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EFFECT OF THE SIZE OF TRITICALE KERNEL ON MILLING ENERGY CONSUMPTION, FLOUR YIELD AND GRANULOMETRIC COMPOSITION OF FLOUR

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Key words: triticale, kernel size, energy consumption of milling, particle size, flour.

Abstract

This study assessed the effect of kernel size on the milling properties of triticale grain, particularly on the flour yield, energy consumption of the milling process and the granulometric composition of flour. The samples of two spring triticale varieties were segregated by kernel size into four kernel-size fractions. The grain fractions were milled in a Brabender Quadrumat Jr. roll mill.

The kernel size had a significant effect on flour yield and on the milling efficiency coefficient. The milling yield increased with an increased triticale kernel size. The energy required to produce 1 kg of flour from triticale grain increased gradually, assuming the lowest value for the smallest kernels and the highest value for the kernel thickness fraction from 2.75 to 3.0 mm. The kernel size was found to have an effect on the protein and ash content in the flour. Flour milled from the smallest-kernel fraction had a significantly lower protein content and a higher ash content. Segregating grain into kernel-size fractions before milling caused significant changes in the minimum and average size of the flour particles.

WPŁYW WIELKOŚCI ZIARNA PSZENŻYTA NA ENERGOCHŁONNOŚĆ PRZEMIAŁU, WYDAJNOŚĆ I SKŁAD GRANULOMETRYCZNY MĄKI

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Słowa kluczowe: pszenżyto, wielkość ziarna, energochłonność przemiału, wielkość cząstek, mąka.

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Abstrakt

Celem badań była ocena wpływu wielkości ziarniaków na właściwości przemiałowe ziarna pszenżyta, w szczególności na energochłonność przemiału oraz wydajność i skład granulometryczny mąki. Ziarno dwóch odmian pszenżyta jarego było segregowane na podstawie wielkości na cztery frakcje rozmiarowe. Każdą z uzyskanych frakcji ziarna mielono w młynie walcowym Brabender® Quadrumat Jr.

Wielkość ziarniaków miała znaczący wpływ na wydajność mąki i współczynnik efektywności mielenia. Wraz ze wzrostem wielkości ziarna pszenżyta zwiększała się wydajność mąki. Energia wymagana do wyprodukowania 1 kg mąki z ziarna pszenżyta stopniowo rosła, przyjmując najniższą wartość dla ziaren najmniejszych i najwyższą wartość dla frakcji ziaren o grubości od 2,75 do 3,0 mm. Stwierdzono wpływ wielkości ziarna na zawartość białka i popiołu w uzyskanej mące. Mąka z ziaren frakcji najmniejszych charakteryzowała się istotnie niższą zawartością białka i wyższą zawartością popiołu w porównaniu z mąką z pozostałych frakcji. Segregacja ziarna przed przemiałem na frakcje rozmiarowe spowodowała istotne zmiany w minimalnej i średniej wielkości cząstek uzyskanych mąk.

Introduction

Triticale is hybrid obtained by crossing wheat and rye. Although triticale is utilized as feed for animals, it also has great potential to be exploited as an alternative cereal in human nutrition (BOROS 2006), particularly in the production of bread and other food products (PÉREZ et al. 2003, OLIETE et. al. 2010). Due to its agronomic (resistance to wheat and rye diseases and to lodging, good winter hardiness characteristics, lower soil requirements and better resistance to drought compared to wheat) and nutritional advantages (a good source of protein with beneficial amino acid composition), triticale is acknowledged as a cereal which can help in combating world hunger (PISULEWSKA et al. 2000, AMMAR et al. 2004, MERGOUM et al. 2009, MCGOVERIN et al. 2011).

There are reports in the literature on the relationship between wheat kernel size and flour yield and flour ash. Large-kernel samples have significantly higher flour yield than smaller kernels (DZIKI and LASKOWSKI 2004, BAASANDORJ et al. 2015). However, GAINES et al. (1997) demonstrated that milling qualities were independent of kernel size.

Other studies have supported the hypothesis that kernel size plays a role in the physicochemical properties of wheat. DZIKI and LASKOWSKI (2004) reported that kernel size has an influence on bulk density and PSI hardness index and large kernels had the lowest values of PSI hardness index and ash content. KONOPKA et al. (2007) reported that kernel size has an influence on grain protein composition. The albumin/globulin and glutenin fractions showed a trend to reduce with diminishing kernel size. MORGAN et al. (2000) indicated significant positive correlations between kernel size and farinograph indicators and baking water absorption. LI et al. (2008) demonstrated that kernel hardness and water absorption of flour increased with increasing kernel thickness and decreasing kernel specific density. In turn, OHM et al. (1998)

reported that bread volumes had significant negative correlations with single weight and single kernel diameter.

Kernel size is of interest not only in wheat, but also in other cereals, such as barley, oat and rice (DOEHLERT et al. 2002, SÝKOROVÁ et al. 2009). Relatively little is known about the effect of triticale kernel size on milling and the granulometric composition of flour. Although the size of cereal grain has been already studied, it was connected to the granulometric composition of flour obtained from kernels of various sizes. The particle size distribution of flour is a very important property from a technological point of view, since it affects subsequent processing steps. The objective of this study was to determine the effect of kernel size on milling properties of triticale grain, especially on the milling efficiency, energy-consumption and the particle size distribution of flour.

Materials and Methods

The grains of two Polish (soft) triticale cultivars: Andrus and Milewo (a spring cv.), were the subject of the study. Triticale was cultivated at the Experimental Farm (53°73'N 20°41'E) of the University Warmia and Mazury, Olsztyn, in north-eastern Poland. Kernels of each cultivar were cleaned using a "cereal cleaning mill" (winnower) and a separator Type SŻD, Sadkiewicz® Instruments, Poland. Grain after harvest was dried to a moisture content below 15% and screened on sieves with rectangular openings widths of 2.50, 2.75, 3.00 mm using a sieve shaker Analysette 3 Pro., Fritsch®, Germany. Four kernel fractions were obtained, with respective thickness > 3.00 (F_1); 3.00 > F_2 > 2.75; 2.75 > F_3 > 2.50 and F_4 < 2.50 mm. Shriveled and broken kernels were discarded before sieving. Thousand kernel weight (TKW) was measured for each sample with the use of an electronic kernel counter (Kernel Counter LN S 50A, Unitra Cemi, Poland) and an electronic scale WPE 120 (Radwag, Poland d = 2 mg).

The samples of kernels (105 g ± 0.10 g) from each triticale kernel fraction (15% moisture content, wet basis) were weighed on a WLC 2/A1 electronic scale (d = ±10 mg) (Radwag®, Poland) and were milled using an a Quadrumat® Junior Mill (Brabender®, Germany). The energy consumption of the milling process was determined (WARECHOWSKA 2014) and the coefficient of milling efficiency K' (kJ kg^{-1}) (GREFFEUILLE et al. 2006) was calculated using the following formula:

$$K' = \frac{E_c - E_s}{m} \tag{1}$$

where:
E_c – the total energy consumed [kJ]
E_s – energy in idle mode [kJ]
m – mass of flour [kg].

Flour moisture was determined on duplicate samples by oven drying (Type UFB 500, Memmert® GmbH+ Co. KG, Germany) 5 g for 2 h at 135°C and then allowing the samples to cool before weighing. The ash content in the flours was obtained after milling (*Determination of ash...* ICC STANDARD NO. 104/1). The protein content in triticale flours was determined by the Kjeldahl method (*Determination of crude...* ICC STANDARD NO. 105/2) with a KjelFlex K-360 (Büchi, Germany).

The particle size distribution of flour received from the mill was obtained with Laser Diffraction Analysis (LDA) with a Malvern Mastersizer 2000 (version 5.22, Malvern Instruments Ltd, Malvern, UK). The measurement was started within 20s after the placement of the specimen in the sample dispersion unit. The result of the measurement was expressed as the mean value from six separate repetitions. On this basis, the average particle size of flour (d_{avg}) was determined as a general parameter characterizing the granulometric composition. It was calculated as the sum of the products of the volumetric part (φ_i) and the average size of each fraction (d_i) with the following formula (VELU et al. 2006):

$$d_{\mathrm{avg}} = \sum_{i=1}^{n} \varphi_i d_i \tag{2}$$

where:
φ_i – share of the size fraction i in the studied sample [kg kg^{-1}],
d_i – average size of fraction i particles [μm].

The sieve mesh sizes were also calculated corresponding to the passage of 10%, 50% and 90% volume of the sample respectively $d(0.1)$, $d(0.5)$ and $d(0.9)$. They were used as indexes of the smallest, median and maximum particle size of flour, respectively. The relative width of particle size distribution (SPAN) was determined as:

$$\mathrm{SPAN} = \frac{d(0.9) - d(0.1)}{d(0.5)} \tag{3}$$

The data was statistically analyzed and a variance analysis was performed. The significance of differences between the means was evaluated with Tukey's test. The statistical calculations were performed with STATISTICA® for Windows v. 10 (StatSoft Inc.). The statistical hypotheses were tested at a significance level of $p = 0.05$.

Results

The share of fraction triticale grains and thousand kernel weight is demonstrated in Table 1. Each of the triticale cultivars had a similar share percentage of individual grain fractions. Kernels of thickness >3.00 mm predominated, and their content ranged from 52% to 60% (cv. Milewo and Andrus, respectively). The mean thousand kernel weight (TKW) was observed to decrease linearly for particular fractions from 50.5 (large kernels) to 22.5 g (small kernels). TKW values decreased by about 55% from large to small kernels.

Table 1

Fractional share and thousand kernel weight

Grain fraction	Share of fraction [%]	TKW [g]
Cultivar		
Andrus		
F_1	60.0^c	52.0^d
F_2	10.0^a	43.0^c
F_3	21.0^b	32.0^b
F_4	9.0^a	23.0^a
Milewo		
F_1	52.0^c	49.0^d
F_2	11.0^a	39.0^c
F_3	22.0^b	30.0^b
F_4	14.0^a	22.0^a
Fraction		
F_1	56.0^c	50.5^d
F_2	10.5^a	41.0^c
F_3	21.0^b	31.0^b
F_4	11.5^a	22.5^a

a, b, c – means followed by the same letter in the column do not differ from each other by Tukey test ($P<0.05$).

Kernel size had a significant effect on the flour yield (Table 2). The flour yield (FY) increased with increasing triticale kernel size, regardless of genotype. The flour yield was highest when the largest kernels were milled (62.3% on average) and it was the lowest for small kernels (57.5% on average).

Table 2

Effect of kernel size on flour yield and quality characteristics

Grain fraction	FY [%]	FAC [%]	FPC [%]	$d(0.1)$ [μm]	$d(0.5)$ [μm]	$d(0.9)$ [μm]	d_{avg} [μm]	SA [m^2Wm^{-3}]	SPAN [-]
Cultivar									
Andrus									
F_1	61.9^d	0.58^b	10.70^b	20.07^b	127.31^b	297.07^b	143.43^b	0.182^b	2.180^a
F_2	60.7^c	0.53^a	10.10^a	18.49^a	114.90^a	290.87^b	135.15^a	0.198^a	2.370^a
F_3	58.1^b	0.57^{bc}	10.00^a	18.42^a	113.72^a	298.63^b	136.74^a	0.197^a	2.460^a
F_4	55.4^a	0.64^c	10.20^a	18.15^a	113.04^a	287.51^a	134.20^a	0.201^a	2.380^a
Milewo									
F_1	63.3^c	0.52^{bc}	12.50^b	21.41^b	127.08^b	311.00^b	147.48^b	0.159^a	2.280^a
F_2	61.7^b	0.50^a	12.00^a	19.74^b	120.89^b	303.47^a	141.71^b	0.180^a	2.347^a
F_3	61.2^b	0.54^b	11.80^a	20.76^b	128.50^b	307.24^a	146.49^b	0.161^a	2.229^a
F_4	59.7^a	0.63^c	11.90^a	18.27^a	110.56^a	307.66^a	138.20^a	0.193^b	2.617^b
Fraction									
F_1	62.6^c	0.55^a	11.60^b	20.74^b	127.19^b	304.03^a	145.45^b	0.170^a	2.230^a
F_2	61.2^{bc}	0.52^a	11.05^a	19.12^a	117.90^b	297.17^a	138.43^a	0.189^a	2.360^a
F^3	59.7^b	0.56^a	10.90^a	19.59^a	121.11^b	302.94^a	141.62^a	0.179^a	2.340^a
F_4	57.5^a	0.64^b	11.05^a	18.21^a	111.80^a	297.59^a	136.20^a	0.197^a	2.500^a

a, b, c, d – means followed by the same letter in the column do not differ from each other by Tukey test ($P<0.05$).

For different kernel size fractions, the flour quality characteristics were also evaluated. The flour ash content (FAC) ranged from 0.52% for the fraction 2.75–3.00 mm (F_2) to 0.64% for small kernels (F_4). The flour ash content of the fraction 2.00–2.50 mm was significantly higher ($p < 0.05$) than the flour ash contents of other fractions. Small kernels had an approx. 23% increase in flour ash content compared to the kernels from fraction F_2. Kernel size has a significant effect on the flour protein content (FPC). The protein content was found to be statistically significantly higher in the flour obtained from the largest kernel size fraction (11.60% on average) compared to the flours from smaller kernels. The protein content was higher in the flour obtained from the largest kernel size fraction (11.60% on average) than the flours from smaller kernels.

As shown in Figure 1, kernel size had an effect on the milling efficiency coefficient K'. The greatest amount of energy consumed to produce flour was for milling kernel fraction F_2 of both the Andrus and Milewo cultivars (82.9 and 84.1 kJ kg^{-1} of flour, respectively). The milling efficiency coefficient was similar for the kernels of the F_1 and F_4 fractions of each of the tested triticale varieties, thus forming a homogeneous group.

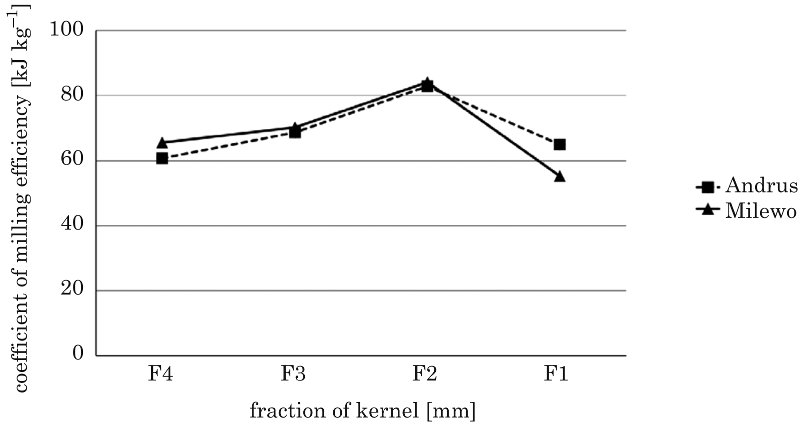

Fig. 1. The influence of kernel size on milling efficiency coefficient (K')

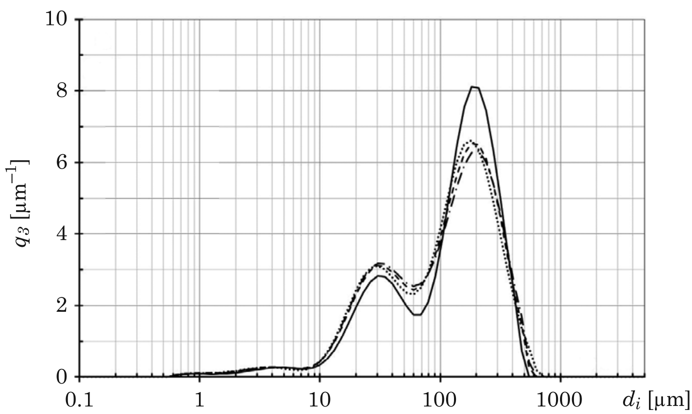

Fig. 2. Granulometric compositions of flours, obtained from different fractions of Andrus triticale grains (Brabender Quadrumat Junior Mill)

From each of milled triticale samples, a multi-modal distribution flour was obtained (Figure 2, Figure 3). The flour was almost entirely composed of two main fractions (a flour particle size of about 30 and about 200 µm) and of two residual fractions with modal values below 10 µm (about 0.8 and about 4 µm). The total share of both residual fractions for each material did not exceed 4% of the obtained flour. The proportions of the main size fractions in the flours obtained from triticale grain of the Milewo cultivar remained the same, regardless of the kernel fraction they were obtained from. A different result was found for the Andrus cultivar. From the kernel fractions from F_2 to F_4, flours were obtained which had a granulometric composition similar to that

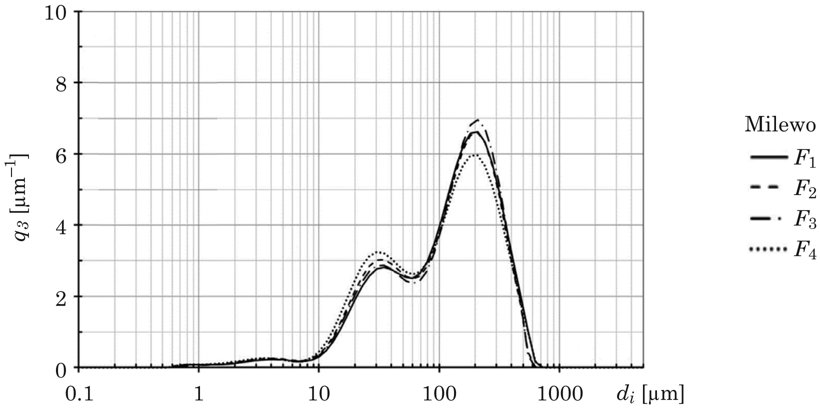

Fig. 3. Granulometric compositions of flours, obtained from different fractions of Milewo triticale grains (Brabender Quadrumat Junior Mill)

of the flours from the Milewo cultivar grain. By milling the largest kernel size fraction, flours were obtained which had different proportions of the main size fractions (Figure 2) – the proportion of the 200 μm fraction increased in relation to the 30 μm fraction. The minimal and the average size of the particles of flour and the median for triticale cultivars depended on the kernel size of the milled grain. The mentioned parameters were highest when flour was obtained from the largest kernels (F_1) and were the lowest when flour was obtained from small kernels (F_4). For the flour obtained from the remaining kernel size fractions (F_2, F_3), the differences in the parameters $d(0.1)$, $d(0.5)$ and d_{avg} were not statistically significant (Table 2). An analysis of the flour specific surface area (SA) showed it to assume significantly different values for milled thick kernels (F_1) of the cultivar Andrus and for the milled smallest kernels (F_4) of the Milewo cultivar. The flour specific surface area value does not depend on kernel size, if the cultivar is not taken into consideration.

The SPAN of the granulometric compositions of the obtained flours formed one homogeneous group. A difference was observed only for the granulometric composition of the flours obtained from the F_4 triticale kernel fraction (the cultivar Milewo) – by milling this kernel fraction, the flour which had the least homogeneous composition was obtained (2.617).

Discussion

Kernel size had a significant effect on most of the tested characteristics of both the triticale grain and the flour obtained from the grain. The thousand kernel weight of triticale increased with increasing kernel size. Many studies concerning wheat show similar results (KONOPKA et al. 2007, BAASANDORJ et al. 2015). The lower weight of small kernels is connected with the endosperm being filled with proteins and starch to a lesser degree. During the initial stage of grain development, the endosperm cells are filled with starch granules to a lesser degree than during the final stage. The protein weight fraction is higher during the initial stage of grain development than during the final stage. This is connected with kernel size. Although during the initial stage of grain development the kernels are smaller, during the later stage they mature and become thicker with the endosperm cells and starch granules becoming larger (LI et al. 2013).

Flour yield increased with increasing triticale kernel size. According to BAASANDORJ et al. (2015) the starchy endosperm proportion in the wheat grain may determine significant differences in flour yield between kernel size fractions. Since the endosperm proportion is higher in large kernels, they have the potential to ensure higher flour yield than small kernels. According to EDWARDS et al. (2008), there is a genetic association between starch granule size distribution and flour yield. The flour yield is higher for the wheat varieties with larger starch granules (GAINES et al. 2000). Flour yield increases with an increasing proportion of the large *A*-type starch granules to the small *C*-type starch granules in wheat grain (EDWARDS et al. 2010). According to the study by LI et al. (2013), wheat kernels of different thickness differ in the proportion of the three types of starch granules *A*, *B*, and *C*. The share of the *A*-type starch granules decreases gradually with decreasing kernel thickness, and in the wheat endosperm of minimal thickness they are not present at all. The proportion of the *B*-type starch granules in the wheat endosperm increases gradually with decreasing kernel thickness, but the proportion of the *C*-type starch granules remains at a certain stable level for wheat kernels of various thicknesses. For smaller kernel sizes, the proportions of the *A*- and *C*-type starch granules and flour yield decrease. Milling efficiency is lower for triticale than for wheat and protein loss during milling tends to be greater for triticale than for wheat (DENNETT and TRETHOWAN 2013a). According to POSNER and HIBBS (1997) the grain protein content decreases with increasing kernel size. Greater protein loss was also observed for milling small kernels, which was also confirmed by BAASANDORJ et al. (2015). In their study, the difference between the wheat grain protein content and the protein obtained from grade flour was greatest for small kernels. In the current study, the protein content in the flour obtained from the largest kernels was the highest and it differed significantly from the protein contents in the flours from the other kernel fractions, as was found by KONOPKA et al. (2007). The total grain protein data for different kernel sizes is not clear. KONOPKA et al. (2007) found the wheat grain protein content decreased with decreasing kernel size and the flours obtained by milling the extreme kernel fractions differed in protein content and composition. In that study, the flours obtained from the largest kernels had the highest protein contents.

Lower flour ash content indicates less contamination with bran and germ (KIM and FLORES 1999). Flour ash content depends on both flour extraction percentage and total triticale ash content but also on ash distribution within the kernel which, in turn, depends on environmental conditions (LORENZ 1977, ANDO et al. 2002, RHARRABTI et al. 2003). The ash content in flour obtained from the smallest triticale kernels was much higher than for the other kernel fractions, which confirms the results of the former studies (DZIKI and LASKOWSKI 2004, BAASANDORJ et al. 2015). The high flour ash content for the fraction 2.0–2.5 could be due to the low proportion of endosperm relative to the bran and aleurone layer, which are rich in ash. According to BAASANDORJ et al. (2015), the high ash content for flour milled from small kernels might be partly due to the fixed roll gap in a mill. As a result, less bran might be removed from small kernels, resulting in poor separation of bran and germ from the endosperm. It needs to be highlighted that the ash contents in the flours obtained from triticale are higher than in those obtained from wheat, in spite of the equal, or even lower, flour extraction rate. This is the result not only of the bran layer being thicker in triticale compared to wheat, but also of the higher mineral content in the endosperm (DENNETT and TRETHOWAN 2013a, DENNETT and TRETHOWAN 2013b).

Measurement of *K*' obtains indications on the mechanical behavior of the grain during the milling process (GREFFEUILLE et al. 2006). Kernel size had a significant effect on the triticale coefficient of milling efficiency (*K*'). The energy necessary to produce 1 kg of flour from triticale grain increased gradually, assuming the lowest value for the smallest kernels and the highest value for the kernel thickness fraction from 2.75 to 3.0 mm. According to FANG et al. (1998), more energy is required to mill wheat with a larger kernel size than to mill wheat with a smaller kernel size. Such a relationship may explain the comparable amount of energy being consumed to produce the same amount of flour from the largest and smallest kernel thickness fractions of triticale grain. To mill small kernels, a smaller amount of energy is consumed and the obtained flour extraction rate is the lowest, while for milling the largest kernels, a greater amount of energy is consumed and the flour extraction rate is the highest. The obtained data may also be the result of differentiated single kernel hardness for kernels of different thickness. BAASANDORJ et al. (2015) found middle-size wheat kernels to be the hardest (HI SKCS) and the small kernels to be softest. Hard wheats require a greater amount of energy to produce the same amount of flour than soft wheats (PUJOL et al. 2000, GREFFEUILLE et al. 2006).

Conclusions

The kernel size had a significant effect on flour yield. The milling yield increased with increasing the kernel size of triticale. The smallest kernels showed worse millability with lower flour yield and higher flour ash content than large-sized kernels. The energy necessary to produce 1 kg of flour was the largest for the kernel thickness fraction of 2.75–3.00 mm. Flour of triticale grain from the smallest-kernel fraction had a significantly lower protein content and a higher ash content than flour from other kernel fractions. Segregating grain into kernel-size fractions before milling caused significant changes in the minimal and the average size of the particles of the flours.

Separating small and large kernels from each other may improve both flour yield and quality and optimize the working parameters of the machines used for cleaning and milling grain in grain processing.

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