THE ENERGY-CONSUMING INDEXES OF WHEAT KERNEL GRINDING PROCESS

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INTRODUCTION

Grinding is one of the most important and energy-consuming processes in food industry. It consumes from 50 to 70% of the total power during flour production [5]. In fact, only about 1% of grinding energy is transformed into receiving a new surface [12]. The main cause of such large energy loss are plastic and elastic strains [8].

The energy consumption during grinding depends on the kinematic and geometric parameters of a grinding machine and physical properties of thew grinding material. From among the physical properties of kernel the greatest influence on power demand during the grinding process is exerted by mechanical properties [11], especially hardness of kernel [2, 7]. Therefore it is important to evaluate the influence of kernel mechanical properties on energy-consuming indexes of wheat grinding process.

Many of the studies describing the grinding energy is aimed at the determination of only the specific grinding energy [6, 15], but this index does not take into account the grinding ratio. Therefore the aim of the present work was to determine other kernel energy-consuming indexes of the grinding process, the hardness of kernel, and interrelations between them for Polish wheat cultivars.

MATERIALS AND METHODS

Polish cultivars of winter (Izolda, Juma, Maltanka) and spring (Banti, Henika) wheat (T. aestivum) were used for the investigation. The kernels were evaluated for moisture content (according PN-93/A-74012 method) and particle size distribution using the sorter Steinecker-Vogl. On the basis of the obtained particle size distributions the average particle size (D) was calculated [4].

Hardness was measured using Single Kernel Characterization System 4100 (Perten Instruments, USA). About 300 single kernels were individually weighed and crushed during sample measurement. Mean hardens index was automatically calculated from the single kernel data [3].

Subsequently samples of wheat were tempered for 24 hours to 14 % moisture and ground using roller mill and hammer mill.

The samples were milled using SK laboratory roller mill. Four grinding stages were applied. The roll gap was 0.85 mm for the first stage, 0.4 mm for the second stage, 0.25 mm for the third stage and 0.15 mm for the fourth stage. The detailed description of the laboratory mill has been provided by Dziki et al [1].

The grinding process was carried out on the laboratory hammer mill POLYMIX-Micro-Hammermill MFC applying the methodology described by Laskowski and Łysiak for 1.0 mm screen size [10]. The peripheral speed of hammers was 94 $m \cdot s^{-1}$.

The changes in the power consumption of the electric current during the grinding process were recorded using laboratory equipment including a grinding machine, transducer of power and a special data acquisition card connected to a PC computer and operated with special computer software [1, 10].

The total grinding energy (E_c) was calculated according to the equation:

$$E_c = \int_0^t P dt \quad \text{(J)} \tag{1}$$

where:

P – the power consumption during grinding process (W),
t – the time of grinding (s).

It was assumed that the power consumption in the kernel grinding process is the difference between the total grinding power and the loss of power transmission system during idle running [13]. The loss of energy in the power transmission system was calculated according to the equation:

$$E_s = \int_0^t P_j dt \quad \text{(J)} \tag{2}$$

where:

P_j – the power consumption during idle running (W).

The specific grinding energy was calculated according to the formula:

$$E_r = \frac{E_c - E_s}{m} \quad \text{(J/kg)} \tag{3}$$

where:

m – the mass of the grinding sample (kg).

After grinding, the particle size distribution was evaluated using laboratory screen Thyr 2. On the basis of the obtained particle size distributions the average particle size was calculated [4].

The grinding ability index was calculated as a ratio of the grinding to the area of the grinding material [2]:

$$E_f = \frac{E_r \cdot \rho \cdot d}{6} \qquad (\mathrm{J/m^2}) \tag{4}$$

where:

ρ – the density of the grinding material (for calculation was taken 1300kg/m^3 [9]),
d – the average particle size of the ground material (m).

The grinding efficiency index was calculated as a ratio of grinding energy to the quantity of product:

$$E_m = \frac{E_r \cdot m}{m_p} \qquad (\mathrm{J/kg}) \tag{5}$$

where:

m_p – the mass of the obtained product (kg).

As a product the fraction of particles below 0.2 mm was taken.

The grinding index K was calculated on the basis of the size reduction theory described by Sokołowski [16]:

$$K = \frac{E_r}{\frac{1}{\sqrt{d}} - \frac{1}{\sqrt{D}}} \qquad (\mathrm{J/kg/m^{0,5}}) \tag{6}$$

where:

D – the average particle size of the material before grinding (m).

Measurements were carried out in 10 repetitions for each wheat cultivar. The obtained data were subjected to variance analysis. The differences among means were evaluated by the Ducan`s test procedure. The coefficients of correlation between energy-consuming indexes of wheat grinding process and kernel hardness were evaluated. The values of means followed by the same letter in the figures were not significantly different (α = 0.05).

RESULTS

The results showed that the highest value of SKCS hardness index was obtained for wheat cultivars Juma and Maltanka (mean 73). The kernel of Banti wheat was characterized by the lowest hardness index (mean 27). For wheat cultivars Juma and Begra similar hardness was observed (mean 65).

The specific grinding energy is one of the most frequently determined parameters characterizing the grinding process. Grinding by a roller mill showed that the lowest value of specific grinding energy was obtained for Banti wheat (18 kJ/kg). The other wheat cultivars were characterized by significantly higher and similar values of specific grinding energy (mean 25 kJ/kg). Grinding by a hammer mill showed a similar tendency, but the values of energy were several times higher. The lowest value of specific grinding energy was obtained for Banti wheat (129 kJ/kg). The other wheat cultivars were characterized by significantly higher values of this index (mean 150 kJ/kg). Mean values of specific grinding energy are presented in Fig. 1.

The specific grinding energy depends mainly on mechanical properties of kernel. Kilborn et al [1982] showed that the total energy consumption for the milling process ranged from 46 kJ/kg for soft wheat cultivars to 124 kJ/kg for *durum* wheat.

The relation between total specific grinding energy obtained for a hammer mill (E_{rb}) and roller mill (E_{rw}) was described according the equation:

$$E_{rb} = 3{,}013 \cdot E_{rw} + 75{,}316; \quad r = 0{,}942 \tag{7}$$

The analysis of particle size distribution of ground kernel received from a roller mill showed that the highest value of average particle size was obtained for Banti wheat (0.42 mm). The average particle size for the other cultivars was similar and significantly lower (0.39 mm).

The result obtained for a hammer mill showed that the highest value of average particle size was received for Maltanka cultivar (0.28 mm). Lower and significantly different values of this parameter were observed for the wheat Banti, Henika and Izolda (0.25 mm).

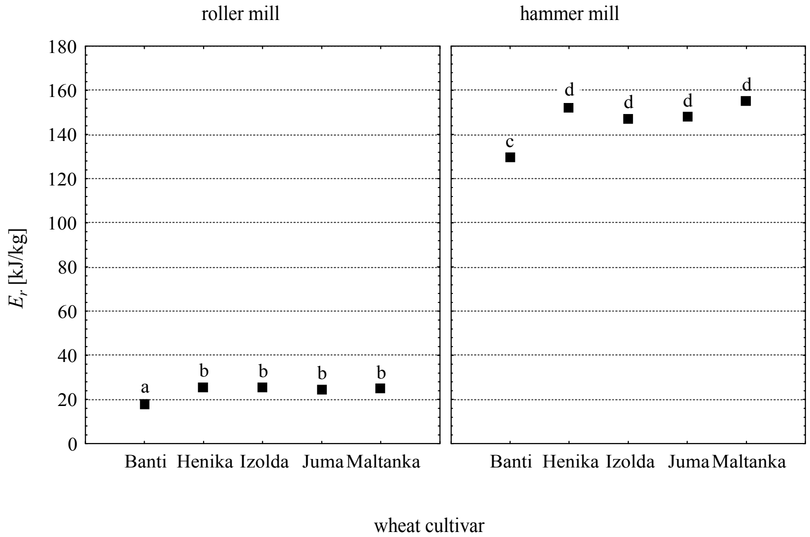

Fig. 1. The specific grinding energy of wheat cultivars obtained for a roller mill and a hammer mill

The results of the grinding ability index were presented in Figure 2. Grinding by using a roller mill showed that the lowest value of this index was obtained for Banti wheat kernel (1.65 kJ/m^2). The values obtained for other wheat cultivars were similar and significantly higher (2.2 kJ/m^2). Grinding by a hammer mill showed that the highest grinding ability index was received for Maltanka wheat (9.4 kJ/m^2). Significantly lower values were obtained for the other cultivars and the lowest grinding ability index was received for Banti wheat (6,9 kJ/m^2).

Grinding by a roller mill showed that the values of grinding ability index of wheat kernel were from 3.6 to 4.2 times higher than the values obtained by using the roller mill. However, the specific grinding energy was higher from 5.7 to 7.2 for a hammer mill.

The specific grinding energy does not take into consideration the grinding ratio. A better parameter is the grinding ability index, which takes into consideration the particle size after grinding.

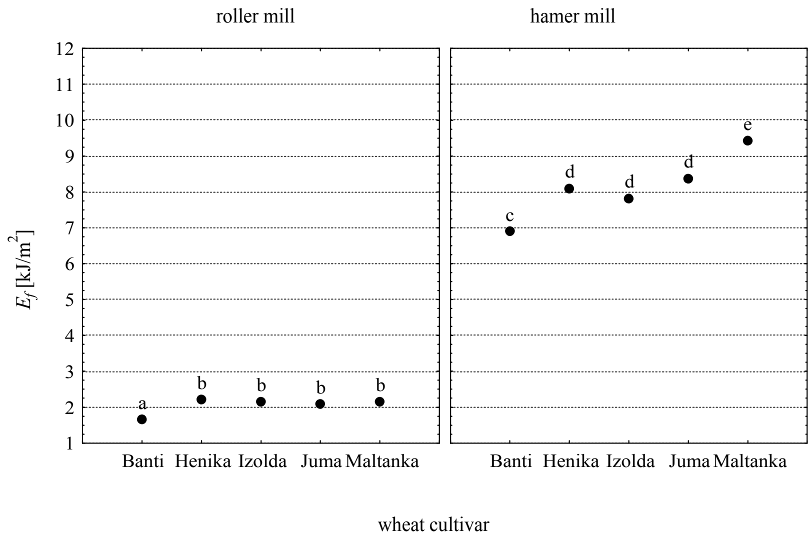

Fig. 2. The grinding ability index of wheat cultivars obtained for a roller mill and a hammer mill

From the economic point of view it is important to determine the grinding efficiency index, which expresses the ratio of grinding energy to the quantity of flour. Grinding by using a roller mill showed that the lowest values of this index were obtained for wheat cutivars Batni, Henika and Izolda (mean 254 kJ/kg of product). Significantly higher values were received for Juma and Maltanka wheat (mean 285 kJ/kg of product). A similar tendency was observed for a hammer mill. The lowest values of grinding efficiency index were obtained for wheat cutivars Batni, Henika and Izolda (mean 415 kJ/kg of product). Significantly higher values were received for Juma and Maltanka wheat (476 kJ/kg of product and 568 kJ/kg of product). The results of grinding efficiency index were presented in Figure 3.

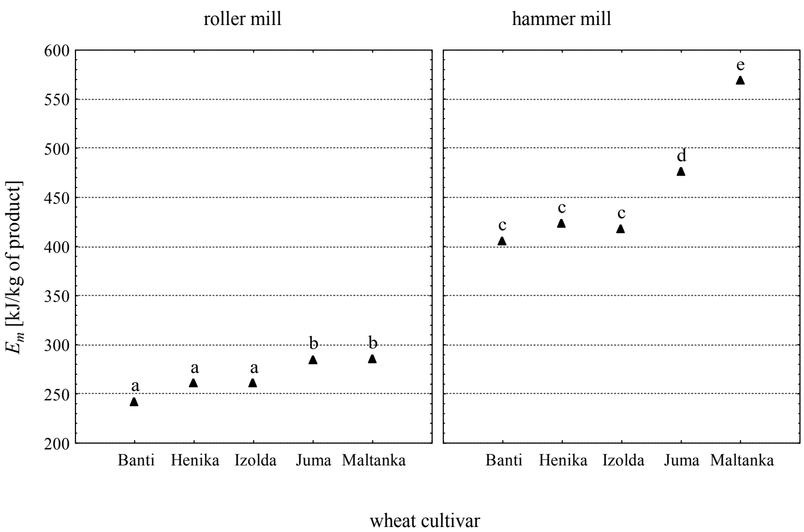

Fig. 3. The grinding efficiency index of wheat cultivars obtained for a roller mill and a hammer mill

The grinding efficiency index obtained by using a hammer mill was from 1.6 to 2.0 times higher than the one obtained by using a roller mill.

The parameter which characterizes the grinding material and the grinding machine is also the grinding index K. For samples ground on a roller mill the lowest grinding index K was obtained for Banti wheat (17 kJ/kg/mm^{0,5}). The values of this index received for the other wheat cultivars were significantly higher and similar (mean 23 kJ/kg/mm^{0,5}). A similar tendency was observed for hammer mill (fig. 4). The lowest value of grinding index K was obtained for Banti wheat (85.7 kJ/kg/mm^{0,5}). A significantly higher value was observed for other wheat cultivars and the highest grinding index was obtained for Maltanka cultivar (112.5 kJ/kg/mm^{0,5}).

The grinding index K obtained by using a hammer was from 4.3 to 4.6 times higher than the one obtained by using a roller mill.

The character of changes of the grinding index K obtained for individual wheat cultivars and fragmentizers was similar to the changes of the grinding ability index. The correlation coefficient for both the used fragmentizers was higher than $r > 0.99$.

The grinding index K, among other things, characterizes well the mechanical properties of the grinding material. Pujol et al [14] shoewed that the grinding index K for the milling process ranged from 22 kJ/kg/mm^{0,5} for soft wheat cultivars to 54 for *durum* wheat.

The higher values of energy-consuming indexes of the grinding process obtained for a hammer mill resulted mainly from using a sieve and it had an influence on the grinding ratio. It was also caused by grinding the bran layer, which is several times more resistant to grind than endosperm.

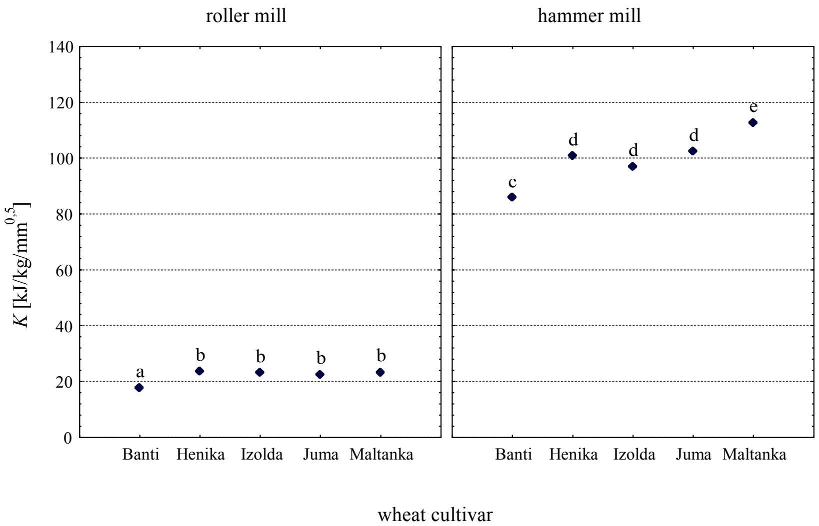

Fig 4. The grinding index *K* of wheat cultivars obtained for roller mill and hammer mill

The milling by a roller mill makes the grinding ratio of the bran layer lower. Therefore the values of energy-consuming indexes of the grinding process are lower, but so is the grinding ratio.

The results showed significant correlations between SKCS hardens index and the following parameters describing the grinding process by a roller mill: average particle size index (r = -0.889), specific grinding energy (r = 0.944), grinding efficiency index (r = 0.942) and grinding index K (r = 0.957). However, grinding by a hammer mill showed significant correlations between hardness of kernel and specific grinding energy (r = 0.962) and grinding index K (r = 0.893).

CONCLUSIONS

The results showed that:

1. The best material to grind was the kernel of Banti wheat. For this cultivar and both the used fragmentizers the lowest values of specific grinding energy (18 kJ/kg and 129 kJ/kg), grinding ability index (1.66 kJ/m^2 and 6.89 kJ/m^2) and grinding efficiency index (242 kJ/ kg of product and 405 kJ/kg of product) were obtained.

2. All the obtained indexes showed that grinding by a hammer mill is more energy consuming. It resulted mainly from using a screen and it had an influence on the grinding ratio.

3. The results showed that for a description of the grinding process the grinding ability index and the grinding index K are better indexes than the specific grinding energy. These indexes take into consideration also the size of particles after grinding.

4. Grinding by a roller mill and a hammer mill showed that as the kernel hardness increased, the specific grinding energy and grinding index K increased too.

5. The energy-consuming indexes of the grinding process could be a tool for an assessment of grinding machines and a search for energy saving possibilities by a correct selection of fragmentizers and their parameters.

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SUMMARY

The energy-consuming indexes of wheat kernel grinding process were evaluated. The results showed that the grinding ability index and the grinding index K are better parameters than the specific grinding energy, because these indexes take into account the size of ground particles. Hardness of kernel had a significant influence on energy-consuming indexes. During the work of grinding machines, as kernel hardness increased, the specific grinding energy and the grinding index K increased too. The best material to grind was Banti wheat. The lowest values of energy-consuming indexes were obtained for kernel of this cultivar.