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Influence of moisture content on the wheat kernel mechanical properties determined on the basis of shear test

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A b s t r a c t. The results of moisture content impact on the wheat kernel mechanical properties determined on the basis of shear test are presented. Four common wheat cultivars differing in kernel hardness were used for tests. The samples of wheat were tempered by adding water or by drying to adjust moisture content. The individual kernels were placed in the hole of a special accessory and cut down by using universal testing machine ZWICK Z020/TN2S. The increase in moisture content caused linear decrease of the shear force and force-to-deformation ratio. The relation between the moisture content and the deformation up to the failure of the kernel was non-linear. The highest changes of deformation were observed at the moisture of kernels ranged from 16 to 20%. When the moisture of kernels was 10 and 12% the significant higher values of shear force were obtained for hard wheat varieties than for soft ones. The moisture content has no significant influence on the shear energy. This parameter average ranged from 11.7 to 14.0 mJ.

K e y w o r d s: wheat, mechanical properties, shear, moisture

INTRODUCTION

The knowledge of the mechanical properties of cereal kernels is useful during harvesting, storing and processing. There are many methods for assessing these properties, especially for wheat kernels. The mechanical properties of wheat kernels concerning both evaluation of whole single kernels (Fornal *et al.*, 1999) and the mass of kernels (Molenda *et al.,* 1998), parts of the endosperm (Haddad *et al.*, 2001), bran (Glenn and Johnston, 1992) and bran layers (Greffeuille *et al.,* 2007). Such parameters as hardness, Young modulus, compression strength and stiffness are very often determined. However, the technological indices of wheat hardness have the most practical application in the wheat processing (Campbell *et al.*, 2007; Jirsa *et al.,* 2008; Williams and Sobering, 1986). Hardness is a primary determinant of milling, end-use and baking quality of wheat (Jirsa *et al.*, 2008). Beside of this, parameters determined on the basis of compression test and shear test are used for description of cereal grinding process (Dziki, 2008; Laskowski *et al.*, 2005).

The mechanical properties of wheat kernels are highly heritable trait (Greffeuille *et al.,* 2006; Morris, 2002; Pomeranz and Williams, 1990). However, they can be affected by the environmental conditions (Pomeranz *et al.,* 1985). The moisture content has also significant influence on kernel mechanical properties. Generally all strength properties of kernels decreased in magnitude with increasing moisture contents (Zoerb and Hall, 1960). Thus, comparison of individual varieties should be made if samples are equilibrated to similar moisture content. It is also important to mention that extent of the changes differs between bran and endosperm. When the moisture content of wheat endosperm increases, the compressive strength and elasticity decrease, and endosperm became more brittle, especially for hard wheats (Glenn *et al*., 1991). However, the bran becomes more compliant and resilient with increasing moisture content (Mabille *et al*., 2001), especially an increase in ultimate strain and in a decrease in elastic stress of brain is observed (Hemery *et al*., 2010). This relation is commonly used during wheat flour milling. The weaker endosperm up into the small pieces during grinding break while the bran is more resistant to breakage and gives larger particles which can be easily separated by sieving (Posner and Hibbs, 1997). Beside of these moistening and drying of wheat kernels cause many of internal cracks of endosperm and in consequence the Young modulus, compressive strength and hardness decreases (Woźniak,

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2001; Woźniak and Styk, 1996). The similar tendency was observed for barley kernels (Woźniak, 2004). An increase of water content during sprouting of wheat caused also many biochemical and physical changes in kernel, especially enzymatic activity increases (Kettlewell, 1999), hardness decreases (Miś and Grundas, 2004a, b) and also internal cross cracks of endosperm are observed (Neethirajan *et al.,* 2007). These changes cause a decrease of specific grinding energy (Dziki and Laskowski, 2010). During milling, first-break rolls exert more shearing forces through the differential rotation of fluted rolls and some compressive force from the roll gap (Edwards *et al*., 2007).

The aim of this study is to investigate the influence of wheat moisture content on the shear properties of wheat kernel.

MATERIALS AND METHODS

Investigations were carried out on four Polish winter wheat cultivars (*Triticum aestivum*, ssp. *vulgare*) Torka, Kaja, Emika, and Zorza collected in the year 2008. According the classification proposed by Williams (2000) the kernels of cv. Torka and Kaja, in relation to the hardness index (HI) were classified as hard (HI = 79 and 66, respectively), whereas the kernels of cv. Emika and Zorza – as soft and very soft (HI = 39 and 20, respectively). In order to minimize the influence of kernel size on the results of the shear test, the samples of individual cultivars were sorted by using a Steinecker-Vogl sorter and the same range of kernel thickness, from 2.9 to 3.1 mm was taken for the investigation. The samples of wheat were tempered by adding water or by drying at 35°C to adjust moisture contents to: 10, 12, 14, 16, 18, and 20% (w.b.) and storing for 48 h. The moisture content was evaluated according to the AACC, Approved Method 39-70A (1990). The shear test was carried out on a Zwick Z020/TN2S universal testing machine equipped with a measuring head of operation range up till 500 N. The individual kernels were placed in the hole of special accessory – 3.5 mm in diameter (Fig. 1). The immovable plate of accessory had the conical end of the hole, blocked the position of kernel. The kernel was shared between two holes of plates. The movable plate was loaded by upper beam, with a constant speed of 10 mm min^{-1}. The changes in the loading force in relation to the kernels deformation were recorded by means of a computer kit. On the basis of the obtained crushing curves (Fig. 1c), the shear force (F), deformation up to the failure of the kernel (l) and shear energy (E_S) were determined. The force-to-deformation ratio was also calculated as a ratio of F to l.

All the experiments were done in 20 repetitions for each kernel moisture level. The obtained data were subjected to statistical analysis. The evaluations were analyzed for variance analysis. Statistical differences between the treatment groups were estimated by Tukey test. All statistical tests were carried out at significance level of $\alpha = 0.05$.

RESULTS AND DISCUSSION

The results of shear force (F) are shown in the Fig. 2. The increase of kernel moisture from 10 to 20% caused about two times decrease of F for all tested cultivars (average from 62 to 33 N). However, for hard wheat Torka and Kaja the decrease of F was higher (52 and 59%, respectively) then for soft cultivars Emika and Zorza (37 and 42%, respectively). Delwiche (2000) showed, that hard wheat endosperm compressive strength is to be much more sensitive to moisture content than soft wheat endosperm. The obtained data confirmed this tendency also for F. The values of F ranged from 30 N (cv. Kaja, 20% kernel moisture) to 71 N (cv. Torka, 10% kernel moisture). There are no statistical differences between average values of F for hard and soft cultivars when the kernel moisture was 14% and higher. For lower moisture (10 and 12%) the significant higher values of F were noted for hard wheat cultivars. Obuchowski and Bushuk (1980) showed that moisture content affects different hardness tests and different cultivars to differing extents, but increasing moisture generally led to reduced hardness. The Pearson coefficients of correlation between F and kernel moisture content were statistically significant

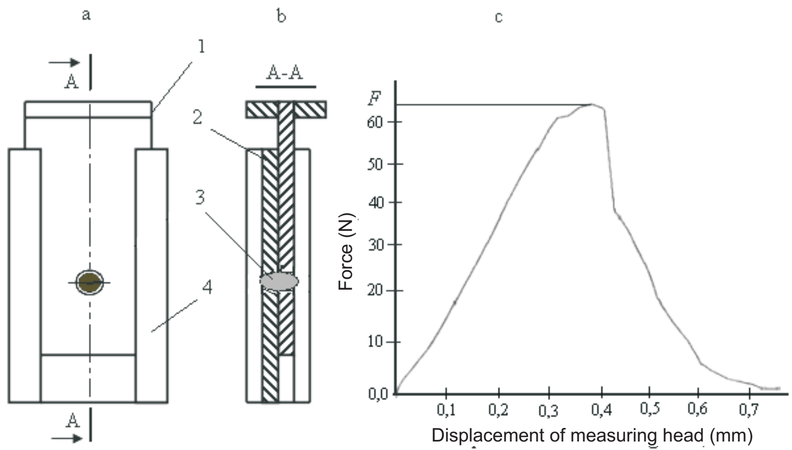

Fig. 1. The accessory for shearing of wheat kernel: a – the front view (1 – the movable plate, 4 – the housing), b – the cross section (2 – the motion less part, 3 – the kernel positioned in the hole), c – the example of shear curve (F – the shear force).

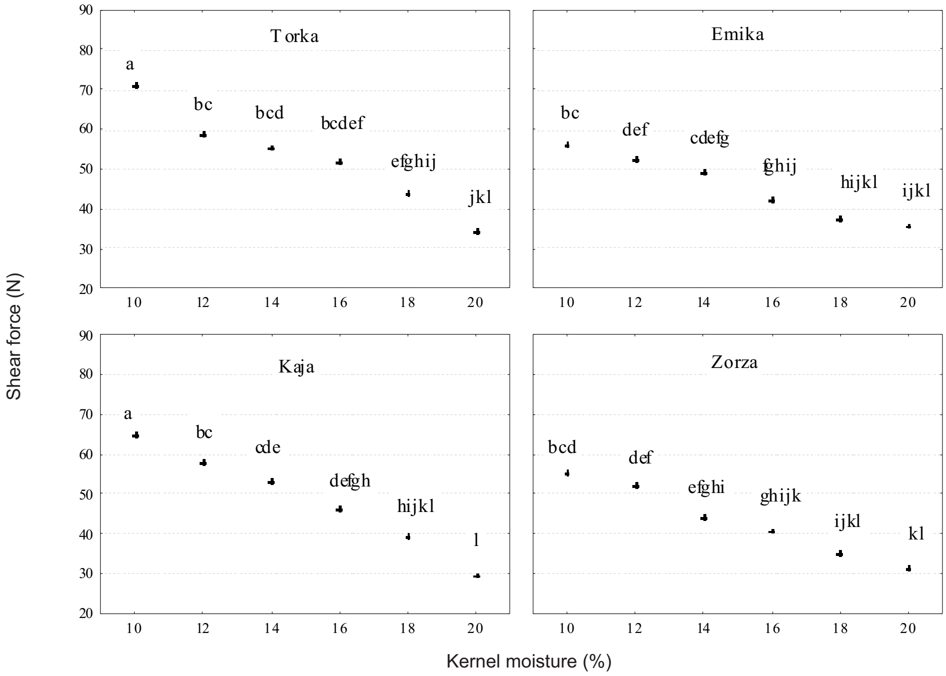

Fig. 2. The changes of shear force in relation to the kernel moisture content; (symbols a-k represent homogenous groups at the 95% level).

($p < 0.05$) and exceed -0.98 for each cultivar. Dziki and Laskowski (2006) showed that kernel virtuousness has also a significant influence on the shear force. They obtained the highest values of F for vitreous kernels. However the values of F obtained for mealy and partially vitreous kernels were not statistically different. Beside of this Dziki (2008) found positive correlations between F and grinding energy indices of wheat kernels.

The analysis of deformation up to the failure of the kernel (l) showed non-linear changes of l with an increase in moisture content from 10 to 20% (Fig. 3). As the kernel moisture increased to 14% in the cases of Torka, Kaja and Emika and to 16% in the case of Zorza, the l slightly increased. When the moisture was 16% and higher a violent increase of l was observed. The changes of l in relation to the kernel moisture were described by the quadratic equations (Table 1). Similar values of l were observed for investigated wheat cultivars (0.39-0.72 mm). There are no statistical differences between l for hard and soft cultivars. Only when moisture was 20% significant differences were observed between Torka and Emika (l = 0.81and 0.62 mm).

The changes of force-to-deformation ratio (β) as a result of kernel moisture increase were similar as the changes of F. The increase of kernel moisture caused a linear decrease of β the for all tested cultivars (Fig. 4) – average from 169 to 48 N mm^{-1}. The Pearson coefficients of correlation between β and kernel moisture content were statistically significant ($p < 0.05$) and exceed -0.98 for each cultivar. There are no statistical differences between mean values of β or individual cultivars with the same moisture content.

The results of kernel shear energy (E_c) were presented in Fig. 5. The values of E_c average ranged from 11.7 to 14.0 mJ. There are no statistical differences between E_c for individual cultivars and also the kernel moisture content had not significant influence on the E_c. Similar range of values of E_c was obtained for rye kernels by Dziki and Laskowski (2007). On the basis of literature data it can be shown that moisture content has differ influence on shear or cutting energy of plant granular materials. Figiel and Frątczak (2001) showed that generally as the moisture of kernel increased the cutting energy decreased. However they observed an inverse relationship for

T a b l e 1. The coefficients of regression equation described the changes of deformation up to the failure of the kernel (l) in relation to kernel moisture content (w)

Cultivar	$l = aw^2+bw+c$			
	a	b	c	R^2
Torka	0.0040	-0.081	0.833	0.996
Kaja	0.0019	-0.028	0.445	0.939
Emika	0.0029	-0.052	0.671	0.989
Zorza	0.0036	-0.079	0.804	0.905

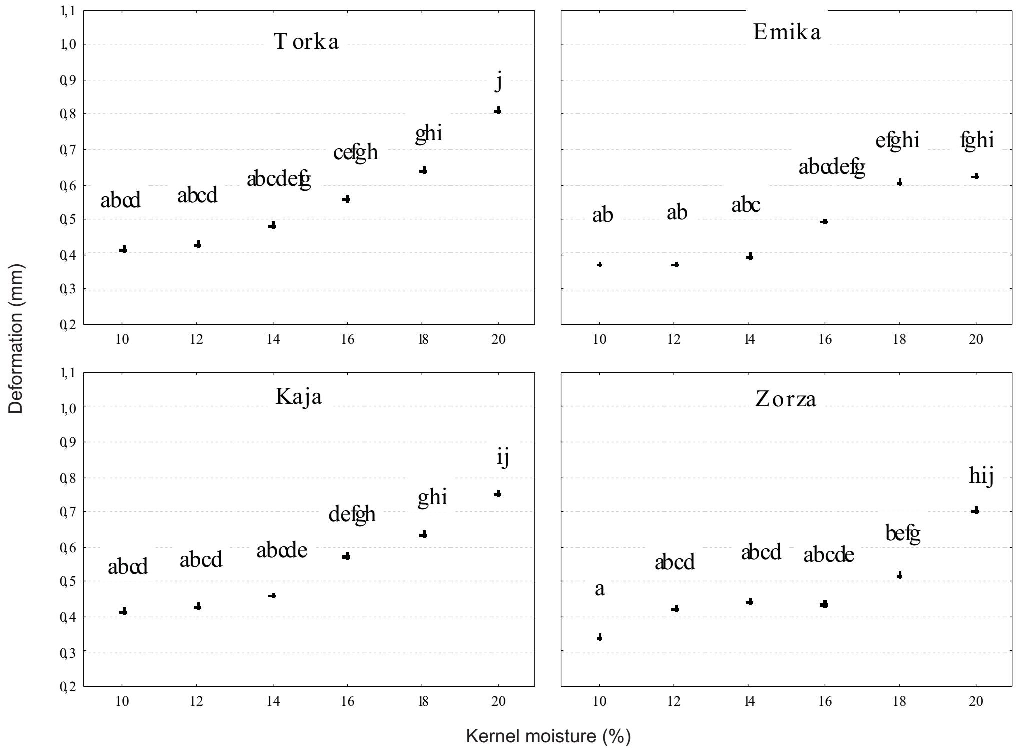

Fig. 3. The deformation up to the failure of the kernel in relation to the kernel moisture content. Explanations as in Fig. 2.

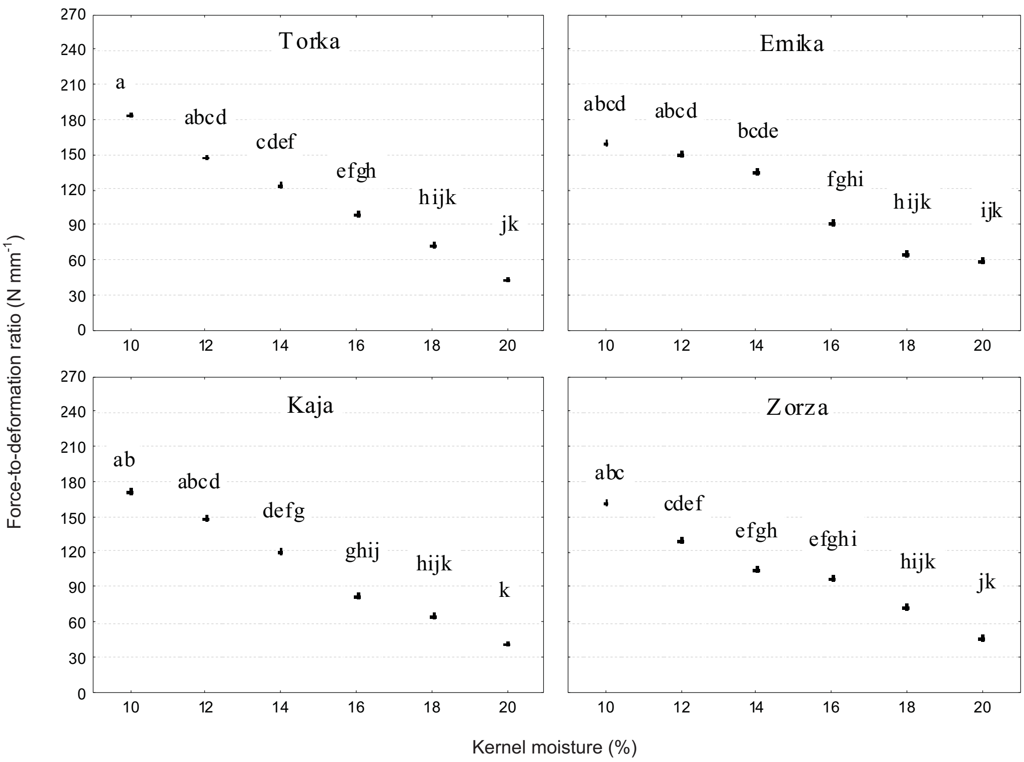

Fig. 4. The force-to-deformation ratio in relation to the kernel moisture content. Explanations as in Fig. 2.

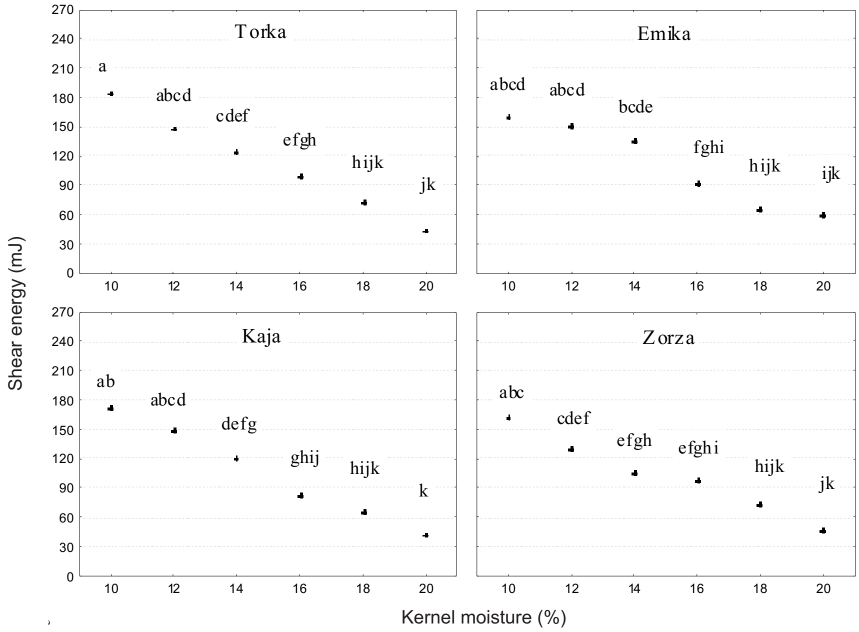

Fig. 5. The shear energy in relation to the kernel moisture content. Explanations as in Fig. 2.

soya-bean and triticale. Romański and Stopa (2003) showed non-linear relation between moisture of wheat kernels and E_c. The highest values of E_c were observed, when the moisture of kernel was between 15-17%. They also found positive correlation between E_c and the mass of kernel. Moreover Romański *et al.* (2006) showed positive correlation between E_c and virtuousness. Dobraszczyk *et al*. (2000) found that wheat mechanical properties of wheat kernel endosperm depend on kernel density. As the density increased the hardness and stiffness are both increased.

The increase of water content causes a increase in kernel extensibility (ultimate strain), due to the plasticizing effect of water, and thus the deformation up to the failure of the kernel increases. Similar dependences can be observed for different plant granular materials, both during shearing (Figiel and Frątczak, 2001) and compression (Łysiak, 2007). In consequence the higher energy is required for grinding, especially when hammer mill is used (Laskowski and Łysiak, 1999). When the moisture of kernel is higher then 18-19% the cohesion of protein matrix is interrupted and decrease of grinding energy is observed when the roller mill is used for grinding (Dexter and Martin 2002). Matveev *et al.* (2000) described the plasticization mechanism caused by water in food biopolymers (polysaccharides, proteins), and showed that it is based on the weakening of dipole-dipole interactions, and intra and inter-macromolecular hydrogen bonds.

CONCLUSIONS

1. The increase of kernel moisture caused a linear decrease of shear force for all tested cultivars (average from 62 to 33 N). Only when the moisture of kernels was 10 and 12% the significant higher values of shear force were obtained for hard wheat varieties (Torka and Kaja) than for soft ones (Emika and Zorza).

2. For all tested cultivars the dependence between kernel moisture content and deformation up to the failure of the kernel was not linear. As the kernel moisture increased from 10 to 14% the increase of deformation was negligible. When the moisture was 16% and higher a violent increase of deformation was observed.

3. The increase of kernel moisture caused a linear decrease of force-to-deformation ratio for all tested cultivars (average from 169 to 48) N mm^{-1}.

4. The moisture content (range from 10 to 20%) has not statistically significant influence on kernel shear energy. The values of shear energy average ranged from 11.7 to 14.0 mJ.

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