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INFLUENCE OF MOISTURE CONTENT ON MECHANICAL PROPERTIES OF RYE KERNELS

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Abstract. The results of investigation of mechanical properties of rye kernels (cv. Fernando and Ursus) of different moisture content (from 10 to 20%) are presented. The uniaxial compression test and shear test were used for determining single kernel properties. For both cultivars, as the kernel moisture increased from 10 to 14% the kernel deformation up to the rapture point increased, too. When the kernel moisture was 16% and higher, the rapture point during compression test was not observed. For both cultivars, increase of moisture content from 10 to 16% caused increase of specific work of kernel deformation up to the end of compression (average from 5.8 to 8.0 J g^{-1}). When kernel moisture was 18 and 20%, a decrease of this work was observed (average up to 7.2 J g^{-1}). The shearing force of single kernels decreased as the moisture increased, and similar levels of values for both cultivars were obtained (average from 60.8 to 31.4 N). Increase of kernel water content caused decrease of shear strength, too (from 7.9 to 3.8 N mm^2 for Ursus and from 7.6 to 3.6 N mm^2 for Fernando).

Keywords: rye, kernel, compression, shear, moisture

INTRODUCTION

Research on the mechanical properties of cereal kernels has been conducted for many years. Analysis of literature data showed that many methods for the evaluation of kernel mechanical properties were proposed, including methods based on classical mechanics and indirect methods, such as PSI hardness index or WHI hardness index, called the technological hardness (Frączek *et al.* 2003). Especially indirect methods showed many correlations with wheat technological quality, particularly with the milling process (Branland *et al.* 1997, Martin *et al* 2001).

Many methods applied and often incomparable results come from difficulties in measurements of cereal kernels mechanical properties on the basis of methods used for construction materials, such as metals. Among others things, this is caused by the complicated structure and small dimensions of kernels. Besides, even within the same cultivar we can find kernels with considerably different strength properties. For example, the compression strength of vitreous kernels is about twice as high as that of mealy kernels (Samson *et al.* 2005). Also individual parts of kernel significantly differ in their mechanical properties (Glen *et al*. 1991, Martin *et al.* 2001).

Besides the genetic factor, the kernel moisture content has a considerable influence on cereal kernel mechanical properties. During the compression test, when the moisture content is low, the kernels behave like a brittle material with some elastic properties. As the moisture content increases, the elastic properties prevail and partially plastic behaviour is observed. When the kernels are very wet, the plastic properties predominate (Kiryluk *et al.* 1996). Cereal kernels are dry when their moisture content (w.b.) does not exceed 14%, semidry from 15 to 16% of moisture, damp from 16 to 17%, and wet when the moisture content is higher than 17% (Grzesiuk *et al.* 1988).

A lot of studies were carried out to determine the mechanical properties of wheat and a few were concerned with those of rye kernels, even though the nutrition value and health properties of rye are higher than those of wheat. The aim of the present experiment was to determine the influence of rye moisture content on mechanical properties of single kernels on the basis of uniaxial compression test and shear test.

MATERIALS AND METHODS

The studies were carried out on two rye cultivars, Fernando and Ursus, collected in 2003 at the Agricultural Advice Centre in Końskowola (Lublin Province). Samples of kernels were conditioned to six moisture levels: 10, 12, 14, 16, 18 and 20% (w.b.). Kernels were moistened by adding adequate amounts of water at room temperature. Samples were closed in special containers and mixed for 30 min by using a laboratory mixer made at the Institute of Agrophysics, Polish Academy of Sciences, in Lublin. Forced drying of samples was performed with the help of a laboratory dryer at 35^{o}C.

The research of kernel mechanical properties was made using the universal testing machine ZWICK Z020/TN2S. In the first part of the study, individual kernels were weighed and placed on the bottom plate of the machine (the kernel crease towards the bottom plate) and compressed until a constant distance (0.7 mm) between the plates was achieved. On the basis of obtained compression curves the following parameters were determined: forces (F_1 and F_2), deformations (Δh_1 and Δh_2), work (L_1 and L_2) and individual work (L_{j1} and L_{j2}) corresponding to the rapture point and the end of the compression, respectively (Dziki 2004).

In the second part of the study the shear test was made. Individual kernels were placed in the central hole of farinator plates. The plates were put on the bottom plate of the machine. The top plate was subjected to a loading force from the upper mobile measuring head. The kernel was sheared between two holes (holes diameter 4.5 mm). During the test, changes of loading force in relation to the displacement of measuring head were recorded by means of a computer set. On the basis of obtained shear curves (Fig. 1), the shear force (F_{max}) and shear work (*W*) were determined. In the next part of the study the cross-section area of kernels was calculated. The cut parts of kernels (ten pieces) were placed in the holes of a special stand and photos were made by using a Nikon Coolpix 4500 digital camera coupled with an SMT 800 optical microscope. The images were saved and converted by using special computer software (MultiScanBase). The measuring system was calibrated according to the measuring stand. Individual images were converted by using different filters (a red filter and a decimal filter for binary conversion ware used). The kernel cross-section areas were calculated after the filtration. The kernel shear strength was calculated as a ratio of shear force to kernel cross-section area.

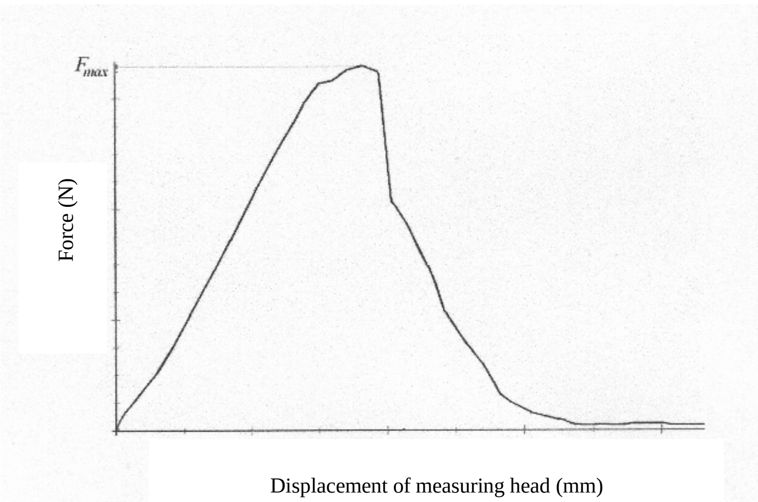

Fig. 1. Example of rye kernel shear curve

The speed of loading head, both during the uniaxial compression test and the shear test, was 10 mm min^{-1}. The range of load applied by the measuring head was form 0 to 2.5 kN. Measurements were replicated thirty times for each sample. The following statistical parameters were evaluated: average values, standard deviations, and 95% levels of confidence. The evaluations were also analysed for variance analysis. Statistical differences between the treatment groups were estimated by Tukey's test. All statistical tests were carried out at significance level of $\alpha = 0.05$.

RESULTS

The results of determinations of the mechanical properties of kernels, obtained on the basis of uniaxial compression test, showed that an increase of kernel moisture form 10 to 14% caused an increase in kernel deformation up to the rapture point (Δh_1) for both cultivars; average form 0.31 to 0.50 mm and from 0.25 to 0.39 mm for Fernando and Ursus, respectively (Tab. 1). Similar tendency was observed for wheat when the moisture of kernels ranged from 12 to 16% (Dziki 2004).

Table 1. Influence of kernel moisture on rye kernel mechanical properties as described by the rapture point

Cultivar	Moisture content (%)	Δh_1 (mm)	F_1 (N)	L_1 (mJ)	L_{j1} (mJ·g^{-1})
Fernando	10	0.31^{a}	111^{a}	22.5^{a}	468^{a}
	12	0.44^{ab}	118^{b}	41.8^{b}	795^{b}
	14	0.50^{b}	98^{ab}	38.6^{ab}	904^{b}
Ursus	10	0.25^{a}	102^{a}	15.3^{a}	337^{a}
	12	0.38^{b}	140^{b}	34.4^{b}	664^{b}
	14	0.39^{b}	115^{a}	29.0^{b}	624^{b}

* values designated in columns by different letters are statistically significantly different ($\alpha = 0.05$).

The compression curves obtained for rye kernels with different moisture content are presented in Figure 2. When the moisture of kernels was 16%, 18% and 20% the rapture point was not observed. On the basis of obtained curve characteristic it can be observed that as the kernel moisture increases the point characterizing the kernel strength is harder to find and the obtained characteristic is similar to compact curve.

For both cultivars the highest values of rapture force (F_1) were obtained when the moisture of kernels was 12% (118 and 140 N for Fernando and Ursus, respectively). The values of F_1 obtained for kernels with 10 and 14% moisture content were not statistically significantly different.

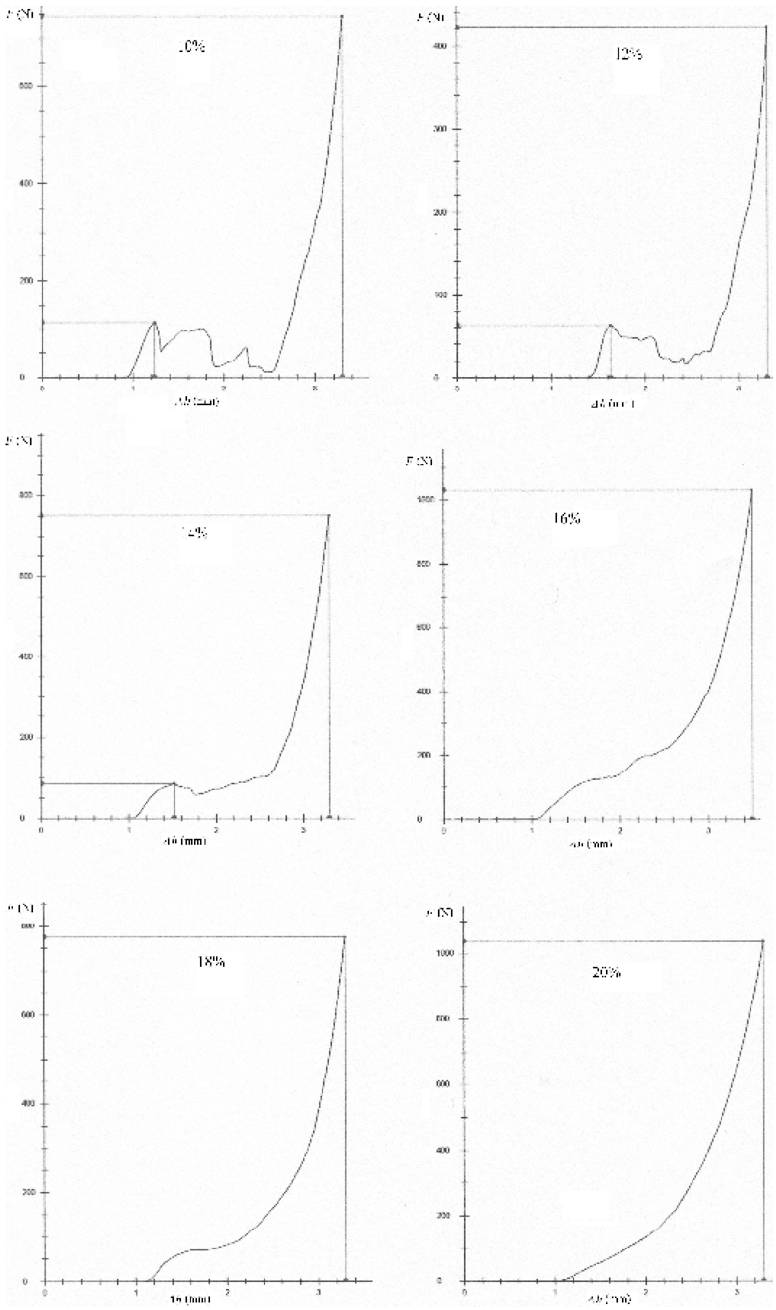

Fig. 2. Example of rye compression curves at different kernel moisture content, F – loading force, Δh – displacement of measuring head

The increase of sample moisture from 10 to 12% caused a significant increase of work and individual work compression of kernels up to the rapture point (L_1 and L_{j1}, respectively). However, further increase of moisture content up to 14% had no significant influence on the parameters. Higher values of L_1 and L_{j1} were obtained for Fernando (Tab. 1)

The lowest and similar values of force at the end of kernel compression (F_2) were obtained when the kernel moisture was 10 and 20% (average of 679 and 640 N for Fernando and Ursus, respectively). When the kernel moisture was between 12 and 18%, slightly higher values of F_2 were obtained. However, significant differences were observed only between average values of F_2 obtained for Fernando when the kernel moisture changed from 10 to 12%. In summary, the influence of kernel moisture content on F_2 was not considerable. In order to prove this influence the number of repetitions should be increased.

The knowledge of the mechanical properties of kernels, obtained on the basis of uniaxial compression test, can be used for the description of grinding process. Łysiak and Laskowski (1999) described the relationships between mechanical properties of legume seeds and the grinding process. They showed a close dependence between the deformation of kernels up to the rapture point and the specific grinding energy.

The individual work of kernel deformation up to the end of compression (L_{j2}) is the parameter which informs about comminution energy requirements. The influence of moisture levels on L_{j2} was similar for both cultivars (Fig. 3). An increase of kernel moisture content form 10 to 16% caused an increase of L_{j2} (average for both cultivars from 5.8 to 8.0 Jg^{-1}). Continuing increase of kernel moisture up to 18 and 20% caused a decrease of L_{j2} (average up to 7.2 J g^{-1}). Similar dependences were obtained by Romański and Niemiec (2001) during crushing of wheat kernels using a crusher mill.

The results shoved that the shear force (F_{max}) decreased as the kernel moisture increased (average from 60.8 to 31.4 N). Similar values of F_{max} were obtained for both cultivars. The cross-section area of cut kernels ranged form 6.4 to 12.8 mm^2. The standard error of single measurement did not exceed 0.15 mm^2. The statistical differences between means are marked in Table 2.

The results of shear work (W) are presented in Table 2. Increase of kernel moisture from 10 to 14% did not have any significant influence on shear work (W). When the moisture was 16% and higher, an increase of W was observed. The changes of W were similar for both cultivars (from 11.0 to 16.4 mJ and form 11.8 to 18.2 for Fernando and Ursus, respectively).

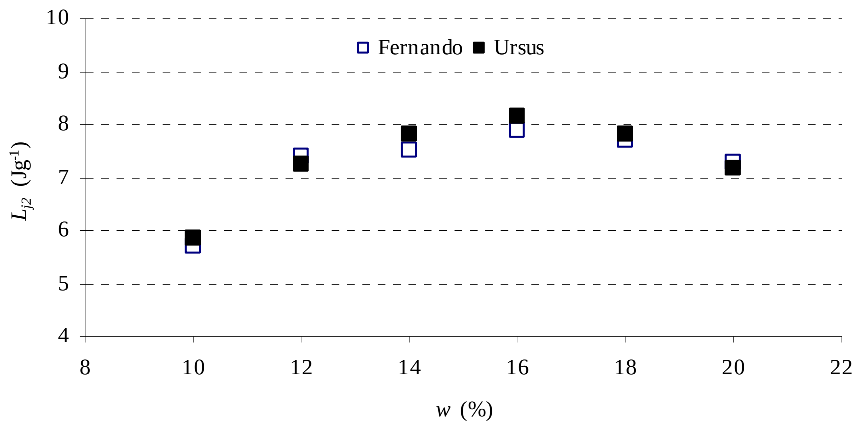

Fig. 3. Relationship between rye moisture content (w) and individual work of kernel deformation up to the end of compression (L_{j2})

Table 2. Influence of moisture content on shear force and shear work of single rye kernels

Cultivar	Moisture content (%)	Shear force (N)	Shear work (mJ)	Kernel cross-section area (mm^2)
Fernando	10	58.6^{a}	12.6^{ac}	7.9^{a}
	12	57.5^{a}	11.9^{a}	9.7^{b}
	14	47.9^{b}	11.0^{a}	8.7^{ab}
	16	41.2^{c}	13.0^{ac}	8.3^{ab}
	18	34.9^{d}	15.1^{bc}	9.3^{ab}
	20	31.7^{d}	16.4^{b}	8.8^{ab}
Ursus	10	63.1^{a}	12.7^{a}	8.0^{ab}
	12	60.8^{a}	11.8^{a}	8.0^{ab}
	14	49.9^{b}	12.7^{a}	8.5^{ab}
	16	48.8^{c}	17.5^{bc}	8.6^{ab}
	18	35.0^{d}	14.3^{ab}	7.8^{a}
	20	31.1^{d}	18.2^{c}	8.3^{ab}

* values designated in columns by different letters are statistically significantly different ($\alpha = 0.05$).

Reference data show that the influence of moisture content on shear work of various cereal seed species is different. Figiel and Frontaczak (2001) analysed the shear work of different species and showed that for most of the analysed cereals as the kernel moisture increased the shear work decreased. However, the reverse relationship was observed for triticale and soy bean.

Increase of moisture content caused a decrease of shear strength (from 7.6 to 3.6 N mm^{-2} and form 7.9 do 3.8 N mm^{-2} for Fernando and Ursus, respectively). Slightly higher values of strength were obtained for Ursus (Fig. 4).

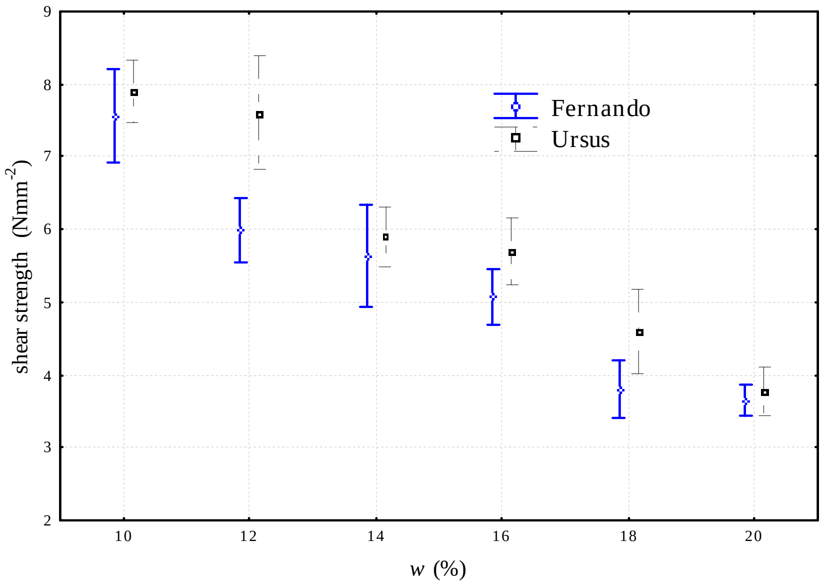

Fig. 4. Influence of moisture content (*w*) on shear strength of rye kernel (95% level of confidence is marked in the figure)

The obtained results showed a significant influence of kernel moisture content on analysed mechanical parameters. The data will be used for evaluation of relations between rye mechanical properties and the grinding process.

CONCLUSIONS

1. The results showed that an increase on kernel moisture form 10 to 14% caused an increase in the deformation of kernels up to the rapture point for both cultivars; average form 0.31 to 0.50 mm and from 0.25 to 0.39 mm for Fernando and Ursus, respectively.

2. On the basis of analysis of the compression curves, the rapture point was not observed when the moisture of kernels was 16%, 18 and 20%.

3. The influence of moisture levels on individual work of kernel deformation up to the end of compression was similar for both cultivars. An increase of kernel moisture content form 10 to 16% caused an increase of this parameter (average for both cultivars from 5.8 to 8.0 J g^{-1}). Continuing increase of kernel moisture up to 18 and 20% caused a decrease of this work (average up to 7.2 J g^{-1}).

4. The results shoved that the shear force decreased as the kernel moisture increased (average from 60.8 to 31.4 N). Similar values of the force were obtained for both cultivars.

5. Increase of moisture content caused a decrease of shear strength (form 7.6 to 3.6 N mm^{-2} and form 7.9 do 3.8 N mm^{-2} for Fernando and Ursus, respectively).

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WPŁYW WILGOTNOŚCI NA WŁAŚCIWOŚCI MECHANICZNE ZIARNA ŻYTA

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Streszczenie. W pracy przedstawiono wyniki badań właściwości mechanicznych ziarna żyta odmian Fernando i Ursus o różnej wilgotności; od 10 do 20% (co 2%). Określono cechy mechaniczne pojedynczych ziarniaków na podstawie testu jednoosiowego ściskania oraz testu cięcia. Dla obu badanych odmian wzrost wilgotności w przedziale 10-14% powodował zwiększenie odkształcenia ziarna do progu wytrzymałości doraźnej. Przy wyższej wilgotności (16, 18 i 20%) nie zarejestrowano występowania na krzywej zgniatania progu wytrzymałości doraźnej. W odniesieniu do obu badanych odmian stwierdzono podobny wpływ wilgotności na pracę jednostkową zgniatania ziarna do progu zgniecenia. W przedziale wilgotności 10-16% wzrost zawartości wody w ziarniakach powodował zwiększenie tej pracy (średnio od 5,8 do 8,0 $J \cdot g^{-1}$). Natomiast dla ziarna o wyższej wilgotności (18 i 20%) zaobserwowano spadek tego parametru (średnio do wartości 7,2 $J \cdot g^{-1}$). Wzrost wilgotności ziarna powodowa spadek siły cięcia ziarniaków oraz wytrzymałości na ścinanie. Parametry te kształtowały się na zbliżonym poziomie dla obu badanych odmian (odpowiednio od 60,8 do 31,4 N i od 7,8 do 3,7 $N \cdot mm^{-2}$).

Słowa kluczowe: żyto, ziarno, zgniatanie, cięcie, wilgotność