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CEREAL GRAINS' RESISTANCE ANALYSIS IN THE ASPECT OF ENERGY UTILISATION IN THE PROCESS OF DISINTEGRATION*

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A b s t r a c t: The highly non-descriptive character of biological materials resulting from their non-standard shapes and their mechanically heterogeneous structure in particular, underlies the lack of any detailed estimation of the raw materials' physicochemical qualities' influence on the course of disintegration process. Hence, it seems that the qualities expressing the relations arising during mechanical loads (mechanical and rheological properties) are especially significant.

In individual tests an attempt was made for a detailed description of cereal grains' resistance parameters. These properties were defined in the single-particle compression test. Test were carried out for rye and barley grains of varying humidity (10-18%). Tests concerning the process of cereal disintegration were carried out on the stand equipped with a laboratory hammer mill.

The measurements showed significant relationships between the kind of cereal, its resistance characteristics and the energy utilisation in the process of disintegration. Results of the tests and the relations were described by means of regressive equations.

K e y w o r d s: biological materials, physical properties, grinding

INTRODUCTION

The course of cereal disintegration depends on its physical properties. The properties describing the particle behaviour under mechanical loads are very important, i.e., hardness, toughness etc. It is necessary also to take into consideration the non uniform shape and unhomogeneous structure of the kernels. The need for a better knowledge of the phenomena accompanying the process induces further and systematic studies in this field.

The aim of the present work is to estimate the influence of the resistance characteristics gained in the single-particle compression test on the energy consumption in the grinding process for barley and rye grains for different moisture content conditions.

MATERIAL AND METHODS

Measurements of grain resistance characteristics were carried out on an universal testing machine INSTRON 4302. Changes in the loading force in relation to kernel deformation were recorded by means of a computer kit. The computer programme was developed in the Department of Machine Operation of the Food Industry.

Individual cereal kernels, after the determination of their mass and basic dimensions (thickness, width, length) were compressed

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with a constant speed 10 mm min^{-1}. The loading force acted along kernel's thickness. Measurements were carried out until a constant distance between the parallel plates 0.5 mm was achieved [1]. On the basis of the obtained compression curves the following parameters were determined: value of force, deformation, work and energy input (work divided by kernel mass) for the proportionality threshold plasticity threshold, biological resistance threshold, immediate resistance threshold and up to kernel collapse [1,3].

Studies were carried out on 4 barley varieties, 4 rye varieties and 5 grain moisture levels, i.e., 10, 12, 14, 16 and 18% (+/- 0.2%) in 50 repetitions.

The determination of characteristic phases of the compression process and its parameters performed according to Laskowski and Janiak [1]. The list of the materials characteristics and the symbols used in work is placed at the end of the paper.

Studies on the energy consumption of grinding process were carried out on the laboratory hammer mill. The value of energy during the process was determined using a special computer programme [2].Two gram kernel samples from each variety and moisture level were crushed using a hammer screen size of 1.0 mm. The value of power consumption of monophase electric current E [kWht^{-1}] with a frequency of 100 Hz was recorded. Measurements were carried out in 15 repetitions.

RESULTS AND DISCUSSION

The analysis of the significance of grain resistance characteristics to the disintegration was done in view of their influence on energy consumption.

The statistical analysis was based on the average values for each cereals variety and moisture level.

The linear relations between the single grains resistance and the energy requirements for grinding are presented in Table 1.

Among the analysed parameters one was to distinguish between those that can be directly related to the kernel and those which characterise the process of kernels compression. The first group represents characteristics of kernels deformation up to the limit of immediate resistance and the second the characteristics from this limit up to the collapse threshold.

In the first group the highest values of the correlation coefficients were seen for the deformation up to the kernels immediate resistance threshold and for the work and energy investment

T a b l e 1. Relations between energy consumption and resistance parameters for barley and rye grains

Parameter	Equation $y = ax+b$		Correlation coefficient	Signif. level
	a	b	r	p
Δh_1	0,0016	0,049	0,463	0,0026
Δh_2	0,0020	0,048	0,514	0,0006
Δh_3	0,0023	0,092	0,565	0,0001
Δh_4	0,013	0,012	0,879	0,0000
Δh_u	-0,006	1,64	-0,409	0,0086
α	-2,61	339,58	-0,585	0,0000
F_4	2,04	35,44	0,655	0,0000
F_5	12,16	-83,05	0,822	0,0000
L_4	0,96	-8,90	0,835	0,0000
L_5	11,19	-185,40	0,879	0,0000
L_u	10,22	-176,54	0,889	0,0000
L_{j4}	0,012	0,147	0,717	0,0000
L_{j5}	0,154	0,824	0,872	0,0000
L_{ju}	0,142	-0,972	0,860	0,0000

for this threshold. An increase of these parameters is a reason for the higher energy requirements for grinding.

In the case of the deformations up to the proportionality, plasticity, and biological resistance thresholds one can see similar dependencies because of small differences in the values between these parameters.

A contrary relation was observed in the case of the proportionality coefficient α. An increase of its value leads to a decrease of the grinding energy consumption.

High correlation coefficients are also characteristic for equations describing relations between the parameters characteristic for the kernel collapse threshold (compression work and compression energy up to this threshold) and the energy utilisation.

For other parameters not included in Table 1 the relations were not significant at the level a = 0.05. Among them were values of the forces, works and energies for kernel proportionality, plasticity and biological resistance thresholds (F_1, L_1, Lj_1, F_2, F_3) and the parameters for the phase of kernel plastic flaw (Δhp, Lp, Ljp).

Identifying the most significant parameters for grinding process description was achieved by multiple regression analysis. Kernels' mass and basic dimensions were also considered. The results presented in form of regression equations (Table 2) show that the relevant features in the aspect of energy consumption are:

- kernels mass used in compression test m,
- deformation up to the kernel plasticity threshold Δh_2,
- proportionality coefficient α,
- deformation up to the kernel immediate resistance threshold Δh_4.

The relations between predicted and observed grinding energy requirements for barley and rye kernels, and for different moisture conditions are presented in Fig. 1. A good grinding energy prediction based on these two resistance characteristics can be noticed.

Table 2. Regression equations between energy consumption and kernel resistance parameters

Material	Δh_2	Δh_4	a	m	Intercept	r	p
Barley	-170,6	74,65	0,118	-	4,54	0,928	0,000
Rye	-	-	0,082	-	54,65	0,863	0,000
Barley+Rye	-60,37	44,31	-	0,69	-7,74	0,919	0,000

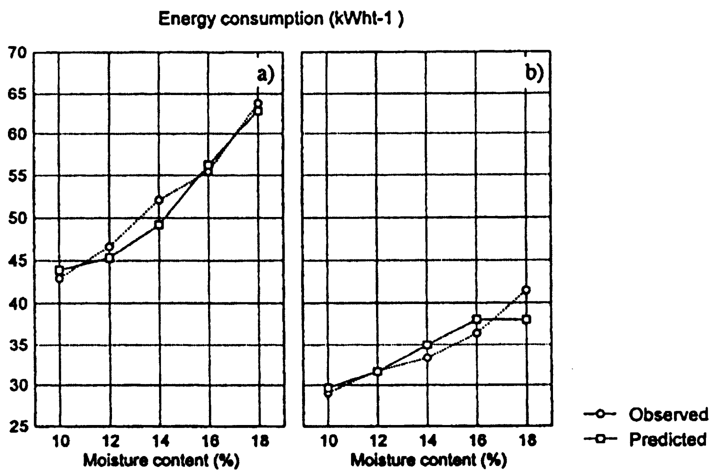

Fig. 1. Observed and predicted energy consumption on the basic of the resistance parameters for: a) barley and b) rye grains.

CONCLUSIONS

The resistance characteristics determined in the single-particle compression test allow us to describe energy consumption in the grinding process. Among the analysed parameters the relevant influence on grinding energy consumption in hammer mills is seen for the kernel deformations up to plasticity and immediate resistance thresholds and for the proportionality coefficient.

A verification of these conclusions on the basis of next studies for different materials and grinding machines with different particle loading conditions shall allow to optimise the grinding process.

LIST OF SYMBOLS

Δh_1 - deformation up to kernel proportionality threshold [mm],

Δh_2 - deformation up to kernel plasticity threshold [mm],

Δh_3 - deformation up to kernel biological resistance threshold [mm],

Δh_4 - deformation up to kernel immediate resistance threshold [mm],

Δh_5 - deformation up to kernel collapse [mm],

Δh_p - deformation up to the phase of kernel plastic flow [mm],

Δh_u - deformation from the kernel immediate resistance threshold up to collapse threshold [mm],

α - proportionality coefficient (relation between force value and deformation established for proportionality threshold) [Nmm-1],

F_1 - loading force for the kernel proportionality threshold [N],

F_2 - loading force for the kernel plasticity thre-shold [N],

F_3 - loading force for the kernel biological resistance threshold [N],

F_4 - loading force for the kernel immediate resistance threshold [N],

F_5 - loading force for the kernel collapse threshold [N],

L_1 - work for the kernel deformation up to the proportionality threshold [mJ],

L_4 - work for the kernel deformation up to the immediate resistance threshold [mJ],

L_5 - work for the kernel deformation up to the collapse threshold [mJ],

L_p - work for the kernel deformation up to the state of plastic flow [mJ],

L_u - work for the kernel deformation from to the immediate resistance threshold up to the collapse threshold [mJ],

L_{j1} - energy for kernel deformation up to the proportionality threshold [Jg^{-1}],

L_{j4} - energy for kernel deformation up to the immediate resistance threshold [Jg^{-1}],

L_{j5} - energy for kernel deformation up to the collapse threshold [Jg^{-1}],

L_{jp} - energy for kernel deformation up to the phase of plastic flow [Jg^{-1}],

L_{ju} - energy for kernel deformation from the immediate resistance threshold up to collapse threshold [Jg^{-1}].

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