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INFLUENCE OF KERNEL SIZE ON GRINDING PROCESS OF WHEAT AT RESPECTIVE GRINDING STAGES

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Key words: kernel size, wheat, grinding process

The aim of the present work was to determine the influence of kernel size on wheat grinding properties. The samples of kernel were divided into three fractions according to different thickness: small (2.0–2.5 mm), medium (2.7–2.9 mm) and large (3.1–3.5 mm). The results showed that the kernels size had an influence on bulk density, PSI hardness index and ash content. As kernel size increased, the bulk density also increased. The large kernels (fraction 3.1–3.5 mm) had the lowest values of PSI hardness index and ash content. Laboratory milling results showed that the kernel size had the largest influence on grinding process at the first grinding stage. After the first grinding stage of small kernels (fraction 2.0–2.5 mm), the highest values of average particle size, grinding ability index and grinding efficiency index and the lowest values of total flour yield were observed. The flour obtained from fraction 2.0–2.5 mm also had the highest ash content. This shows that the energy-consuming indices can be a useful tool for describing the grinding process.

INTRODUCTION

Knowledge of the grinding properties of grain is essential to adjust the correct parameters of grinding and sieving machines. It is the best way to produce higher and better-quality flour yields. In spite of this, many millers describe the baking rather than the milling properties of grain.

A wheat milling value assessment is performed with indirect and direct methods. The indirect methods are based mainly on an evaluation of kernel physical tests such as hardness and other mechanical properties, bulk density, vitreosity and thousand-kernel weight [Kiryluk & Gąsiorowski, 1999]. Among the chemical properties of grain it is the ash content that is mainly evaluated [Spiegel & Klabunde, 1995]. On the basis of these properties, a miller can draw an indirect conclusion about the grain behaviour during the milling process and about the properties of flour. However, the best direct method to determine the milling value is experimental milling performed by using various laboratory mills. The objective of this method is to simulate the milling process in such a way as to provide quantitative, qualitative and energy-consuming indices of this process. However few publications exist concerning evaluating the energy-consuming indices of the grinding process.

The milling properties of wheat depend mainly on the mechanical properties of kernel. However the mechanical properties depend, among others, on kernel size [Janiak & Laskowski, 1993]. Even in the midst of the same wheat cultivar small and large kernels differ in chemical composition [Li & Posner, 1987]. Therefore, the aim of the present work was to determine the influence of kernel size on wheat milling properties, especially on the energy-consuming indices of the grinding process.

MATERIALS AND METHODS

The influence of kernel size on wheat milling properties was evaluated with the use of Polish winter wheat cultivar (*T. aestivum*) Juma collected in 1997. This cultivar belongs to class B and is common in the production of bread-stuffs flour [Szymczyk, 2001]. A detailed description of technological value of used cultivar has been given by Dziki and Laskowski [2002a]. The particle size distribution of kernel was evaluated and the average particle size of kernel was calculated [Grochowicz, 1996]. The samples of kernel were divided into three fractions according to different thickness: small (2.0–2.5 mm), medium (2.7–2.9 mm) and large (3.1–3.5 mm). To divide the samples, a Vogl sorter was used. The fractions were evaluated for bulk density [PN-ISO7971-2:1998], hardness according to PSI method [AACC 55-30: 1995], and wheat ash [PN-ISO2171:1994]. The moisture of wheat kernel was 13% (±0.2%). Subsequently 100 g samples of wheat fractions were tempered for 24 h to 15% (±0.2%) moisture and milled.

The samples were milled using laboratory equipment made in INRA Montpellier (France). The laboratory equipment included a vibratory feeder, laboratory mill and measurement system (two transducers of torque and two transducers of roll speed collaborated with an Advantech PCL818L data acquisition card) connected to a PC computer and operated with special computer software.

The mill was equipped with Moulin Chopin-Dubois rolls measuring 50 mm in length and 80 cm in diameter. The rolls were either corrugated (30°/60° profile, 8 corrugations/cm, 13% inclination). The roll configuration was dull-to-dull with a fast roll rotational speed of 500 rpm and a slow roll speed of 250 rpm. Three grinding stages were applied. The

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roll gap was 0.7 mm for the first stage, 0.15 mm for the second stage and 0.04 mm for the third stage. The milling stock was sized and quantified by sieving. The sieving was performed for 5 min on a laboratory rotary screen Rotex and the oversized fractions were then weighed. Figure 1 shows the applied milling diagram.

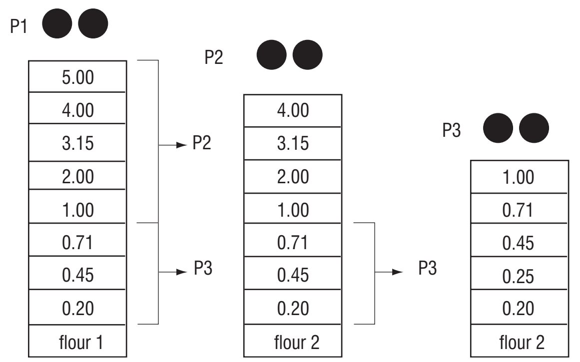

FIGURE 1. The milling diagram used (dimensions of sieves in mm): P1, P2, P3 – the first, the second and the third stage.

After each stage, samples were evaluated for size distribution, average particle size [Grochowicz, 1996] and flour yield. The total yield and flour ash content [PN-ISO2171:1994] were also evaluated. The index of milling efficiency KP was calculated as the ratio of total flour yield to flour ash.

The rotational speed of rolls and torque for each roll was recorded during the grinding process. The energy requirements for each roll (E_1 and E_2) were calculated according to the equation:

$$E_1 = \frac{\omega_1}{M}\int_0^T A_1(t)dt \quad (1)$$

$$E_2 = \frac{\omega_2}{M}\int_0^T A_2(t)dt \quad (2)$$

The roll angular velocities (ω_1, ω_2) were almost constant during the grinding period (T). M represents the mass of milled wheat fraction whereas A_1 and A_2 represent the areas under the torque curves.

The total specific milling energy was calculated using the equation:

$$E = E_1 + E_2 \quad (3)$$

A detailed description of laboratory equipment and the method of milling energy measurement has been provided by Pujol *et al.* [2000].

The grinding ability index (E_f) was calculated as the ratio of grinding energy to area of grinding material [Kiryluk & Różycka, 1996]. The grinding efficiency index E_m was also calculated as the ratio of specific milling energy to the quantity of flour.

The grinding index parameter was calculated on the basis of size reduction theories described by Sokołowski [1996]:

$$E = K\left(\frac{1}{\sqrt{d}} - \frac{1}{\sqrt{D}}\right) \quad (4)$$

where E is the total specific milling energy and D and d represent the particle size of the product before and after milling.

Measurements were replicated three times for each fraction. The data obtained were subjected to a statistical analysis. The evaluations were analyzed for variance analysis. The significant differences among means were evaluated by Duncan's multiple range test (α=0.05). The values followed by the same letter in the table and the figures were not significantly different.

RESULTS AND DISCUSSION

Table 1 shows the bulk density, hardness and ash content of different wheat fractions. The bulk density was significantly different between respective fractions of kernel. As kernel size increased, the bulk density also increased (from 748 to 810 kg/m^3). The higher bulk density, the better the technological value of the wheat. Smaller kernels can have a substantially smaller ratio of endosperm to coat and germ. Endosperm has greater density than bran and thus has a smaller kernel bulk density [Gaines *et al.*, 1997]. In addition, large kernels are more spherical. Dziki and Laskowski [2002b] showed the strong positive correlation between the bulk density of wheat and coefficients of sphericity.

TABLE 1. Bulk density, PSI hardness index and ash content affected by kernel size.

Fraction of kernel (mm)	Bulk density (kg/m^3)	PSI hardness index (%)	Ash content (%)
2.0–2.5 (small)	748^a	11.1^a	1.682^a
2.7–2.9 (medium)	785^b	11.2^a	1.590^b
3.1–3.5 (large)	810^c	10.4^c	1.583^b

Values designated by the different letters are significantly different (α = 0.05).

The results showed the significant influence of kernel size on PSI hardness index and ash content. The large kernels (fraction 3.1–3.5 mm) had the lowest PSI hardness index and ash content.

Pomeranz *et al.* [1985] found a similar dependency between kernel size and kernel hardness. The variables of grain hardness within the same cultivar can result from the differences in maturation. Smaller kernels develop later. Being late, they do not fill out well during the grain-filling period and may become shriveled and softer, because they had less time to develop [Gaines, 1986].

The effect of kernel size on the average particle size of milling stock is shown in Figure 2. After the first stage, as kernel size increased, the average particle size of milling material decreased (form 1.16 to 0.95 mm). After the second and the third stage, the average particle size for large (3.1–3.5 mm), medium (2.7–2.9 mm) and small kernels (2.0–2.5 mm) was not statistically different.

During grinding, the size of ground particles determines the quantity of material delivered for next stage and hence has an influence on load grinding and sieving machines. The differences in the average particle size of ground material can result from the differences in the mechanical properties of small and large kernels. The differences also result from changes in the size of grinding zone. In a roller mill, the size of kernel has an influence on the size of grinding zone [Hague, 1991]. The forces of interactions for large kernels during grinding are larger.

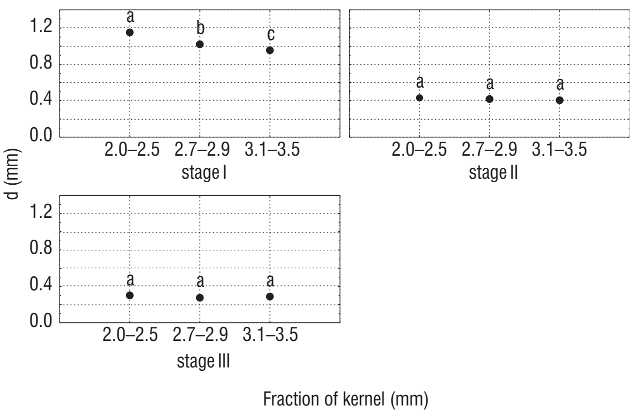

FIGURE 2. The influence of kernel size on the average particle size of ground material (d) for respective grinding stages (values designated by the different letters are significantly different, $\alpha = 0.05$).

After the first grinding stage, the lowest yield of flour was obtained for the fraction 2.0–2.5 mm (5.6%). Significantly more flour yield was obtained for fractions 2.7–2.9 mm and 3.1–3.5 mm (6.4 and 7.3% respectively). After the second stage, kernel size had no significant influence on flour extraction, but after the third stage, the highest flour yield was obtained from grinding material acquired from the medium (2.7–2.9 mm) and large (3.1–3.5 mm) fraction. The flour yield for medium (2.7–2.9 mm) and large (3.1–3.5 mm) kernels after the second and the third grinding stage was not significantly different (Figure 3).

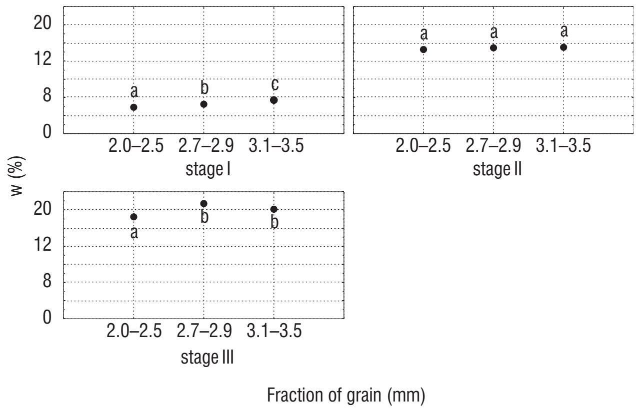

FIGURE 3. The influence of kernel size on flour yield (w) for respective grinding stages (values designated by the different letters are significantly different, $\alpha = 0.05$).

The lowest total flour yield was obtained for the fraction 3.1–3.5 mm. However no significant differences were observed between total flour yield obtained for medium (fraction 2.4–2.9 mm) and large kernels (3.1–3.5 mm) (Figure 4).

The flour ash ranged from 0.528% for the fraction 3.1–3.5 mm to 0.629% for small kernels (fraction 2.0–2.5 mm). The flour ash of the fraction 2.0–2.5 mm was significantly lower than the flour ash content of the medium (2.7–2.9 mm) and large kernels (3.1–3.5 mm) (Figure 4). The higher level of mineral substances in the flour obtained from small kernels may be caused by the lower resistance of small kernels coat to grinding and the higher content of ash in small kernels (Table 2).

The highest value of milling efficiency index was obtained for the fractions 2.7–2.9 mm and 3.1–3.5 mm. For

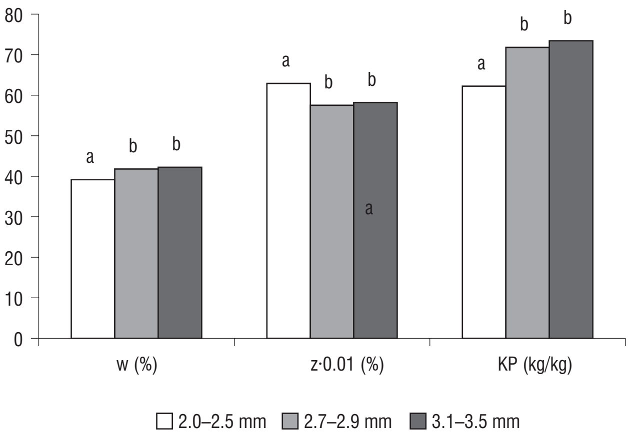

FIGURE 4. The influence of kernel size on the total flour yield (w), ash content (z) and milling efficiency index (KP) (values designated by the different letters are significantly different, $\alpha = 0.05$).

small kernels (2.0–2.5 mm), a significantly lower value was obtained (Figure 4).

At the first grinding stage the kernel size had an influence on the specific milling energy. The highest value of this parameter was observed for the fractions 2.7–2.9 mm and 3.1–3.5 mm (mean 14.3 kJ/kg). A significantly different value of this index was obtained for kernels 2.0–2.5 mm thick (13.2 kJ/kg). No significant differences were observed between the specific milling energy for medium and large kernel. On the second and the third passage, kernel size had no influence on the specific milling energy (Figure 5).

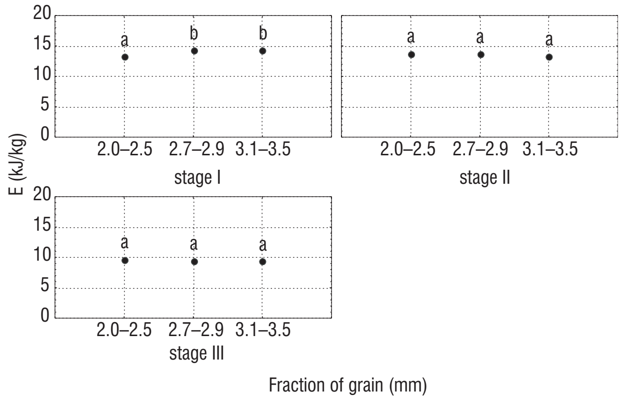

FIGURE 5. The influence of kernel size on specific milling energy (E) for individual grinding stages (values designated by different letters are significantly different, $\alpha = 0.05$).

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

The obtained results indicated that the kernel size has also an influence on the specific milling energy on the first grinding stages. This can be caused by the differences in the size of the grinding zone for small and large kernels and the differences in the resistance properties of kernels.

The results showed that the kernel size influenced the grinding ability index for individual grinding stages. After the first stage, as kernel size increased the grinding ability index decreased from 3.3 to 2.9 kJ/m^2. After the second stage, an inverse tendency was observed as the lowest value of grinding ability index was obtained for the fraction

2.0–2.5 mm (0.92 kJ/m^2). The values obtained for the grinding stock medium (2.7–2.9 mm) and large (3.1–3.5 mm) fractions were not significantly different. The kernel size had no influence on the grinding ability index after the third grinding stage (Figure 6).

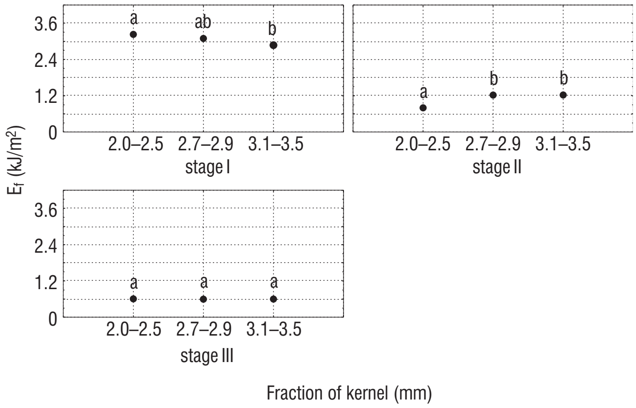

FIGURE 6. The influence of kernel size on grinding ability index (E_f) for individual grinding stages (values designated by the different letters are significantly different, $\alpha = 0.05$).

The kernel size had a similar influence on the grinding efficiency index. This index could be a very useful prediction tool for millers. It expresses energy consumption per quantity of flour produced. After the first grinding stage, the grinding efficiency index ranged from 196 kJ/kg of flour for the fraction 3.1–3.5 mm to 237 kJ/kg of flour for the fraction 2.0–2.5 mm. After the second stage, an inverse tendency was observed as the lowest value of grinding ability index was obtained for the grinding stock of fraction 2.0–2.5 mm (85 kJ/kg of flour). The values obtained for medium (2.7–2.9 mm) and large (3.1–3.5 mm) fraction of kernels were not significantly different. The kernel size had no influence on the grinding index after the third grinding stage (Figure 7).

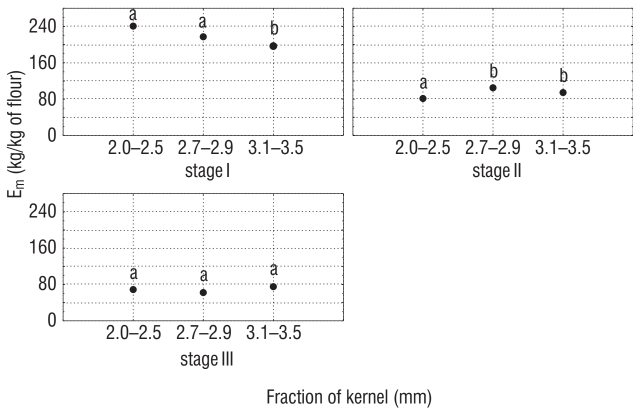

FIGURE 7. The influence of kernel size on grinding index (E_m) for individual grinding stages (values designated by the different letters are significantly different, $\alpha = 0.05$).

The effect of kernel size on the grinding index parameter was shown in Figure 8. After the first grinding stage, as kernel size increased the grinding index decreased from 33.2 kJ·kg^{-1}·mm$^{0.5}$ for the fraction 2.0–2.5 mm to 27.0 kJ·kg^{-1}·mm$^{0.5}$ for the fraction 3.1–3.5 mm. The inverse relationship was observed after the second stage. The highest grinding index value was found for particles obtained for the fraction 3.1–3.5 mm (24.8 kJ·kg^{-1}·mm$^{0.5}$) and the lowest for particles of small kernels (21.8 kJ·kg^{-1}·mm$^{0.5}$). Kernel size had no significant influence on the grinding index after the third grinding stage.

The grinding index characterizes the mechanical properties of the grinding material very well. Pujol *et al.* [2000] observed that values of K parameter range from 22 kJ·kg^{-1}·mm$^{0.5}$ for soft wheat cultivar to 54 kJ·kg^{-1}·mm$^{0.5}$ for *durum* wheat.

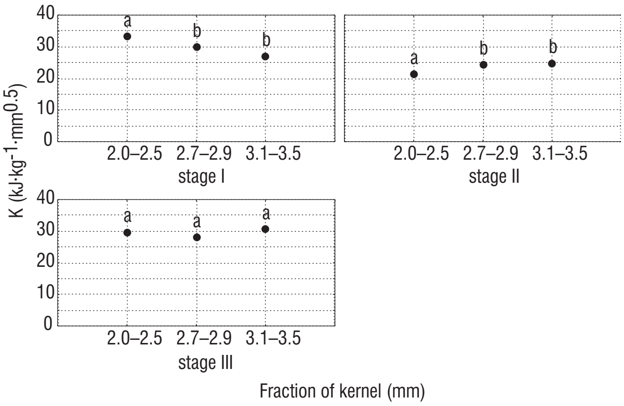

FIGURE 8. The influence of kernel size on grinding index (K) for individual grinding stages (values designated by the different letters are significantly different, $\alpha = 0.05$).

CONCLUSIONS

The results showed that the kernel size had significant influence on grinding properties of the investigated cultivar of wheat. As the kernel size decreased the bulk density also decreased. The fraction 3.1–3.5 mm had the lowest PSI hardness index values and ash content.

The results obtained on the basis of laboratory milling indicated that the kernel size had the largest influence on grinding process in the first grinding stage. The fraction of kernel 2.0–2.5 mm was more difficult to grind than the fraction of kernel 3.1–3.5 mm. After the first grinding stage of small kernels (2.0–2.5 mm), the highest values of the average particle size of grinding stock, grinding ability index, grinding efficiency index, grinding index and the lowest values of flour yield were observed.

It was also found that kernel size had an influence on the total flour yield and the flour ash content. The highest flour yield with the lowest ash content was obtained for the fraction 3.1–3.5 mm.

On the basis of these results it can be concluded that the work parameters of the grinding rolls should be adjusted to kernel size. Moreover, the energy-consuming indices could be a useful tool for describing and optimization of the grinding process.

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WPŁYW WIELKOŚCI ZIARNA NA PROCES MIELENIA PSZENICY NA POSZCZEGÓLNYCH PASAŻACH PRZEMIAŁOWYCH

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Celem pracy było określenie wpływu wielkości ziarna na właściwości przemiałowe pszenicy. Ziarno podzielono na frakcje o różnej grubości: 2,0–2,5 mm, 2,5–2,7 mm i 3,1–3,5 mm. Na podstawie uzyskanych wyników badań stwierdzono, że wraz ze wzrostem wielkości ziarna zwiększała się gęstość usypowa. Frakcja ziarna 3,1–3,5 mm charakteryzowała się najniższym wskaźnikiem twardości PSI oraz najmniejszą zawartością popiołu (tab. 1). Wyniki otrzymane na podstawie przemiału laboratoryjnego wykazały, że wielkość ziarna ma największy wpływ na zachowanie się surowca podczas mielenia na pierwszym pasażu przemiałowym. Po pierwszym pasażu przemiałowym ziarna drobnego (frakcja 2,0–2,5 mm) uzyskano największy średni wymiar cząstki mlewa (rys. 2) oraz najwyższe wartości energochłonności jednostkowej mielenia, wskaźnika podatności ziarna na mielenie oraz wskaźnika efektywności mielenia (rys. 6 i 7). Również z ziarna najdrobniejszego otrzymano najniższy całkowity wyciąg mąki o najwyższej zawartości popiołu (rys. 4). Wykazano, że wskaźniki energochłonności przemiału mogą być użytecznym narzędziem do opisu tego procesu.