Scientific quarterly journal ISNN 1429-7264

Agricultural Engineering

2014:1(149):239-249

Homepage: http://ir.ptir.org

DOI: http://dx.medra.org/10.14654/ir.2014.149.025

SOME PHYSICAL PROPERTIES OF CEREAL GRAIN AND ENERGY CONSUMPTION OF GRINDING

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ARTICLE INFO

Article history:
Received: December 2013
Received in the revised form: February 2014
Accepted: March 2014

Keywords:
cereal grain
grinding
physical properties
specific energy consumption

ABSTRACT

The objctive of the paper was to assess a relation between some physical properties of cereal grain and energy consumption. Grain of common wheat, spelt and triticale of 15% moisture was ground using a cylinder mill. A relation between energy consumption and vitreousness, thousand kernel weight, test weight and ash content have been determined. Unit energy consumption depended on vitreousness, test weight and ash content in grain. Unit energy consumption increases with the increase of vitreousness and test weight, and decreases with grain ash content. The grinding efficiency index increases with increasing vitreousness, test weight and thousand kernel weight and it decreases with increasing ash content in grain. Vitreousness influenced the consumption of energy more considerably than the test weight and grain ash content.

Introduction

Common wheat, spelt wheat and triticale are important crops which play a considerable role in human nutrition. Spelt wheat is one of the oldest subspecies of common wheat. In recent years it has attracted a lot of attention due to a more beneficial chemical composition and higher nutritional value compared to common wheat grain (Bonafaccia et al., 2000). On the other hand, triticale is a potential alternative to wheat in processed flour products. Grinding is the main form of processing cereal grain; its first purpose is to separate endosperm, pericarp and germ and then to reduce the size of endosperm particles to a fraction which passes through a sieve with an opening size not exceeding 200 μm (Posner, 2003). Grinding is one of the most energy-intensive processes (McCabe et al., 2004). About 60-75% of energy in industrial processing is spent on grinding (Danciu et al., 2009). The energy of grinding cereals has also attracted the attention of scientists. Pujol et al. (2000) as well as Danciu and Danciu (2011) described micro-mills designed to conduct precise measurements of consumption of mechanical energy when small amounts of wheat grain were ground. The amount of energy consumed during the grinding process depends on the type of mill applied, the mill settings and on the physical and chemical properties of grain and the degree of grinding (Dziki and Laskowski, 2002; Dziki, 2008; Fang et al., 1998; Greffeuille et al., 2007; Scanlon and Dexter, 1986; Wiercioch et al., 2008). A number of studies have dealt with the effect of moisture content in grain on the amount of energy needed to grind it (Kowalik et al., 2002; Marks et al., 2006; Opielak and Komsta, 2001; Romański and Niemiec, 2000). The energy consumption of the grinding process increases with grain moisture content. Energy consumption of grain grinding also depends on kernel hardness. Hard wheat requires more energy for grinding than soft wheat (Dziki and Przypadek-Ochab, 2009; Dziki et al., 2012; Greffeuille et al., 2007; Kilborn et al., 1982). The vitreosity of grain is related to its hardness. Kernels with more vitreous endosperm are usually harder (Glen and Johnson, 1994). An increase in grain hardness results in an increase in the amount of energy spent on grinding (Dziki et al., 2012; Laskowski and Różyło, 2003). According to the findings of the study conducted by Wiercioch et al. (2008), energy consumption of cereal grinding is also affected by the kernel weight. The amount of energy spent on grinding wheat grain is proportional to the weight of kernels.

An analysis of literature reports leads to the conclusion that the majority of studies have dealt with the effect of moisture content and hardness of kernel on the amount of energy needed to grind it. Far fewer studies have dealt with the correlation between grinding energy and other properties of grain, such as: thousand kernel weight, test weight, ash content in grain and vitreousness of grain. Therefore, the aim of this study was to asses the dependence between some physical properties of cereal grain and energy consumption.

Material and methodology of the research

The experiment was conducted with grain of four cultivars of common wheat (Bombona, Korweta, Parabola, Radunia), two cultivars of spelt wheat (Schwabenkorn, Franckenkorn) and two cultivars of triticale (Andrus and Milewo). Grain samples were purified and the spelt was hulled on an LD 180 ST 4 laboratory device manufactured by WINTERSTEIGER. The moisture content of the grain was determined (ICC Standard No. 110/1). Subsequently, moisture content was increased up to 15% by adding an appropriate amount of distilled water. This was done in leak-tight containers over 48 h. The following were determined: thousand kernel weight (PN EN ISO 520:2011), test weight (PN EN ISO 7971-3:2010), kernel vitreousness (PN 70/R-74008). The total ash content in grain was also determined according to PN-EN ISO 2171:2010 methodology. The grain was ground in a Quadrumat Junior mill manufactured by Brabender, with a cylindrical sifter tightly wrapped with a 70GG (PE 236 µm) sieve. It is a four-cylinder laboratory mill with an aspiration system and a drum sifter. The energy consumption of the grinding process was determined by measuring the amount of electricity consumed by the mill during its operation. The energy used to set in motion the mill parts was calculated by multiplying the active power of the idle run and the time of grinding. The work done to grind a sample of grain was calculated with the assumption that total energy consumed by the mill equals the total energy of grinding and the energy needed for putting the elements of the mill into motion. The unit energy of grinding Er ($kJ \cdot kg^{-1}$) was calculated from the formula:

$$E_r = \frac{E_c - E_s}{m} \quad (1)$$

where:
E_c – total energy needed for the mill work ($E_c = P_c \cdot t_r$), (kJ)
E_s – energy of the idle run ($E_s = P_s \cdot t_r$), (kJ)
P_s – active power consumed during the idle run, (kW)
P_s – active (total) power consumed by the mill, (kW)
t_r – sample grinding time, (s)
m – ground sample weight, (kg)

The grinding efficiency index K' ($kJ \cdot kg^{-1}$) (Greffeuillea et al., 2007) was also determined:

$$K' = \frac{E_c - E_s}{m_m} \tag{2}$$

where:
m_m – mass of flour, (kg)

Measurements were conducted in sextuplicate for each kind of grain. Calculations were made in the MS Excel® spreadsheet (Microsoft). The results were processed statistically. An analysis of variance was conducted for the mean values of each attribute in order to identify the statistically significant differences. Significance of differences between the attributes was determined by Tukey's test. Linear correlation coefficients between the measured attributes was calculated. Significance was assessed at two levels ($p<0.05$) and ($p<0.01$). Linear regression equations were also determined, which describe the effect of the attributes of grain on unit grinding energy. Statistical calculations were made with STATISTICA® for Windows v. 10 (StatSoft Inc.). Statistical hypotheses were tested at the level of significance of $p=0.05$.

Results and discussion

The unit grinding energy (Er) ranged from 35.9 $kJ \cdot kg^{-1}$ (spelt – Franckenkorn cultivar) do 70.1 $kJ \cdot kg^{-1}$ – (common wheat – Parabola cultivar) (fig. 1). Grinding the grain of common wheat required more energy than grinding grain of spelt or triticale.

This was confirmed by the study conducted by Cacak-Pietrzak and Gondek (2010), in which grinding of spelt grain was found to require less energy than grinding common wheat grain. The grain grinding efficiency K', which corresponds to the energy necessary to obtain a set amount of flour, ranged from 57.6 (Milewo triticale) to 101.4 $kJ \cdot kg^{-1}$ (Parabola wheat) (fig. 2). Like the energy used for grinding grain, the energy used to obtain 1 kg of flour (particle size under 236 µm) was larger for common wheat than spelt or triticale.

The grain under study was characterised by vitreousness ranging from 6-62%. The relationship between grain vitreousness and the unit grinding energy was linear (fig. 3).

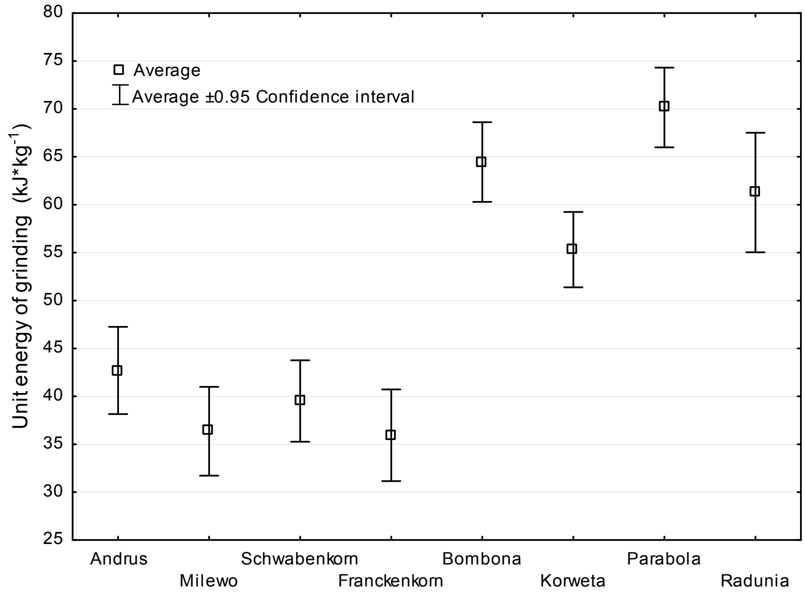

Figure 1. Average values of unit energy of grinding of the cereal grain (kJ·kg^{-1})

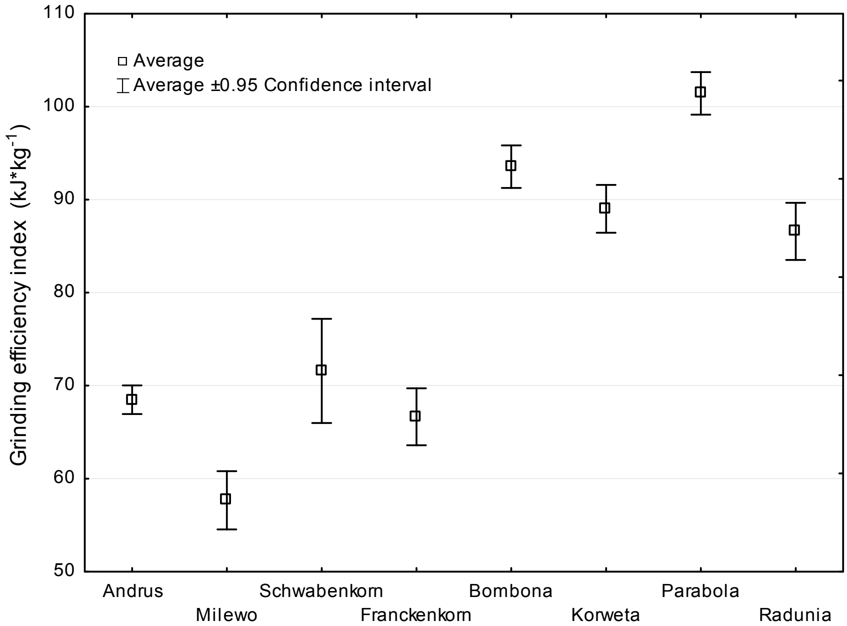

Figure 2. Average values of the index of grinding efficiency of the cereal grain

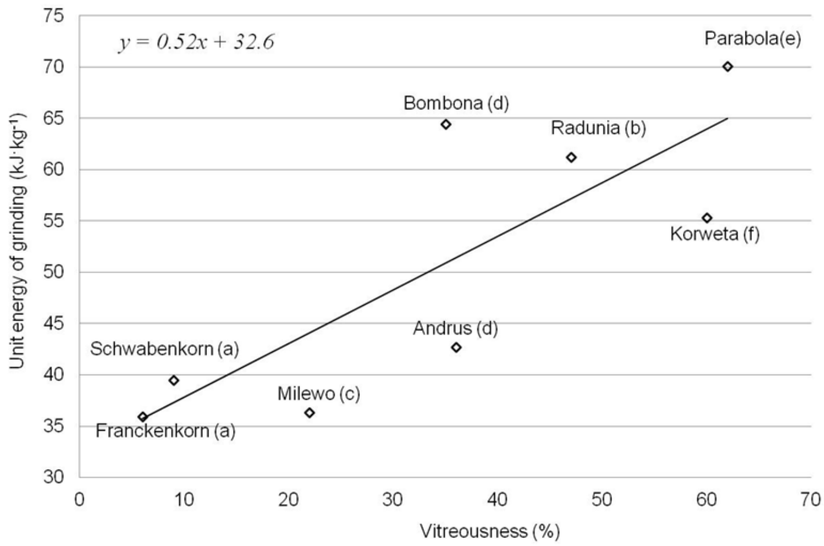

Figure 3. Dependence of the unit energy of grinding on vitreousness of grain (average values of vitreousness marked with these letters do not differ statistically significantly)

The linear correlation coefficient was 0.814 (Table 1) and was similar to that calculated by Dziki et al. (2012).

Table 1
Values of linear correlation coefficients between the researched properties

	Vitreousness	Test weight	Thousand kernel weight	Ash content
Unit energy of griding (E_r)	0.814^{**}	0.750^{**}	0.413	-0.692^{**}
Grinding efficiency index ($K^{'}$)	0.772^{**}	0.740^{**}	0.541^{*}	-0.681^{**}

* – significant at p< 0.05 ; ** – significant at p< 0.01

The relationship between grain vitreousness and energy intensity of grinding was also studied by Laskowski and Różyło (2003). They showed grain vitreousness to affect unit grinding energy and a change of vitreousness from 15% to 85% resulted in an increase in the unit grinding energy by about 68%. This confirms the findings of studies of other authors (Dziki et al., 2012; Wiercioch et al., 2008).

This is caused by the internal structure of grain, because in them – unlike in floury grain, which is characterised by a loose structure of endosperm (grains of starch are separate from one another) – grains of starch are deeply embedded in the protein matrix (Edwards, 2010). The relationship between changes of the unit grinding energy and ash content is described by a linear equation: y=-64.569x+182.25, where r=-0.692 (fig. 4). The grinding energy decreased with increasing ash content in grain. The opposite relationship between the unit grinding energy and ash content in grain was shown in a study conducted by Dziki et al. (2012).

The test weight of grain as measured in this study ranged from 65.9 to 77.2 kg·hl^{-1}.

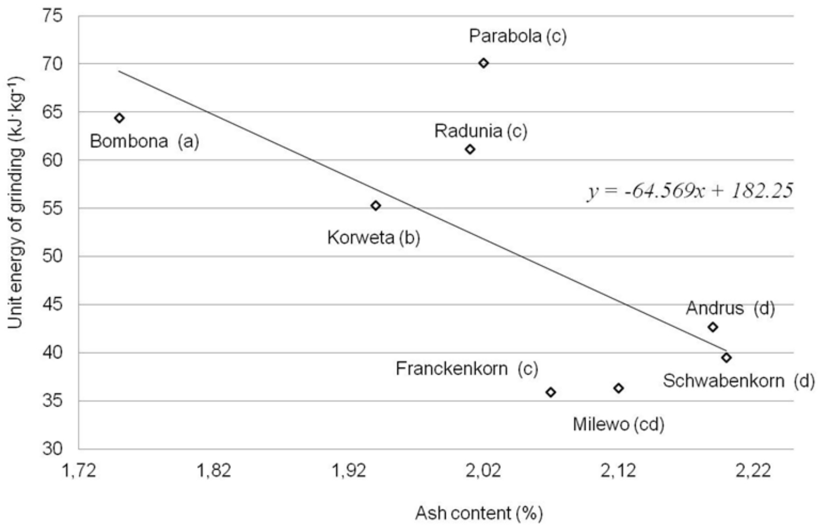

Figure 4. Dependence of the unit energy of grinding on the ash content in a grain (symbols as in figure 3)

As found in this study, a difference in vitreousness between 6% and 62% resulted in a difference in the unit grinding energy of about 95%. A number of studies (Cacak-Pietrzak et al., 2009; Laskowski and Różyło, 2003; Wiercioch and Niemiec, 2006) have indicated that grinding hard and vitreous grain requires more energy compared to floury grain. According to Cacak – Pietrzak (2009), vitreous grain is more durable and more energy is needed to grind it.

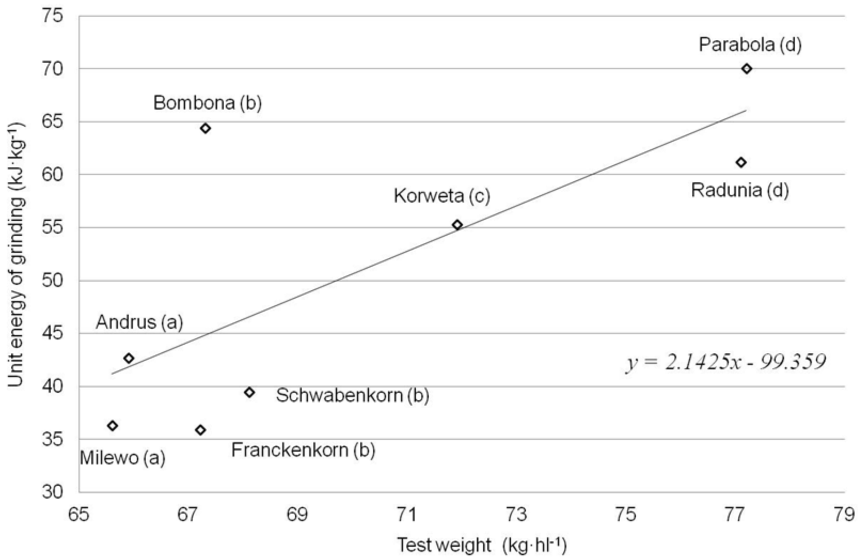

Figure 5. Dependence of unit energy of grinding on the test weight. (symbols as in figure 3)

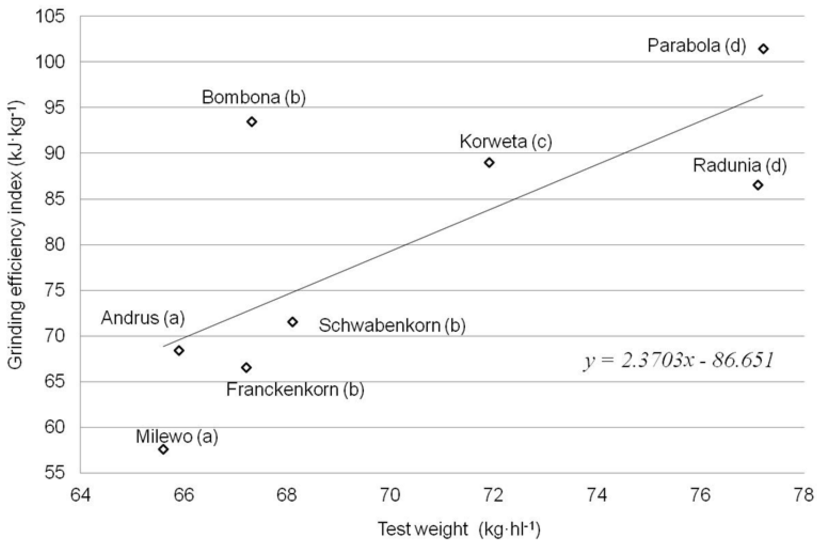

Figure 6. Dependence of grinding efficiency index on the test weight (symbols as in figure 3)

The relationship between the test weight of grain and the unit grinding energy was linear (Fig. 5). An increase in the test weight of grain was accompanied by an increase in the unit grinding energy (r=0.750). A significant correlation was found to exist between the test weight and the grain grinding efficiency index K' (fig. 6). The correlation coefficient was r=0.740. No significant correlation was found to exist between the thousand kernel weight (TKW) and the unit grinding energy. This study found a significant correlation between TKW and the grinding efficiency index K', i.e. the amount of energy needed to obtain 1 kg of flour (fig. 7).

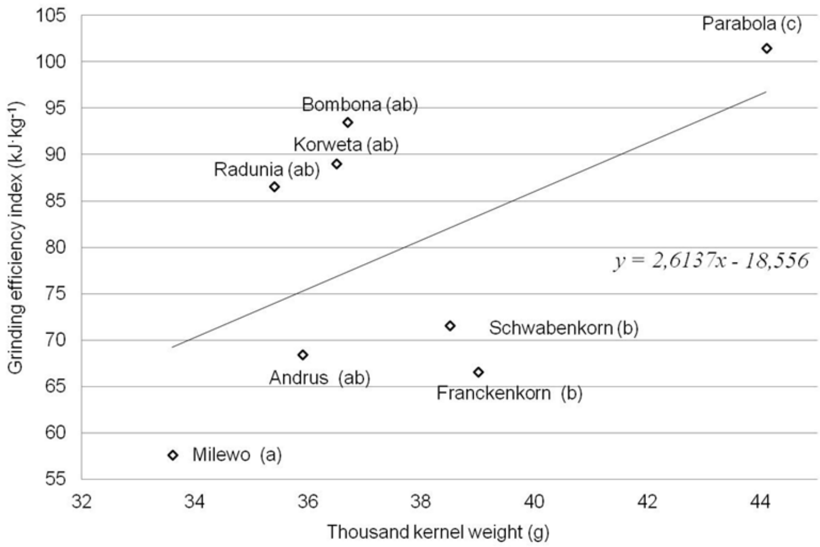

Figure 7. Dependence of grinding efficiency index on the thousand kernel weight (symbols as in figure 3)

This relationship is described by the equation: y=2.6137x–18.556; where r=0.541. It can be assumed that grinding large kernels requires more energy than grinding small ones to obtain the same amount of flour. Wiercioch et al. (2008) showed that the demand for energy needed for grinding increased with increasing kernel weight. It was found in this study that increasing the kernel weight two-fold contributed 46% to 80% to an increase in the unit grinding energy, depending on the material vitreousness.

Of the grain properties under study, vitreousness had a stronger effect on the energy consumption of grinding than the test weight or ash content (table 1).

Conclusion

1. Unit energy consumption depended on the vitreousness, test weight and ash content in grain. Unit energy consumption increases with the increase of the vitreousness and test weight, and decreases with the grain ash content.
2. The grinding efficiency index increases with increasing the vitreousness, test weight and thousand kernel weight and it decreases with the increasing ash content in grain.
3. Vitreousness influenced the consumption of energy more considerably than the test weight and grain ash content.

References

Bonafaccia, G.; Galli, V.; Francisci, R.; Mair, V.; Skrabanja, V.; Kreft, I. (2000). Characteristics of spelt wheat products and nutritional value of spelt wheat-based bread. *Food Chemistry, 68*(4), 437-441.

Cacak-Pietrzak, G.; Ceglińska, A.; Gondek, E.; Jakubczyk, E. (2009). Wpływ struktury ziarna pszenicy na proces rozdrabniania. *Postępy Techniki Przetwórstwa Spożywczego, 2*, 53-56.

Cacak-Pietrzak, G.; Gondek, E. (2010). Milling value of spelt wheat and wheat grain. *Acta Agrophysica, 16* (2), 263-273.

Danciu, C.; Danciu, I. (2011). Grinding resistance of the wheat grain related to the grinding degree for the first break in the wheat milling. *Bulletin UASVM Agriculture*, *68*(2), 235-242.

Danciu, I.; Danciu, C.; Banu, I.; Vaduva, M.; Mester, M. (2009). Researches regarding the grinding resistance of the wheat grain. *Journal of Agroalimentary Processes and Technologies, 15*(3), 393-395.

Dziki, D. (2008). The crushing of wheat kernels and its consequence on the grinding process. *Powder Technology, 185*(2), 181-186.

Dziki, D.; Cacak-Pietrzak, G.; Miś, A.; Jończyk, K.; Gawlik-Dziki, U. (2012). Influence of wheat kernel physical properties on the pulverizing process. *Journal of Food Science and Technology,* DOI 10.1007/s13197-012-0807-8.

Dziki, D.; Laskowski, J. (2002). Wpływ wielkości ziarna na wybrane właściwości pszenicy. *Inżynieria Rolnicza, 5*(38), 337-344.

Dziki, D.; Przypek-Ochab, D. (2009). Evaluation of energy consumption for crushing wheat seed with diversified hardness*.* *Inżynieria Rolnicza, 5*(114), 61-67.

Edwards, M. A. (2010). Morphological features of wheat grain and genotype affecting flour yield. PhD thesis, Southern Cross University, Lismore, NSW, 85-87. Pozyskano z: http://epubs.scu.edu.au/cgi/viewcontent.cgi?article=1232&context=theses

Fang, Q.; Haque, E.; Spillman, C.K.; Reddy, P.V.; Steele, J.L. (1998). Energy requirements for size reduction of wheat using a roller mill. *American Society of Agricultural Engineers,* 41(6), 1713-1720.

Glenn, G.M.; Johnston, R.K. (1994). Water vapor diffusivity in vitreous and mealy wheat endosperm. *Journal of Cereal Science,* 20(3), 275-282.

Greffeuille, V.; Abecassis, J.; Barouh, N.; Villeneuve, P.; Mabille, F.; Bat, L`Heloguac`h, C.; Lullen-Pellerin, V. (2007). Analysis of the milling reduction of bread wheat farina, physical and biochemical characterization. *Journal of Cereal Sciences, 45*(1), 97-105.

Kilborn, R.H.; Black, H.C.; Dexter, J.E.; Martin, D.G. (1982). Energy consumption during flour milling. Description of two measuring systems and influence of wheat hardness on energy requirements. *Cereal Chemistry, 59*(3), 284-288.

Kowalik, K.; Opielak, M. (2002). Badanie wpływu wilgotności i rodzaju ziarna zbóż na jednostkowe zużycie energii podczas rozdrabniania. *Problemy Inżynierii Rolniczej, 10*(4), 51-55.

Laskowski, J.; Różyło, R. (2003). Wpływ zawartości glutenu i szklistości na energochłonność rozdrabniania ziarna pszenicy. *Acta Agrophysica, 2*(3), 589-596.

Marks, N.; Sobol, Z.; Baran, D. (2006). Wpływ wilgotności na energochłonność procesu rozdrabniania ziarna zbóż. *Inżynieria Rolnicza, 3*(78), 281-288.

McCabe, W.L.; Smith, J.C.; Harriott, P. (2004). *Unit Operations Of Chemical Engineering.* New York, McGraw-Hill Science Engineering, ISBN 0-07-284823-5.

Opielak, M.; Komsta, H. (2001). Badanie wpływu wilgotności ziarna pszenicy na wydajność rozdrabniacza żarnowego i stopień rozdrobnienia materiału. *Inżynieria Rolnicza* 9(29), 187-192.

Posner, E.S. (2003). *Milling/Principles of Milling w* Encyclopedia of Food Science and Nutrition. (Second Edition), London, Academic Press, Harcourt Brace Jovanovich Publishers., ISBN: 978-0-12-227055-0. Pozyskano z: http://www.sciencedirect.com

Pujol, R.; Letang, C.; Lempereur, I.; Chaurand, M.; Mabille, F.; Abecassis, J. (2000). Description of a micromill with instrumentation for measuring grinding characteristics of wheat grain. *Cereal Chemistry, 77*(4), 421-427.

Romański, L.; Niemiec, A. (2000). Badanie wpływu wilgotności ziarna wybranych gatunków zbóż na energię rozdrabniania w gniotowniku modelowym. *Inżynieria Rolnicza, 9*(20), 255-259.

Scanlon, M.G.; Dexter, J.E. (1986). Effect of smooth roll grinding conditions on reduction of hard red spring wheat farina. *Cereal Chemistry, 63*(5), 431-435.

Wiercioch, M.; Niemiec, A. (2006). Energochłonność procesu rozdrabnia pszenicy ozimej o różnej szklistości przy stosowaniu gniotownika i śrutownika walcowego. *Inżynieria Rolnicza, 11*(86), 511-518.

Wiercioch, M.; Niemiec, A.; Romański, L. (2008). Wpływ wielkości ziarniaków pszenicy na energochłonność ich rozdrabniania. *Inżynieria Rolnicza, 5*(103), 367-372.

WYBRANE WŁAŚCIWOŚCI FIZYCZNE ZIARNA ZBÓŻ A ENERGOCHŁONNOŚĆ ROZDRABNIANIA

Streszczenie. W pracy określono zależności między wybranymi właściwościami ziarna zbóż, a energochłonnością rozdrabniania. Ziarna pszenicy zwyczajnej, orkiszu i pszenżyta o wilgotności 15% poddano przemiałowi wykorzystując rozdrabniacz walcowy. Ustalono relacje między energochłonnością rozdrabniania, a szklistością ziarna, masą tysiąca ziaren, gęstością usypową i zawartością popiołu w ziarnie. Jednostkowa energia rozdrabniania zależała od szklistości, gęstości usypowej ziarna oraz od zawartości popiołu w ziarnie. Ze wzrostem szklistości i gęstości usypowej ziarna zwiększało się zapotrzebowanie na jednostkową energię rozdrabniania. Wskaźnik efektywności rozdrabniania zwiększał się wraz ze wzrostem szklistości, gęstości usypowej oraz masy tysiąca ziaren, a zmniejszał się ze wzrostem zawartości popiołu w ziarnie. Szklistość ziarna wywierała silniejszy wpływ na energochłonność rozdrabniania niż gęstość usypowa i zawartość popiołu.

Słowa kluczowe: Słowa kluczowe: ziarna zbóż, rozdrabnianie, właściwości fizyczne, energochłonność