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Milling of Different Moisture Content Wheat in Mills with Fluted Rolls

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Abstract

In the paper are presented the experimental part of some researches regarding power and specific energy consumption for wheat seeds grinding (variety Dropia, the harvest of 2011) with a pair of fluted rolls (with distance between rolls of 1 mm and differential of 2.5:1), with six different moisture contents (between 10% and 18%). Also, the moisture content of initial material was put in correlation with the mean diameter of grinded particles, determined by particle size distribution analysis, and with grinding degree. This correlation is expressed by the distribution function of power or exponential type, the correlation degree having relatively high values. However, the correlation between the power required for grinding and moisture content was tested with known distribution laws (power, exponential or logarithmic), the paper presenting the degree of correlation between these.

Key words: *grinding, wheat, moisture content, grinding degree, mean diameter.*

Introduction

The physical characteristics of wheat seeds directly influence their grinding process. Shape, size, volumes, density, specific surface, humidity of seeds are important physical properties in analysis the behavior of grain during grinding process, including in roller mills [1].

Moisture content in wheat seeds is distributed differently between endosperm and bran, which significantly influences the grinding process [2].

All physical properties of wheat seeds, mainly size, depending on the moisture content. Thus, for wheat variety Shiraz [3], to a moisture content of 8%, wheat seeds sizes have mean values of 6.78 mm for length, 3.45 mm for width and 2.48 mm for thickness. For moisture content of 12% and 18% the sizes changed as follows: the length had a mean value of 6.86 mm and 7.04 mm, width – 3.47 mm and 3.50 mm, thickness 2.74 mm and 2.82 mm. Weight of 1000 seeds had values of 20.13 g to 24 g, for moisture content of 8% to 18%. The same was demonstrated by Tabatabaeefer in [6], who evaluated the physical properties of five wheat varieties at different moisture contents. Similar observation were made in [4] for three varieties of wheat in Serbia.

Increase grain moisture results in their increased porosity, while the bulk density and density decreases. This has been shown by many researchers [3, 5, 6]. Thus, K. Kheiralipour (2008) showed that with increasing the moisture content from 8% to 18% wheat seeds porosity increased from 0.42% to 0.44%. Also, for increasing the moisture content from 0% to 22% the density decreases from 1240 to 847.2 kg/m^3 [6]. For the same moisture content, in paper [4] was determined bulk density and density for two durum wheat varieties (Dragana and Simonida) and a soft wheat variety (NS 40S) from Serbia. It has been shown that between values of density and bulk density of the tow durum wheat varieties no significantly difference (density – 1103.5 kg/m^3 – Simonida and 1150.52 kg/m^3 – Dragana; bulk density – 791.34 kg/m^3 – Simonida and 788.51 kg/m^3 - Dragana), but that are higher than the values of soft wheat variety (density was 1075.56 kg/m^3, and bulk density 731.77 kg/m^3). This is explained by the fact that soft wheat seed endosperm is less dense in comparison with durum wheat seed endosperm.

Humidity is the amount of water contained in seed mass, expressed as a percentage, reported in wet weight of substance (100) [7, 8]. Wheat seed moisture content can vary from 8% (arid zone) to 14% (temperate zone) [9]. Depending on the moisture content, in processing, the wheat seeds are classified as follows: dry seeds with moisture content < 14 %; semidry seeds – 14.1-15.5 %; wet seeds – 15.6-17 %; seeds very wet – moisture content > 17 %, [2, 7].

The seeds with low moisture content (12.5% - 12.8%) have a low elastic characteristic in dynamic stresses, they are fragile and easily broken, requiring low energy consumption for grinding, [10]. For moisture content ranging from 17 % to 18%, the seeds behave as elastic bodies, requiring high energy consumption for grinding, especially for seed [10, 11].

For any kind of wheat is an optimal moisture for which the grinding process goes well. In the grinding process coat humidity must be higher than the endosperm humidity [8].

If the wheat seeds are excessive wetting, than the working capacity of machines on the grinding technological flow decreased, because the wheat seeds soften and wet endosperm adheres to surface work. On the other hand, an insufficient wetting has a negative influence on the grinding process, because it determines the crushing of coat to the size of flour and appearance of its inseparable mixture of flour [8].

It is known that the main mechanisms of fracture (grinding) of the material in the grinding process, in roller mills, are those crushing (compressive) and shear.

When a wheat seed has low moisture content, it is fragile and when the grinding forces are applied the seed is broken into coarse particles of polyhedral form, fine and very fine particles. If continuous force application, seeds begin to deform elastically, then forces produce some plastic deformation before they crack or break. This is caused by crack propagation from stress points, which, normally, are contact points [12].

Applying forces on the seeds with higher moisture content resulting in obtaining a wide range of particles size close, less fine particles and may result even flat clusters. A wet wheat seed is relatively soft, and when applying a force it deforms elastically, to some extent. Even if the applied force increase, before breaking, a seed is able to maintain the plastic deformation, more than one dry [12]. Shear stress tends to break the wet seeds along different fracture planes [12].

This paper presents the results of experimental researches on the power required to grinding wheat seeds (variety Dropia, the harvest of 2011) with a pair of fluted rolls (with distance between rolls of 1 mm and differential of 2.5:1) with six different moisture contents (10% and 18%).

Material and Method

Experimental researches were performed on the wheat seeds from Dropia variety growth in the South-East of Romania, production from 2011. The researches aimed to determine the influence of seed moisture on their grinding degree and on the mean diameter of grist and specific energy consumption.

For experimental determinations five samples of Dropia wheat seeds were first subjected to a wetting process to change the moisture content, which was initially about 10%.

To bring the moisture content to values of 14%, 15%, 16%, 17% and 18% it was determined initial amount of water and then the seeds were sprinkled, homogenized and placed in sealed vessels and left to rest about 30 hours. Initial mass of the seeds samples was 500 g for 10% moisture content and time trial of 30 s.

The samples were grinded with a laboratory stand with two fluted rolls and differential about 2.5:2 (fig. 1). The length of fluted rolls is 345 mm and the diameter is 110 mm. Flutes have inclination 0 to the horizontal, and their number is 310 flutes around the circumference. The speed of fast roll was about 550 rot/min. During grinded process, in all cases, the roll gap was set to e = 1 mm. After grinding the grist was analyzed with a particle size analyzer equipped with 5 overlapping sieves model Analysette 3 Spartan.

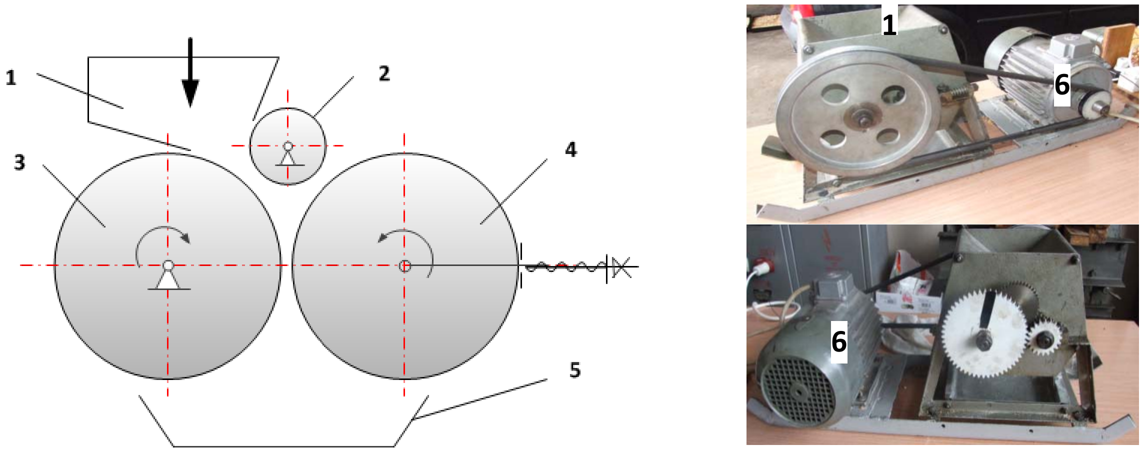

Fig. 1. Laboratory roller mill scheme:
1-feeding hopper; 2-feeding roll; 3-fast grinding roll; 4-slow grinding roll;
5-collection tray; 6-electric motor drive

Measurement and data acquisition on intensity of electrical current, necessary to calculate the consumed power to grinding the 6 material samples, were used an acquisition card NI USB-6008 and a current sensor ACS 758-CB. Processing of the results obtained from measurements for the current intensity was performed using LabVIEW graphical programming.

Grinding index λ and mean diameter d_m (finesses or grist module), of grist particles were determined by sieve analysis using particle analyzer with overlapping sieves, arranged in descending order from top to bottom in terms of mesh size.

Grinding index, denoted by λ, represent the ratio between mean equivalent particle size before grinding, D_e, and after grinding, d_m, or the ratio of the surface area of particles results in the grinding process, S_f and initial specific surface particle subjected to grinded, S_i [13,14]:

$$\lambda = \frac{D_e}{d_m} \quad \text{or} \quad \lambda = \frac{S_f}{S_i} \tag{1}$$

Mean diameter can be determined with the equation:

$$d_m = \frac{\sum_{i=0}^{n} m_i d_i}{\sum_{i=0}^{n} m_i} \tag{2}$$

where: d_i is the mean diameter of the fraction particles of sieve i, considered the arithmetic mean of sieves holes sizes containing fraction i; m_i is the percentage of fraction i (material collected on the sieve *i – 1*).

An actual value of power required was calculated with the equation:

$$P = \sqrt{3} \cdot U \cdot I \cdot \cos\varphi \quad \text{(kW)}, \tag{3}$$

Power required for grinding was determined by the difference between value obtaining to operating in load and value obtained to operating in no load.

Energy specific consumption was calculated with equation:

$$E = \frac{P}{Q} \quad \text{(kJ/kg)} \tag{4}$$

Were made in correlation the initial moisture content of material with grinding index using power distribution function (5), linear function (6) and exponential function (7), with mean diameter of grist particle using power function and linear function and with power consumed using power function, lognormal function (8) and exponential function.

The distribution functions used for correlations are:

- Power distribution function:

$$y = ax^b \tag{5}$$

- Linear distribution function:

$$y = a + bx \tag{6}$$

- Exponential distribution function:

$$y = ae^{-bx} \tag{7}$$

- Lognormal distribution function:

$$y = \frac{a}{x} \cdot e^{-(b\ln x - c)^2} \tag{8}$$

where *a* and *b* are coefficients experimentally determined, taking into account the physical characteristics of the material and constructive characteristics of the grinding machine.

Results and Discussions

Grinded material aspect to mention content moisture is shown in Figure 2.

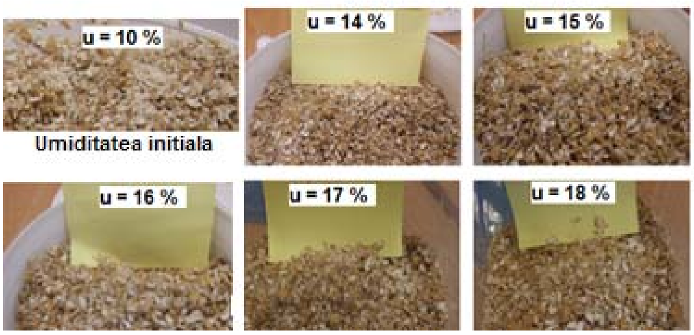

Fig. 2. Grinded material aspect for all six moisture contents

Data obtained from sieve analysis and power measurements as well as calculations are presented in Table 1.

In the graphs in Figure 3 are shows the variations of particles mean diameter obtained from grinding in mill with fluted rolls, depending on the moisture content. Variation curves were drawn by regression analysis of experimental data with power and liner distribution laws.

Table 1. Experimental researches results on grinding index of wheat seeds

Sample	Moisture content (%)	Mean diameter of grist particles, d_m (mm)	Grinding index, λ	Current intensity, I (A)	Power, P (W)	Energy consumed, W (kJ/kg)
Sample 1	10	1.59	2.26	10.06	3141.195	188.47
Sample 2	14	2.07	1.73	8.25	2576.03	154.56
Sample 3	15	2.33	1.54	7.71	2407.42	144.45
Sample 4	16	2.39	1.50	7.49	2338.72	140.32
Sample 5	17	2.46	1.46	7.43	2319.99	139.19
Sample 6	18	2.61	1.37	7.26	2266.91	136.01

As shown in Figure 3 and the data presented in Table 1, the mean diameter of particles increases as the moisture content of seeds increased. Thus, the mean diameter ranging from 1.59 mm for seed with moisture of 10 % to 2.61 mm for seed with moisture content of 18 %. In Table 2 are presented the values of regression coefficients and for correlation coefficients R^2 and χ^2.

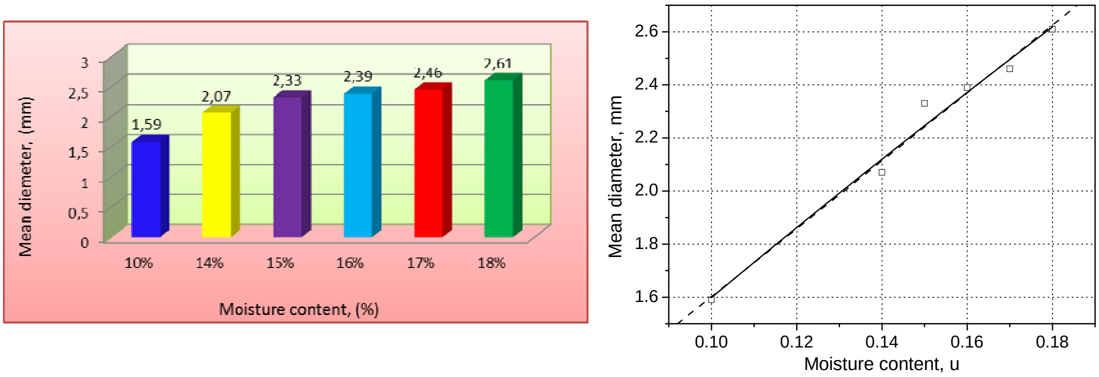

Fig. 3. Mean diameter variation of grist particle with moisture content
———— power function; - - - - - - - - - linear function

Knowing the mean sizes of wheat seeds was determined equivalent mean diameter (the equivalence of seed volume to the volume of a sphere), then the grinding index λ, was calculated for each of the six moisture content.

In Figure 4 is presented the variation of grinding index of seeds with moisture content, the curves were obtained by regression analysis of experimental data with power, linear and exponential law distribution. There was a very good correlation of the three laws experimental data with correlation coefficient R^2 having values above 0.98 in all cases.

From analysis of grist material and graphs in Figure 4 it is shown that the grinding index is highly dependent on the moisture content of initial material. Grinding index decreased with increasing moisture content. If from moisture content of 10%, the grinding index is about 2.26, from moisture content of 14% is 1.73, it significantly decreases to about 1.37 for moisture content of 18%.

In Figure 5 the power variation with moisture content is presented. Curves are plotted by regression analysis with power, lognormal and exponential laws type. The degree of correlation is appreciated by the high value of the correlation coefficient ($R^2 \geq 0.963$).

Analyzing the data obtained, intensity variation curves, energy consumption and power consumption curves and images presented in Figure 5, we can see that grinded seeds with low moisture content (10%), current intensity and power consumption have the highest values, I = 10.06 A, P = 3.141 W, and grinded particles have the smallest mean diameter (d_m = 1.59 mm).

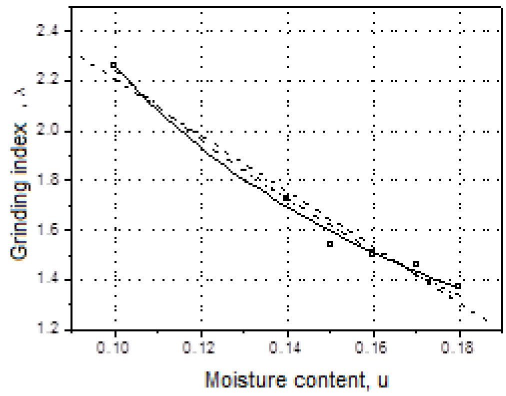

Fig.4. Variation curves of grinding index depending on moisture content of material
——— power function; - - - - - - linear function; - · - · exponential function

Table 2.

Function	Mean diameter				Power					Grinding index			
	Parameter				Parameter					Parameter			
	a	b	χ^2	R^2	a	b	c	χ^2	R^2	a	b	χ^2	R^2
Power function	11.062	0.84	0.03	0.983	0.804	-0.589	-	0.002	0.984	0.314	-0.857	0.001	0.990
Linear function	0.322	12.8	-	0.991	-	-	-	-	-	3.331	-11.25	-	0.980
Exponential function	-	-	-	-	4.814	4.409	-	0.05	0.963	4.286	6.491	0.002	0.981
Lognormal function	-	-	-	-	61.271	0.008	23.145	0.003	0.984	-	-	-	-

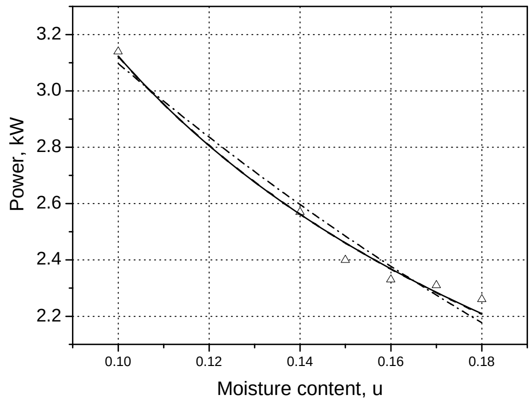

Fig. 5. Variation curves of power depending on moisture content of material
——— power function; - - - - - - lognormal function; - · - · - · exponential function

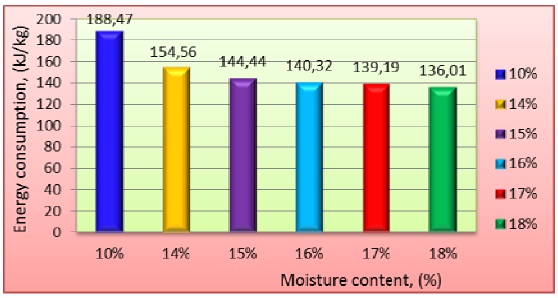

Fig. 6. Variation of energy specific consumption depending on moisture content

As moisture content increases, the power consumption decreases and particles mean diameter is increasingly higher. This is explained by the fact that with increasing moisture content the coat seed is soft, the endosperm is not brittle and no longer breaks into small particles, seeds being especially compressed (flattened). Thus, in case of seeds with high moisture content (18%) resulted largest size particles, d_m = 2.61 mm, for a power consumption with the lowest value, P = 26.54 kW.

Conclusions

Both mean size and grinding index of grist changes with increasing moisture content. If the mean size grist increases with increasing moisture content, than grinding index has a decreasing trend with its increases.

The lows governing these variations correspond to mathematical function such as power, linear and exponential function, the degree of correlation of experimental data with these is very high, estimated by the high value of the correlation coefficient, R^2.

The coefficient of regression equations (eq. 5-8) have values that depend on the physical characteristics of the material (moisture) and constructive and functional characteristics of grinding equipment (flutes geometry, differential).

Power required for grinding is higher (P = 3.14 kW) for grinded material with low moisture content (10%) and lower (P = 2.26 kW) for grinded material with high moisture content (17%, 18%).

Wheat seeds with low moisture content (10%) are not recommended for grinding, this resulting in high energy consumption. Grinding seeds with high moisture content (17%, 18%) not proceeding well (particles diameter is larger, the phenomenon of flattening appear, the endosperm not crumble) and also are not recommended.

Knowledge of phenomena and factors influencing the grinding process, selection and adjustment of equipment according to them, can mean significant energy savings.

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Mărunţirea grâului cu umidităţi diferite cu mori cu cilindri rifluiţi

Rezumat

În lucrare se prezintă rezultatele unor cercetări experimentale privind puterea necesară la mărunţire şi consumul specific de energie la mărunţirea seminţelor de grâu (soiul Dropia, din recolta anului 2011) cu o pereche de cilindri rifluiţi (cu distanţa între cilindri 1 mm şi raportul turaţiilor circa 2,5:1), având şase conţinuturi diferite de umiditate (între 10% şi 18%). A fost pus în corelaţie, de asemenea, conţinutul de umiditate al materialului iniţial cu diametrul mediu al particulelor mărunţite, prin analiza granulometrică a acestuia, precum şi cu gradul de mărunţire. Această corelaţie este exprimată prin funcţii de distribuţie de tip putere sau de tip exponenţial, gradul de corelaţie având valori relativ ridicate. Totodată, corelaţia dintre puterea necesară la mărunţire şi conţinutul de umiditate a fost testată cu legi de distribuţie cunoscute (de tip putere, exponenţială sau logaritmică), în lucrare prezentându-se gradul de corelaţie dintre acestea.