

## INFLUENCE OF SELECTED FACTORS ON WHEAT GRINDING ENERGY REQUIREMENTS

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**Summary.** The paper presents the results concerning the influence of grain moisture content and debranning ratio on wheat grinding energy utilization using a hammer mill. The results showed that as the grain moisture increased (range 12-16%) the specific grinding energy increased, too (from 15 to 21%). The debranning caused the decrease of this parameter from 20 to 46%. The highest changes of grinding energy efficiency index were observed for grain after the first stage of debranning (debranning ratio 49%). As the debranning ratio increased the values of this index increased, too (from 16 to 31%). However, as the size of screen holes increased, a higher increase of energy efficiency index was observed. The changes of grinding energy indices were described by using the multiple linear regression equations. The models, which were the functions of screen holes size and grain properties (moisture content, debranning ratio, mass of grain) explained most of the variability in the experimental data.

**Key words:** wheat, grinding, energy consuming, hammer mill

### INTRODUCTION

Wheat is one of the most important cereal crops in the world. Wheat constitutes about 29% (about 584 million tones) of the total world production of cereals by weight, with rice and maize 27% and 28%, respectively [Dendy and Dobraszczyk 2001].

The majority of the world wheat production is used as food, mainly as bread, cakes, cookies, pastas and cuscus, and also as a source of animal feed. Wheat is also used in the manufacture of beer and whisky, and meat substitutes. In the recent years, some researches are concerned with the production of biodegradable plastic from wheat starch and wheat-based raw materials, for cosmetics. In all these technologies, the grinding has great importance and is very energy consuming. Thus, it is important to evaluate the grinding energy and the factors affecting this parameter. The grinding energy depends both on the properties of the grinding material and on the used machines and their work parameters. Wheat grinding by using a hammer mill is less energy efficient than by using a roller mill [Dziki and Laskowski 2004]. From the physical properties of grain, the mechanical properties have the greatest influence on grinding energy. These properties

depend mainly on a cultivar, but also on agro-climatic and agro-technical factors. Wetting or drying the grains can also modify them. Łysiak and Laskowski [1999] used a hammer mill for evaluation of wheat specific grinding energy. They found out that as the grain moisture content increased, the specific grinding energy increased, too. However, Romański and Niemiec [2001] obtained a different dependency. when they used a roller mill. They described this dependency by using a square equation. When the grain moisture was 16-17%, the highest specific grinding energy was observed. Below and above this level, lower values of this parameter were obtained. Thus, we can conclude that the relation between grinding energy and grain moisture content depend on the used grinding machine.

Pansikatan *et al.* [2001b] used a roller mill for modeling the energy requirements of first-break grinding. They developed a multiple regression model based on milling data from six wheat classes ground at five roll gaps with an experimental roller mill. The models, which were functions of roll gap, single kernel properties, and wheat class as a classification variable, explained most of the variability in the experimental data. Roll gap and single kernel hardness had the greatest influence on the grinding indices.

The mechanical properties of individual grain depend mainly on the endosperm properties and the bran layer (fruit and seed coat, nucellus and aleurone) properties. The bran layer is about ten time more resistant to grinding then is endosperm [Jurga 1997]. The way of the grinding depend, among other things, on whether or not the bran layer should be separated from the endosperm. White flour or semolina production require the bran layer separation during milling and in some milling systems the wheat is debranned prior to milling [Dexter and Wood 1996, Mousia *et al.* 2004]. Also, in some cases the presence of anti-nutrient substances in bran layers caused the necessity of grain dehulling.

Peyron *et al.* [2002] investigated the relationship between bran mechanical properties and milling behavior of durum wheat. They showed that rapture force and rapture tensile strain weren't affected by bran thickness, however, they were affected by bran density. On the other hand, they showed that linear rigidity was negatively correlated with bran thickness.

The grinding energy requirements of cereals grain has been the subject of many studies. However there are no works concerning the grinding energy of debranned grain. Thus this work aims to determine the influence of wheat debranning ratio and moisture content on the grinding energy requirements.

## MATERIALS AND METHODS

The investigations were carried out on Polish spring wheat cultivar (*Triticum aestivum*, *ssp. vulgare*) Turnia collected in 2002. This cultivar belongs to class A and flour obtained from this cultivar is characterized by a very good baking value. Grains were debranned using debranning machine Ekonos, by courtesy of Lubella S.A. from Lublin. After the first stage of debranning, one part of grains was separated and the rest was taken in to the second stage. Three kinds of samples were taken for the investigation: kernel without debranning, kernel after the first and after the second stage of debranning. The ash content was evaluated for grains before and after debranning [PN-ISO 2171, 1994]. The debranning ratio was calculated according to the equation:

$$d_r = \frac{\Delta m_b}{\Delta m_t} \cdot 100\% \quad (1)$$

where:

$\Delta m_b$  – the difference between the kernel ash content before and after debranning, %

$\Delta m_t$  – the difference between the total kernel ash content before debranning and endosperm ash content, %

Subsequently, samples of wheat were tempered for 24 hours to three levels of moisture: 12, 14 and 16%. The grinding process was carried out on the laboratory hammer mill POLYMIX-Micro-Hammermill equipped with changeable screens. For investigations three screens with different diameters of holes were used: 1.0; 1.5 and 2.0 mm.

The changes of power consumption of electric current during the grinding were recorded using laboratory equipment included in the grinding machine, transducer of power and a special data acquisition card connected to a PC computer. After grinding, the energy consumption was calculated by a special computer software [Laskowaki and Łysiak 1997].

The specific grinding energy ( $E_r$ ) was calculated according to the equation:

$$E_r = \frac{E_c - E_s}{m} \quad (2)$$

where:

$m$  – the mass of ground sample, kg,

$E_c$  – the total grinding energy consumption, J,

$E_s$  – the idle running energy consumption, J.

The particle size distribution of ground material was evaluated using the laboratory sieve machine Thyr 2. On the basis of the obtained particle size distributions the average particle size was calculated [Laskowaki and Łysiak 1997].

The energy efficiency index ( $E_g$ ) was determined as the ratio of the grinding stock surface area ( $A$ ) to grinding energy ( $E_w$ ).

The surface area ( $A$ ) of the ground material was calculated according to the equation:

$$A = \frac{6 \cdot m}{\rho \cdot d} \quad (3)$$

where:

$d$  – the average particle size of particles, m<sup>2</sup>,

$\rho$  – density of particles (for calculation was taken 1300kg/m<sup>3</sup> [Kirylyuk *et al.* 1998])

The grinding index  $K$  also was calculated on the basis of size reduction theory described by Sokołowski [1996]

Measurements were replicated ten times for each sample. The obtained data were subjected to statistical analysis. The evaluations were analyzed for variance analysis. Statistical differences between the treatment groups were estimated by Duncan's test. The Pearson's correlation coefficients and regression equations were also evaluated. All statistical tests were carried out at significance level of  $\alpha = 0.05$ .

## RESULTS AND DISCUSSION

The grain ash for grain prior to debranning was 1.51%. Debranning caused the decrease grain ash content about 0.48% and 0.71% after the first and second stage, respectively (the debranning ratio 49% and 73%, respectively).

The results showed that when the diameter of screen holes 1.0 and 1.5 mm were used, the grain moisture and debranning ratio had no influence on the average particle size of particles ( $d$ ). However, when the screen with holes size 2.0 mm, both moisture content and debranning caused a statistically significant increase of  $d$  (Fig. 1). Therefore, it can be concluded that when a hammer mill is equipped with a higher size of screen holes, the differences between the properties of the grain have a greater influence on the particle size of the ground material. The highest influence on the size of particles had the size of screen holes ( $r = 0,981$ ).

Haddad *et al.* [1999] showed that wheat hardness had an influence on granulometric distribution of ground particle size. Much finer particles (smaller than 50  $\mu\text{m}$ ) are obtained from soft wheat. These differences appear to result more from cultivar differences than agro-climatic factors.

It is not beneficial to fine-grind the cereals grain, both from the economic point of view (high energy consumption) and for other reasons, such as dust explosion or respiratory disease.

The results showed, that both kernel moisture and debranning ratio affected the specific grinding energy ( $E_r$ ). As the grain moisture increased, the energy requirements also increased (from 15 to 21%). Debranning caused the decrease of  $E_r$  (form 20 to 46%). The highest changes of the specific grinding energy were observed after the first stage of debranning (Fig. 2).

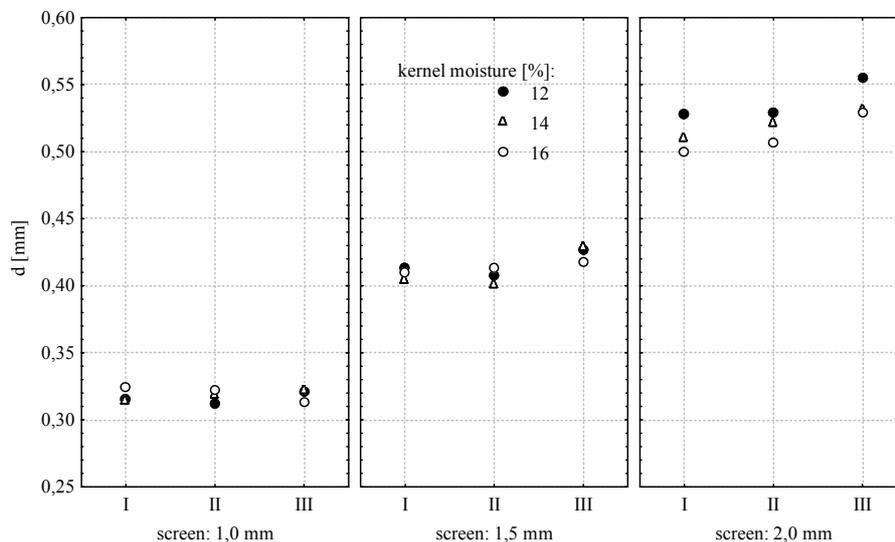


Fig. 1. Average particle size of the ground material obtained from grain with different moisture content and different debranning ratio; I – grain without debranning, II – grain after the first stage of debranning, III – grain after the second stage of debranning

The changes of  $E_r$  were described by using the multiple linear regression equation, where grain moisture ( $w$ ), mass of grain ( $m$ ) and diameter of screen holes ( $d_s$ ) were taken as independent variables:

$$E_r = 4.52w + 1271.96m - 71,84d_s + 105.66; R^2 = 0.963 \quad (4)$$

The observed values versus the predicted ones are presented in Fig. 3.

The increase of grain moisture content caused an increase of grain plasticity and thus difficulties with grinding (the higher energy requirements). On the other hand wheat debranning resulted in faster grinding, because grains without bran are ground more easily than undehulled wheat and thus the specific grinding energy was lower.

Fang *et al.* [1998] used a roller mill for modeling the wheat grain energy requirements of first-break grinding. They developed a statistical model from the response surface regression that related the specific grinding energy to single kernel properties (mass, moisture content, hardness) and roll parameters (the clearance between rolls of a roller mill, fast roll speed, the ratio of fast roll speed to slow roll speed). The determination coefficient was greater than 0.94. Dziki and Laskowski [2004] showed that energy requirements of first-break grinding also depend on grain thickness. As the grain thickness increased, the specific grinding energy increased too.

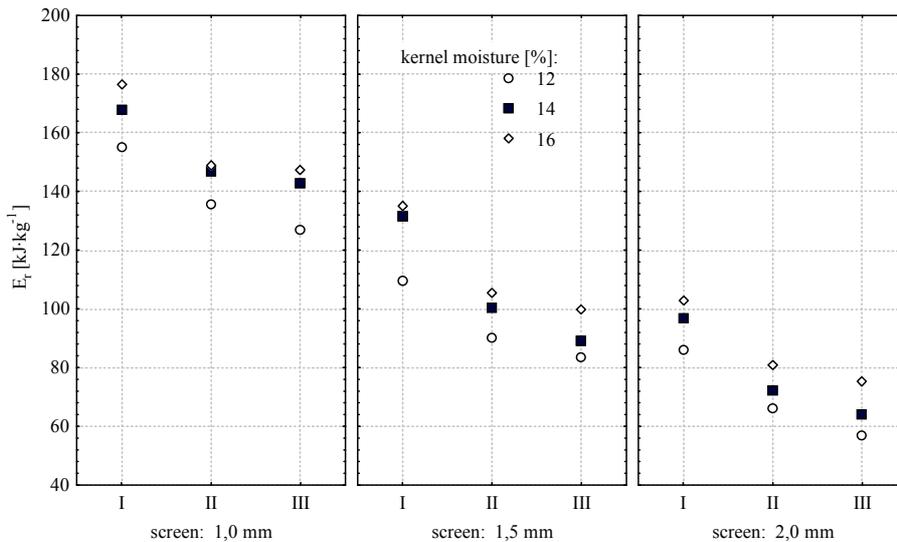


Fig. 2. The specific grinding energy of grain with different moisture content and different debranning ratio; I – grain without debranning, II – grain after first stage of debranning, III – grain after second stage of debranning

The highest changes of the grinding energy efficiency index ( $E_g$ ) were observed for grain after the first stage of debranning (increase from 16 to 30%). However, as the size of screen holes increased, the higher changes of  $E_g$  were obtained (Fig. 4).

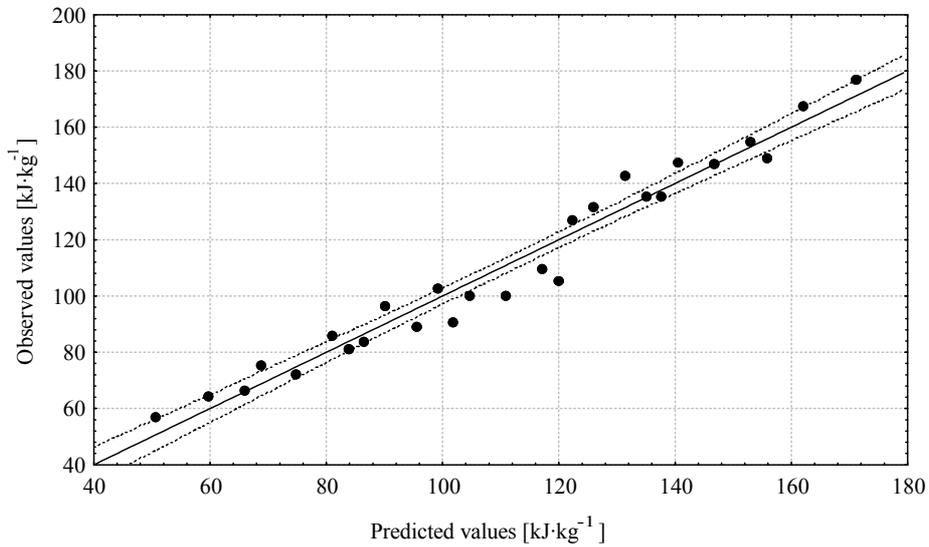


Fig. 3. The predicted values of the specific grinding energy versus the observed values

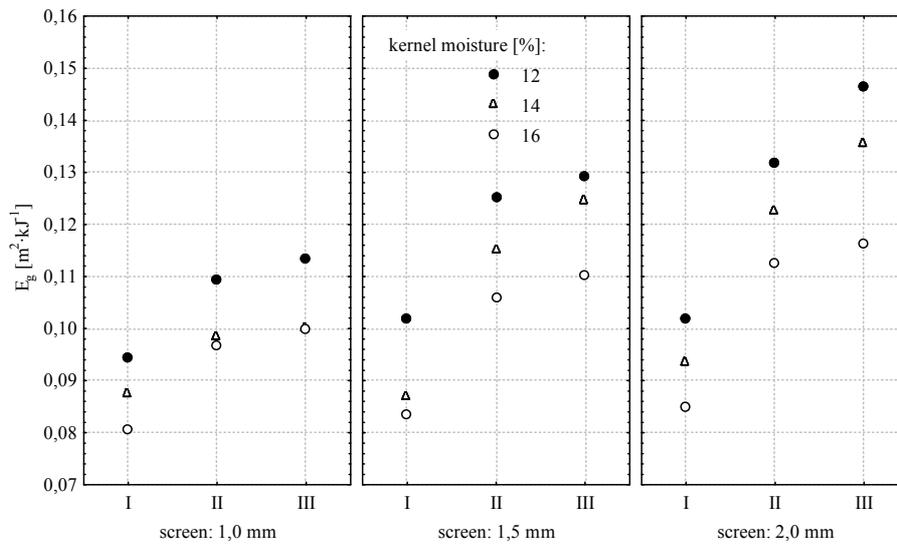


Fig. 4. Grinding energy efficiency index obtained for grain with different moisture content and different debranning ratio; I – grain without debranning, II – grain after the first stage of debranning, III – grain after the second stage of debranning

An increase of grain moisture caused the decrease of  $E_g$  (from 14 to 21%). The higher decrease was observed when screens with higher size of holes were used. The changes of  $E_g$  were described by using the multiple linear regression equation, where grain moisture ( $w$ ), debranning ratio ( $d_r$ ) and diameter of screen holes ( $d_s$ ) were taken as independent variables:

$$E_g = -0.0045w - 0.000405d_r + 0.0057d_s + 0,188; R^2 = 0.895 \quad (5)$$

Debranning caused the decrease of grinding index  $K$  (from 13 to 39% in relation to used screen). The highest decrease was observed for grain after the first stage of debranning. The increase of grain moisture also had a significant influence on  $K$ . As the moisture of kernel increased, the grinding index increased, too (from 16 to 19%). Based on the grinding data, the statistical model was developed that related the grain moisture ( $w$ ), diameter of screen ( $d_s$ ) and the debranning ratio ( $d_r$ ):

$$K = 4.22w - 9.09d_s - 0.328d_r + 114.25; R^2 = 0.901 \quad (6)$$

Grinding index  $K$  is a good parameter for describing the grinding properties of wheat. This parameter depends mainly on the mechanical properties of grains, especially on hardness. Pujol *et al.* [2000] observed that  $K$  is about two times higher for durum wheat than for common soft wheat.

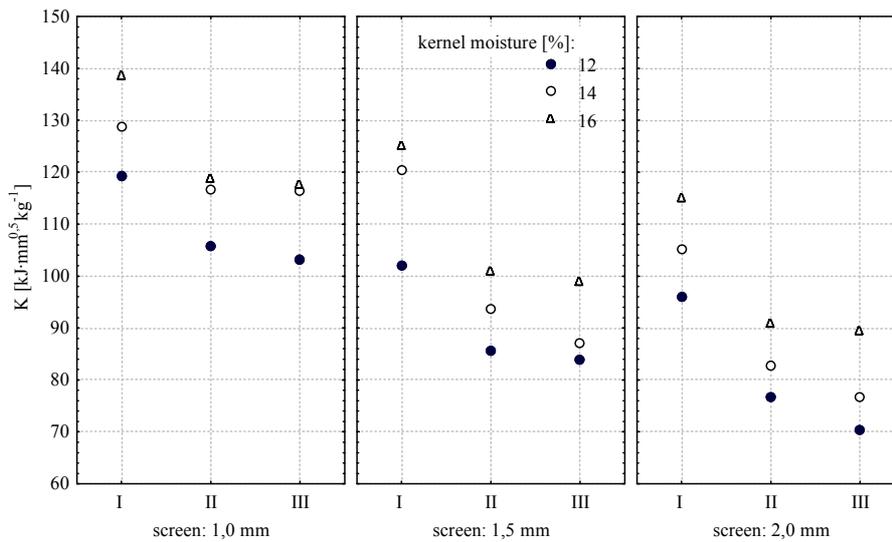


Fig. 5. The grinding index  $K$  obtained for grain about different moisture content and different debranning ratio; I – grain without debranning, II – grain after the first stage of debranning, III – grain after the second stage of debranning

The results showed that both the debranning ratio and grain moisture content have a significant influence on wheat grinding energy consumption by using a hammer mill. The range of energy changes depends also the used screen holes size. A further study should take into account the energy of debranning.

## CONCLUSION

1. The results showed that debranning has a greater influence on the specific grinding energy ( $E_r$ ) than grain moisture content. As the grain moisture increased (range 12-16%) the  $E_r$  increased, to (from 15 to 21%). The debranning caused the decrease of  $E_r$  from 20 to 46%.

2. The highest changes of grinding energy efficiency index ( $E_g$ ) were observed for grain after the first stage of debranning (the debranning ratio 49%). As the debranning ratio increased,  $E_g$  increased, too (from 16 to 31%). However, as the size of screen holes increased, a higher increase of energy efficiency index was observed. The increase of grain moisture caused the decrease of  $E_g$  (from 14 to 21%).

3. The debranning caused the decrease of grinding index  $K$  (from 13 to 39%). The highest changes were observed for grains after the first stage of debranning. An increase of kernel moisture caused an increase of  $K$  (from 16 to 19%).

The changes of grinding energy indices were described by using the multiple linear regression equations. The models, which were functions of screen holes size and grain properties (moisture content, debranning ratio, mass of grain) explained most of the variability in the experimental data.

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