sedimentation value measurements were taken with the near-infrared method (NIR) on an Inframatic 8100 apparatus.

Statistical analysis of the results was performed and a variation analysis was made with STATISTICA for Windows v. 10 (StatSoft Inc.) software. The significance of differences was determined with a Tukey test. Linear correlation coefficients were calculated along with the variability coefficient as a standard deviation and the average value quotient. Statistical hypothesis were tested at the significance level $\alpha = 0.05$.

Results and Discussion

The kernels of each wheat variety differed significantly for most of the physical and technological properties (Table 1). The test weight, an important parameter of wheat technological value, was significantly correlated with wheat variety.

Table 1

Physical and technological properties of spring wheat grain

Feature		BANTI				ETA			
		mean	min.	max	V [%]	mean	min.	max	V [%]
TW [kg · hl^{-1}]		75.68[a]	74.4	76.8	0.8	78.29[b]	76.8	80.0	1.0
Static friction coefficient of wheat kernels [–]	steel	0.42[a]	0.40	0.47	3.1	0.43[b]	0.41	0.46	2,2
	glass	0.27[a]	0.25	0.29	2.7	0.28[b]	0.26	0.30	2.4
TKW [g]		39.2[b]	35.75	45.64	4.7	36.3[a]	33.42	37.96	2.8
KV [%]		13[a]	7	20	23.4	81[b]	61	90	8.9
L [mm]		6.31[b]	5.7	7.15	5.9	6.05[a]	5.5	6.7	4.1
W [mm]		3.31[a]	2.80	3.80	8.2	3.33[a]	2.85	3.85	6.3
T [mm]		3.03[a]	2.55	3.65	7.9	2.97[a]	2.60	3.25	5.1
V_g [mm^3]		36.8[a]	22.7	57.8	26.2	34.8[a]	23.0	57.7	24.5
TD [g · cm^{-3}]		1.250[a]	1.038	1.731	16.8	1.281[a]	1.040	1.739	17.9
PC [%]		13.1[a]	12.3	13.9	4.0	13.6[b]	11.5	14.6	5.9
GC [%]		27[a]	25	28	2.5	28[b]	23	30	4.5
SV [ml]		19[a]	10	28	27.6	42[b]	26	61	20.0

a, b – differences of values in lines marked with the same letters are insignificant at $\alpha = 0.05$.

The static coefficient of friction is important for designing storage bins, hoppers, pneumatic conveying systems, threshers, forage harvesters, etc. (SHARMA et al. 2011). The static coefficient of friction, which affects the design of the processing machine, was determined based on two different contacting materials (steel sheet, glass). The static coefficient of friction is higher for steel sheet than for glass. It was demonstrated that the static coefficient of friction of wheat kernels on two surfaces was higher for wheat Eta variety (0.43 steel sheet; 0.28 glass). KHEIRALIPOUR et al. (2008) showed that this coefficient of wheat grains increased linearly against the surface of three structural materials (0.33–0.4 for glass, 0.46–0.55 for plywood and 0.34–0.54 for galvanized iron).

Thousand kernel weight is one of the basic indices of sowing potential and commodity quality of cereals and indicates the ripeness of grain. The statistical evaluation indicated the statistically significant influence of the variety and

a Banti vr. (39.2) had the highest thousand kernel weight of all the analyzed varieties.

The average length, width and thickness kernels were 6.31 mm, 3.31 mm and 3.03 mm for vr. Banti and 6.05 mm, 3.33 mm, 2.97 mm for vr. Eta. Significant differences were observed in kernel length between wheat varieties. The true density value of wheat vr. Eta (1.281 g · cm³) was higher than that of wheat vr. Banti (1.250 g · cm⁻³). Grain was characterized by a high variability of volume (V = 24.5% for Eta and 26.2% for Banti vr.) and Zeleny sedimentation value (respectively V = 20% and 27.6%).

Only such geometrical parameters as width, thickness and volume were comparable for each variety. There were no significant differences in the true density of kernels between the analyzed wheat varieties.

An analysis of the obtained results found a correlation between the physical and technological properties of wheat grain. The vitreousness of the investigated samples was between 13% and 81%. This property is dependent on protein content (Table 2). The correlation indices were 0.58 for Banti vr. and 0.67 for Eta vr. A significant positive correlation of grain protein content with vitreousness was reported by EL-KHAYAT et al. (2003), EL-KHAYAT et al. (2006), MARTINEZ et al. (2005), FIGIEL et al. (2011), RÓŻYŁO, LASKOWSKI (2007a). It was found that wheat of higher vitreousness also had a higher protein content.

The influence of protein content on other physical properties was not as clear as in the case of virtuousness. There were weak negative correlations between protein content and the test weight of wheat (r = -0.39), but only for the Eta variety. A significant negative correlation between grain protein content and test weight was reported by MATSUO and DEXTER (1980) and RHARRABTI et al. (2003), while a positive correlation was reported by SCHULER et al. (1995). A significant positive correlation was observed between grain protein content and the static coefficient of friction of wheat kernels on glass (r = 0.54) for vr. Banti. For vitreous variety (Eta), as in other studies (RÓŻYŁO and LASKOWSKI 2007a), a significant correlation between virtuousness and gluten content was observed (r = 0.50).

The relationship between Zeleny sedimentation value and grain physical properties is unclear for all varieties. A correlation between Zeleny sedimentation value and the static coefficient of friction of wheat kernels on glass (r = -0.55) and vitreousness for the Banti variety (r = -0.61) was observed. For Eta vr., a correlation between sedimentation volume and test weight (r = 0.50) and thousand kernel weight (r = 0.39) was observed.

The correlations between the physical properties of investigated grain wheat types are shown in Table 2. A statistical analysis of the results showed a significant correlation between test weight and the static friction coefficient of wheat kernels on glass. The correlation coefficients were r = -0.46 and

Table 2

Values of linear correlation coefficients between physical and technological properties of wheat

Variety	Feature		PC	GC	SV	Static friction coefficient of wheat kernels		TKW	KV	TD	W	T	V_g
						steel	glass						
Banti	TW		-0.18	-0.02	0.17	-0.20	-0.46*	0.73*	-0.38*	-0.36			
	Static friction coefficient of wheat kernels	steel	-0.02	0.02	-0.05		0.23	-0.06	0.05	-0.02			
		glass	0.54*	0.25	-0.55*			-0.55*	0.56*	0.13			
	TKW		-0.27	-0.16	0.19				-0.35	-0.44*			
	KV		0.58*	0.14	-0.61*					0.15			
	TD		0.06	0.05	0.11						0.06	-0.13	-0.64*
	L										0.58*	0.68*	0.59*
	W											0.56*	0.51*
	T												0.66*
Eta	TW		-0.39*	0.01	0.50*	0.13	-0.56*	0.42*	-0.26	0.17			
	Static friction coefficient of wheat kernels	steel	0.09	0.27	0.31		-0.07	-0.16	0.45*	0.25			
		glass	0.19	-0.11	-0.33			-0.50*	0.19	0.05			
	TKW		-0.28	0.01	0.39*				-0.41*	-0.13			
	KV		0.67*	0.50*	-0.15					0.12			
	TD		-0.11	-0.04	0.22						0.06	-0.04	-0.69*
	L										0.16	0.41*	0.34
	W											0.39*	0.16
	T												0.38*

* Significant correlation coefficients at $p < 0.05$

r = -0.56 for Banti and Eta varieties, respectively. With the increase in test weight, the static coefficient of friction on glass decreased. The basic factors that affect the test weight of wheat are kernel size and shape and kernel density (POMERANZ 1964). Positive correlations between test weight and thousand kernel weight were also observed. Stronger correlations were demonstrated for a variety of larger grains (r = 0.73). A correlation between thousand kernel weight and static coefficient of friction for glass was also found (the correlation coefficients were -0.55 and -0.50 for Banti and Eta varieties, respectively).

A comparison of the physical properties for investigated cereal grains indicates that correlation coefficients values are relatively small, which is not good for determining regression equations with a high degree of explained variability.

A correlation between volume and true density of grain (r = -0.69 Eta, r = -0.64 Banti) was also found (Table 2) as well as between basic linear sizes of wheat grain. These correlations were not as significant as those reported by other authors (HEBDA, MICEK 2005, 2007). The strongest correlation was calculated for grain length and thickness (r = 0.68 and r = 0.41 for vr. Banti and vr. Eta respectively). HEBDA and MICEK (2005) found the strongest correlation between the length and width of the grains.

Conclusions

The studied wheat varieties differed in most physical and technological properties. An analysis of the obtained results found correlations between the physical features and technological properties of the grain:

1. Banti variety wheat had significantly longer grains than Eta variety wheat.

2. Grain vitreousness is positively correlated with grain protein content.

3. The static friction coefficients for glass and steel are not useful for determining grain technological properties.

4. Test weight increased linearly with a thousand kernel weight increase. Stronger correlations were found for a variety of larger grains.

5. The higher the volume of wheat grain for Banti and Eta varieties is, the lower the true density will be.

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