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THE INFLUENCE OF SELECTED FACTORS ON THE FORCE VALUE OF INTERNAL FRICTION OF RYE AND WHEAT GRAINS*

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A b s t r a c t. The phenomenon of internal friction plays a major role in the majority of processing procedures. Thus, it is imperative to determine the internal friction coefficient for products under processing. It is not a simple objective in case of biological materials for which application of classic friction definitions is rather limited. The studies presented aimed at determination of the impact of selected factors on the internal friction value of rye and wheat grains. The measurements were taken on an original measuring equipment. The analysis of obtained results enabled to categorize three motion phases of grain layers shifted toward each other. The statistic tests performed proved that for the both cereals there was a correlation among the studied parameters.

K e y w o r d s: mechanical properties of cereals, internal friction of cereal grains

INTRODUCTION

The development of the processing and storage industry of agricultural products has led to increased interest in the studies over their physical and mechanical properties. This refers especially to loose vegetable media such as cereal grains, maize, ground grains, flour, various types of granulated products, etc. The mechanics of these media derives from the soil mechanics [2,8]. Usually, such materials constitute a three- phase medium composed of grains or particles of a so called frame, of water and air filling free spaces among the grains. The physical properties of this medium depend - among others - on the mutual weight ratio of individual phases, the properties and dimensions of grains constituting the frame, the density of their packing, as well as on many other factors. The strength properties of these materials, defined as a measure of their defor mation resistance and measured under specific conditions, can vary significantly with the change of these conditions (e.g., the change of moisture, density, etc.). Deformation of such a medium consists in a mutual displacement of grains, whereas the deformation of single grains influences insignificantly the entire deformation process. These materials display a property of a limited or null ability to transfer tensile stresses. But the capability to transfer compressive stresses depends on the hydrostatic pressure. In many instances it is referred to as a damageability of a biological granular medium [5].

Internal friction, defined as a series of phenomena occurring within the contact zone of

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particles or layers of the same medium, mutually displacing, exists in each particular processing procedure involving transportation, mixing, compaction, storage, etc. Resistance occurring in the mentioned operations consti- tutes its measure. Thus, it is crucial to determine the value of this resistance in order to ensure proper utilization of existing devices and equipment of this industrial branch, as well as optimum design of new units.

Several authors investigated the friction process of vegetable materials and conducted detailed analyses of the theory in relation to such materials [1,3,4,6]. The results obtained justify the application of some theoretical or empirical models derived from tribology. Of course, diverse engineering methods used to assess some parameters of the friction nodes are well known, and they could be applied in the agricultural technology. However, the authors of these methods underline their limited application potential.

The published research results show that a large group of factors highly influencing the friction coefficient of vegetable materials has been identified. First of all, moisture, size and shape of particles should be mentioned here, followed by surface roughness, pressure value, slip velocity, material density, orientation of the longest particle axes in relation to the slip plane, etc. In most cases, however, the impact of individual agents on the internal friction resistance values has been determined.

In consequence, these studies aimed at determining the impact of such factors as moisture, relative velocity of surfaces undergoing mutual displacement, on the internal friction resistance values of rye and wheat grains.

OBJECT AND METHOD OF RESEARCH

In order to reach the adopted objective, the experiment was planned in accordance with the experimental design presented in Fig.1.

Various levels of humidity have been obtained through the moisturing of grains up to the level of 25% and subsequent gradual drying. The drier method was applied to measure humidity. In periods between experiments, grain was stored in tight sealed containers (in order to preserve humidity "throughout") in room temperature.

Qualified wheat grains, the Almari variety, and rye grains, the Dańkowskie Złote variety, both preselected on specially designed laboratory sieves (to obtain uniform shapes), were applied as a tested material. According to generally accepted procedures [7], representative samples of both species, containing 100 grains each, were four times collected. Next, the following parameters of each grain were measured: length D, width S and thickness G, and

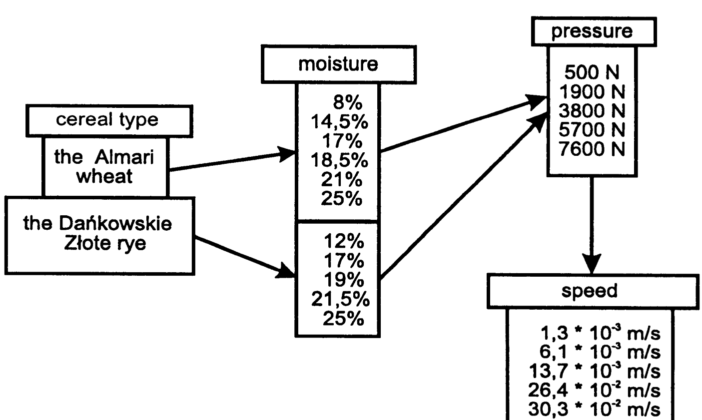

Fig. 1. Model of experiment.

shape factors were determined according to the formulas [Grochowicz]:
- thickness coefficient

$$K_W = G x D^{-1} \quad (1)$$

- width coefficient

$$K_M = S x D^{-1} \quad (2)$$

Histograms showing the variability of both cereal coefficients are indicated in Figs 2-5.

Friction measurement method

Research has been implemented in an original measurement device; the diagram of its operation is shown in Fig. 6. An appropriately (dimensionally) processed amount of grains was placed into a container in a way assuring random arrangement of longer grain axes. In this way, a non-oriented system of two fractions: an air fraction and granular frame was created. Then, a transparent cover was put on the container through which it was possible to trace the propagation of disturbance. The pressure volume was changed by use of a spring-supplied screw mechanism. The slip surface is formed by shifting the material batch placed between the two rigidly connected pistons. The initial research mentioned in paper [1] indicate that this slip surface has the shape of a cylinder wall, provided the distance between the pistons does not exceed 5 cm. Internal friction of the medium is shown by the friction at the front surface of the active piston with a special tensometer head. In order to ensure high speed stability, as well as short acceleration time towards the adopted velocity at the starting point (a high instantaneous acceleration), the active pistons are driven by a bilaterally operating servo-motor - an element of a typical hydraulic system. This solution provided a possibility for wide-range active velocity changes (due to applied flow damper). It can be assumed that the start-up time is close to zero in case when pressure surplus is applied.

Measurement results were filed by an analog-to-digital converter, type Daq-Book, manufacturer IO-Tech, with a special software installed. First of all, the measurement range was selected as well as maximum strength, displacement and sampling frequency. Next, after the determination of pressure value (depending on the spring deflection) and the required shifting

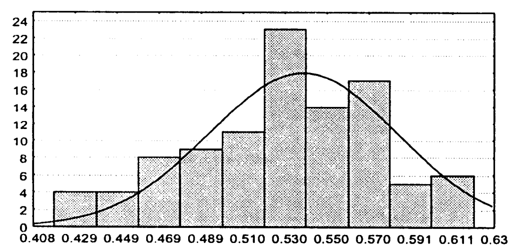

Fig. 2. Histogram of the width coefficient K_M. The Almari wheat.

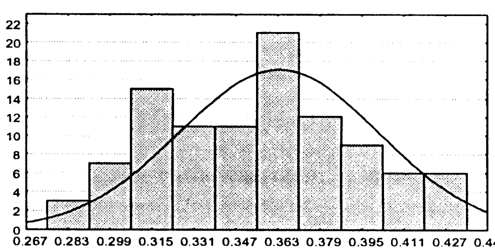

Fig. 3. Histogram of the width coefficient K_M. The Dańkowskie Złote rye.

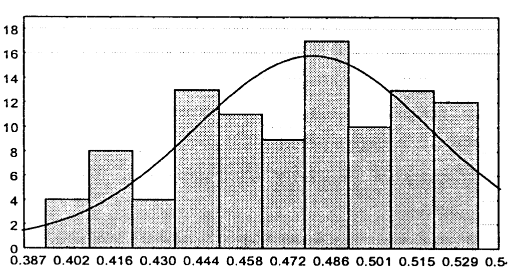

Fig. 4. Histogram of the width coefficient K_W. The Almari wheat.

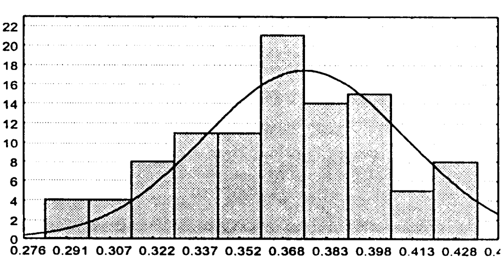

Fig. 5. Histogram of the width coefficient K_W. The Dańkowskie Złote rye.

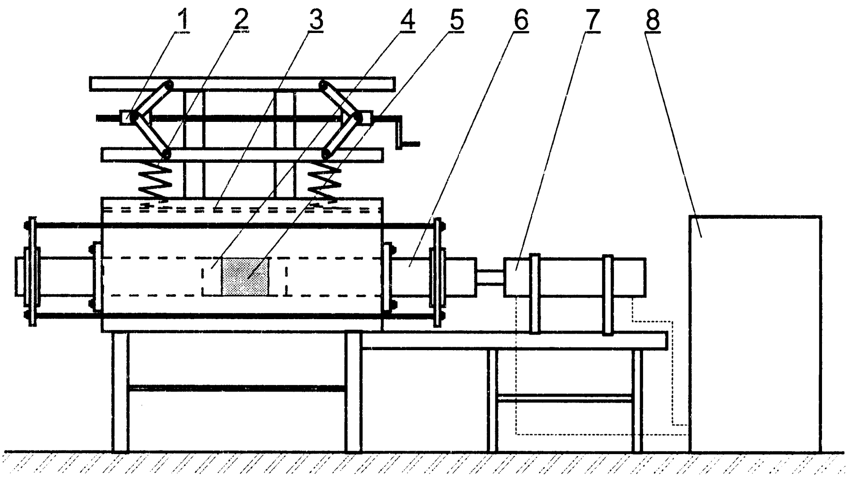

Fig. 6. Scheme of a measuring stand: 1-screw mechanism, 2-clamping (pressing) spring, 3-covering plate, 4-deformeter head, 5-slip surface, 6-active piston, 7-hydraulic servo-motor, 8-driving system.

speed of a piston rod (through appropriate regulation of the flow-damper), the drive was switched on. While pistons were moving, the following data were recorded:

- friction - measured by a system of tensometers affixed to the front surfaces of pistons,
- displacement - measured by the piezometric displacement sensor connected to the device by a carrier wave.

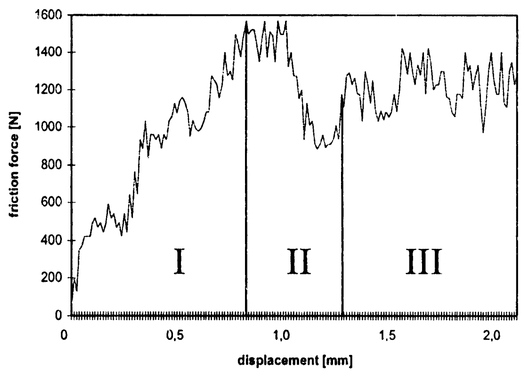

Fig. 7. Change of the internal friction force as a displacement function. The Almari wheat. Moisture 16 %. Pressure 1900 N. Displacement speed 1.3 10^{-3} m s^{-1}.

RESULTS AND DISCUSSION

A series of internal friction measurements has been implemented according to above indicated methods. Obtained results were used to monitor the changes in the friction values depending on displacements. A typical sequence of changes *T=f(s)* is presented in Fig.7.

The observed regularities allowed to divide the friction "cycle" into three phases:

- phase I - proportional growth of the friction (reaction) accompanying the increased displacement. It is an initial period of movement and according to the classic interpretation it corresponds to the static friction phase. This phase continues until the moment of discontinued adherence between the formed granular cylinder and remaining grains, reflected in rapid decline of the registered force;
- phase II - the decrease of friction accompanying the displacement of material layers. At this phase, with displacement of friction surfaces, individual frames change their arrangement in order to assure the minimum resistance;
- phase III - friction stabilization. Further displacement of cylinders does not alter reaction. This phase corresponds to the kinetic friction phase.

In the case discussed, it is very difficult to distinguish between the slip and fluent frictions. The observations show that in the course of displacement of friction surfaces, grains placed within the contact zone slip and rotate simultaneously. Probably this is the cause of distinct friction pulsation in the third motion phase - a short-term local distortion of the measurement cylinder side walls occurs.

In further calculations, the maximum reaction value, read on the diagram, is adopted as the measure of internal friction. This is a minimum force to be applied to the formed granular cylinder in order to move it.

The obtained data were used in three-way variance analysis, separately for each studied cereal species. The test performed proved that all factors considered (moisture, velocity and pressure) influence the value of internal friction in a statistically significant way. Besides, secondary interactions were found between moisture and remaining factors in the case of wheat, and between all factors in the case of rye. This finding underlined the necessity of including all factors simultaneously in the scientific research. A graphic presentation of the indicated interactions is shown in Figs 8-12. The analysis of these diagrams leads to the formulation of the following rules:

- in the case of Almari wheat the moisture pressure interaction (Fig. 8) - here, the friction tends to rise with the growing pressure. The growth rate is strictly related

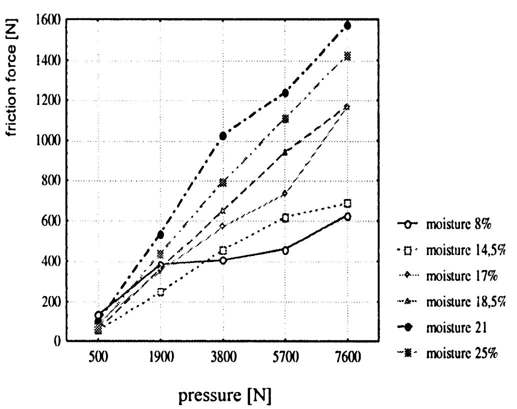

Fig. 8. Moisture-pressure interaction. The Almari wheat.

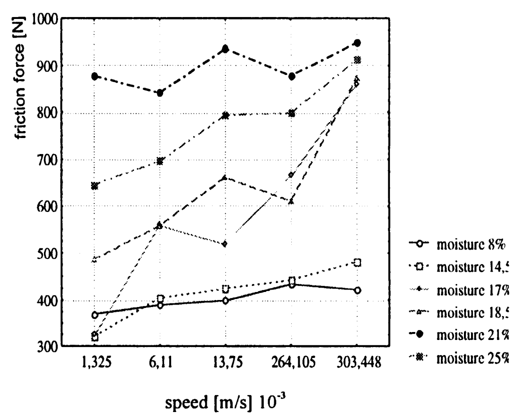

Fig. 9. Moisture-velocity interaction. The Almari wheat.

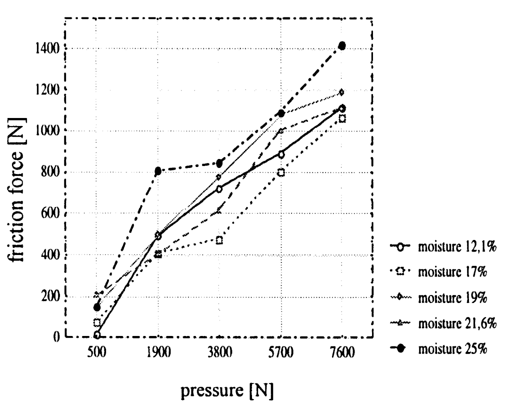

Fig. 10. Moisture-pressure interaction. The Dańkowskie Złote rye.

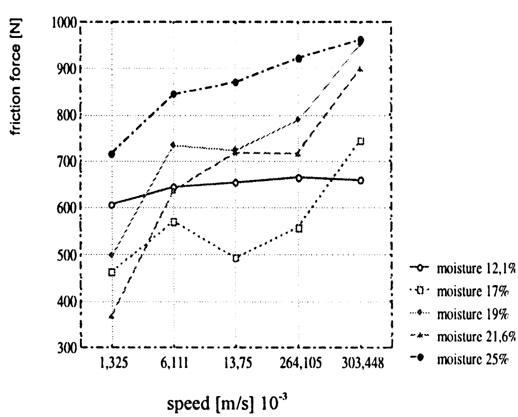

Fig. 11. Moisture-velocity interaction.The Dańkowskie Złote rye.

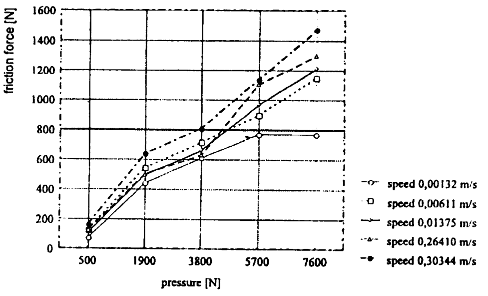

Fig. 12. Moisture-pressure interaction. The Dańkowskie Złote rye.

to the grain moisture. In low pressure values ranging between 500 and 1900 N, the differences between sequences are insignificant, the curves run close to each other. At the pressure above 1900 N, the differentiation is greater. For low moisture values 8 - 17%, the sequence of friction change depending on the pressure is no longer linear and tends to become exponential. In the case of higher moisture values, function T=f(N) remains linear; the moisture velocity interaction (Fig. 9) - it is possible to find growing friction with the simultaneous increase of moisture and velocity. In the case of moisture values 8 and 14.5%, the differences between their sequences are insignificant. At high displacement velocities, moisture can be clearly classified into two groups:

- low moisture 8 and 14.5%,
- high moisture 17 - 25 %;

- in the case of Dańkowskie Złote rye species (Figs 10-12) the moisture - pressure interaction (Fig. 10) - similarly to wheat, friction grows parallelly to the increased pressure. However, the moisture influence on rye is apparently lower compared to wheat. Curves illustrating the sequence of changes are similar. They can be approximated by straight lines. The internal resistance of displaced layers, reported in the rye grain, was relatively the lowest at the moisture level of 17%, and the highest - at the moisture level of 25%; for the moisture-velocity interaction (Fig. 11), high differences were found between the friction of rye grains at various displacement velocities. Similarly to the moisture - pressure interaction, extreme values of internal friction were indicated by the grain with moisture of 25% (max) and 17% (min); the velocity - pressure interaction (Fig. 12) - clearly different influences of pressure at various displacement velocities. With the pressure not exceeding 1900 N, this influence is relatively insignificant, and the curves run almost parallelly at a small distance. When the pressure exceeds 900 N, the curves are increasingly divergent.

This clear moisture classification into two groups: low moisture to 17%, and high moisture - above 17%, could result from the changed properties of a granular mass from friable-elastic to viscoelastic.

In conclusion: at the present stage of research it has not been possible to find precise differences in processing properties of rye and wheat, at various humidity levels. The hypothesis may be formulated to the effect that internal resistance level is significantly determined by shape coefficient. Wheat grains, having more regularly spherical shape (Figs 2 and 4), are easier to displace. They partly slip and partly roll on each other. Observations showed that the rye grains, which are more oblong (Figs 3 and 5), were frequently fractured in the process when arranged perpendicularly to displacement surfaces. Consequently, at low humidity levels the internal friction value for rye was much higher compared to wheat. Such inter-variety differences are significantly reduced at higher humidity levels, in effect of changed resistance characteristics of individual grains. However, the complete analysis of internal friction is not possible without the consideration of other factors influencing the process. The following should be included: parameters defining the condition of friction surfaces (the height and density of irregularities), resistance properties of analysed materials (elasticity) and their density. It is also necessary to consider the contact stresses, the intensity of which depends principally on the contact surface. For given level of stress, this intensity changes depending on humidity (in high humidity levels, grains are more plastic; therefore they are deformed asily under stress, causing the expansion of slip surfaces).

The final calculation phase consisted in estimation according to the adopted model:

$$S = W^A P^B N^C \qquad (3)$$

where S - friction, P - velocity (m/s), W - moisture (%), N - pressure (N), A, B, C - exponents.

Table 1. Results of the regression analysis

Exponents	A		B		C	
Cereal	rye	wheat	rye	wheat	rye	wheat
Estimation	0.361	0.626	0.064	0.050	0.699	0.599
Standart error	0.071	0.060	0.009	0.010	0.022	0.020

The computed exponents (Table 1) may show the intensity of the influence of a given factor on the friction value. So, for both wheat and rye, very high impact of pressure was found (C_{rye}~0.7, C_{wheat}~0.6). Moisture was the next analysed factor (A_{wheat}~0.63, A_{rye}~0.36). The analysis show the relatively weakest though significant influence of displacement velocity (B_{wheat}~0.05, B_{rye}~0.06). Empirical models obtained may be used to define the friction value depending on mutual displacement conditions of grain layers.

CONCLUSIONS

1. This research showed the statistically significant impact of studied factors (velocity, moisture and pressure) upon the internal friction value.

2. The analysis of friction changes in relation to grain displacement allowed to categorize three phases:
- start of motion,
- period when conditions of motion get stabilized,
- stabilized motion.

3. The following interactions were stated: in the case of the Almari wheat - an interaction between moisture and pressure, as well as between moisture and velocity, in the case of Dańkowskie Złote rye - an interaction between moisture and pressure, moisture and velocity, as well as between moisture and pressure.

4. The internal friction was described by means of the exponential equation of the following type: $S = W^A P^B N^C$ where W - moisture, P - slip velocity, N - pressure.

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