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INVESTIGATION OF MECHANICAL PROPERTIES OF FABA BEAN FOR GRINDING BEHAVIOR PREDICTION*

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Abstract. The paper presents results of studies concerned with the relationships between mechanical properties of a material and grinding process parameters. Polish variety of faba bean cv. *Nadwiślański* was used in the studies. Universal testing machine Zwick Z020 was adapted to the material properties determination. On the basis of load-deformation curves, characteristic values of loads, seed deformation, and energy inputs during crushing were determined. Grinding experiments were made with the help of a small laboratory hammer mill. Influence of moisture on the character of load-deformation curves and specific energy requirements during grinding were evaluated. For low material moisture levels, sharp fracture as a result of load (internal stresses) was observed. More relevant contribution of strain, plastic in nature, for moist seeds resulted in their distinct fracture mechanism. The increase of seed moisture caused larger deformability relative to the loads applied. Grinding process of moist bean seeds required more energy to be utilized. Relevant relations of energy requirement according to change in seeds moisture and their mechanical properties were observed.

Keywords: faba bean, mechanical properties, grinding

INTRODUCTION

In the grinding process, large quantities of materials are involved, various in structure, composition and physico-chemical properties. This high variability, especially important

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for materials of biological origin, inevitably makes the analysis and process description very difficult and complicated. It makes, therefore, the problem of process optimisation still current and underlines the need for continuous research.

Grinder selection procedure, as the one presented by Muller and Polke [5], is of great importance in many aspects of this. Before the most suitable grinder type is selected, the following two aspects must be respected. First – the product property function presented by Rumph, i.e. the relationships between the particle size, shape, size distribution etc. and the product properties. Second – the ability of a material to be ground (material property function for grinding) [6]. The latter is highly dependent on intrinsic material properties.

In respect to the above, the formulation of any process model with regard to the physical properties of raw materials is expected. Hence, the objective of our research was formulated as the determination of relations between the mechanical characteristics of faba bean seeds and their grinding process parameters.

MATERIAL AND METHODS

Polish cv. of faba bean Nadwiślański was used in our studies. Uniaxial compression testing was applied for seeds properties determination. The mechanical testing was done with the help of the Zwick universal machine type Z020. Data collection and analysis were realised with the help of testXpert software. Selected fraction of seeds with thickness from 7.0 to 8.0 mm was used for the compression experiments. Average seed size in the direction of loading force for every individual seed were additionally determined on the basis of the compression characteristics. The average values ranged form 7.44 to 8.06 mm, with standard error from 0.06 to 0.09 mm. Individual seeds, randomly positioned between two parallel plates, were crushed within the load range of 0-2.5 kN. The compression rate of 10 mm min^{-1} was adjusted according to the standard proposition presented by Frączek *et al.* [2]. For each moisture, 20 repetitions were done. On the basis of the crushing tests, compression characteristics, load vs. deformation, were obtained. On their basis, the forces, deformations, works up to the rupture point were determined. Tangent modulus was also evaluated from the compression characteristics until rupture occurred with a step in the load value of 5N. The average value of the tangent was calculated for every individual compression curve. The rupture corresponded to the first visible fracture event (decrease in force value).

Grinding experiments were curried out with the help of a small laboratory hammer mill Polymix Hammermill. It was equipped with the screen of 1.0 mm mesh size. Energy measurement (based on the electrical power requirements) was done with the help of a computer system described in previous authors' papers [3,4]. The grinding tests were done in 10 replications. The sieve analysis method was used for particle size distribution assessment. Total amount of ground products from ten experiments was sifted with the help of the Tyhr 2 sieve shaker apparatus.

On the basis of the grinding experiments the following were calculated: specific energy requirements E_s, particle size distribution, and on its basis – the mean particle size d_s and the specific surface of particles S_s. The particle size was determined according to equation (1):

$$d_s = \sum_{i=1}^{n} P_i \cdot d_i / 100 \tag{1}$$

where: P_i – percentage by weight of particles of diameter d_i, n – number of class sizes.

Specific surface determinations were based on simple mathematical adjustments in which particle shape was approximated to a sphere with density of 1.4 g cm^{-3}. The total particle size distribution was used for the calculations.

The energy utilisation index E_u relating the particle surface and the grinding energy inputs was also calculated.

The experiments were curried out for six moisture levels of the seeds (wet basis) 8, 10, 12, 14, 16 and 18% (±0.2%). Seeds samples after the addition of required amount of water were stocked at ambient temperature for minimum 48 hours.

RESULTS AND DISCUSSION

Some chosen compression characteristics in relation to the seeds moisture are presented in Figure 1. Only in very few cases, for very moist seeds, the fracture point was not observed. In each case the fracture was determined automatically with the help of testXpert software.

For dry seeds, a sharp fracture was characteristic. Seed deformation was accompanied by comparatively larger number of fracture events. For them a relatively higher energy release was observed. This demonstrates a mechanism which can be, with a certain approach, treated as brittle. On the other hand, for more moist seeds (above 12-14%) the fracture was preceded by non elastic seeds deformations.

The energy release was much smaller, if at all noticeable. This allows the second fracture mechanism, the ductile one, to be observed.

Average values of the mechanical properties of the seeds are presented in Table 1. Linear decrease in the loads at the rupture point in relation to seeds moisture can be observed. Values of the deformations up to this point increased with the same range of moisture, but above the 14% level the average values were not statistically different. High variability was observed in average values of the energy inputs until the rupture occurred. Increase in the energy up to 12% of moisture was followed by the continuous decrease for the seeds of higher moisture. For this parameter much higher variability in measured values was also characteristic, especially for the seeds with moisture at 14%. These observations are similar to the observations of Dobrzański [1]. The main problem in explaining the above relations seems to be connected with precise characterization of the fracture event in terms of crack propagation. For dry seeds, cracks can propagate within the seeds cotyledons, but for higher moisture, the observed seeds fracture was related mainly to the damage of its coat. These are reasoned by observed decrease in seeds elasticity with increase of the moisture. High decrease of this property was observed particularly in the moisture range of 8-14%.

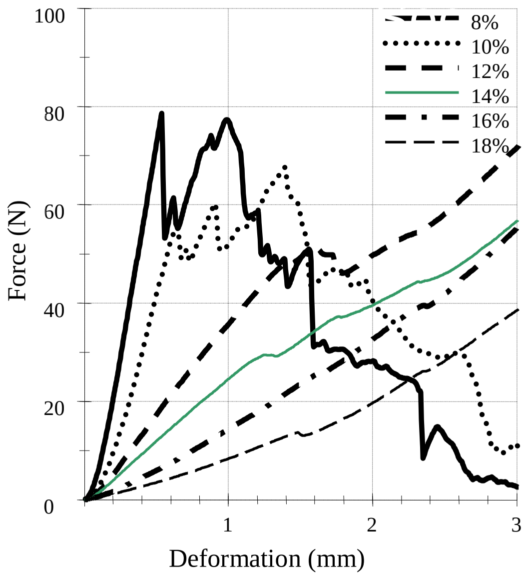

Fig. 1. Compression characteristics for faba bean seeds at different moisture content

Table 1. Average values of the mechanical parameters in relation to the moisture content of faba bean seeds

Moisture (% w.b.)	F_{rup} (N)		L_{rup} (mm)		L_{rup} (mJ)		$dFdl^{-1}$ (N mm^{-1})	
	Mean	Std. Err.	Mean	Std. Err.	Mean	Std. Err.	Mean	Std. Err.
8	581.6	33.0	0.44	0.019	112.8	9.8	1236.2	51.2
10	465.4	11.8	0.54	0.021	121.1	6.74	824.5	27.4
12	429.0	17.8	1.10	0.056	246.1	20.4	406.9	9.7
14	260.1	26.5	1.37	0.076	193.7	32.8	191.8	4.6
16	253.4	7.2	1.34	0.049	167.5	8.7	186.9	4.6
18	140.3	6.5	1.33	0.052	90.0	6.7	105.4	4.1

Results of the grinding process (Tab. 2) confirm its high dependence on material properties (moisture). Non linear increase in specific grinding energy requirements was observed. Statistical analysis confirmed significant differences between average energy values for the moisture levels above 12%. Increase in moisture resulted also in changes in final product characteristics. Linear decrease in the particle mean size, and inversely, increase in the specific surface of particles were observed. Smaller particle sizes as a result of grinding of more moist seeds (more plastic seeds), which was rather unexpected, may be reasoned by high energy inputs observed during grinding, resulted from the grinder construction i.e. small outlet of the grinder. The tendency to particle adhesion to the internal surface of the grinder chamber and the screen could have an influence too.

Table 2. Average values of the grinding parameters in relation to the moisture content of faba bean seeds

Moisture (% w.b.)	E_s (kJ kg^{-1})	d_s (mm)	S_s (cm^2 g^{-1})	E_u (cm^2 J^{-1})
8	100.2	0.345	349.5	3.48
10	93.0	0.337	371.2	3.99
12	120.9	0.327	413.5	3.42
14	174.1	0.287	486.3	2.79
16	254.3	0.277	519.5	2.04
18	340.3	0.254	538.2	1.58

Correlation matrix between the parameters of the two processes allows the highest values of linear coefficients between the product properties (size and surface of particles) and the values of seeds rupture force to be observed (Fig. 2 and 3). A good correlation in respect to the grinding parameters was also noticed for tangent modulus expressing seeds elasticity. The highest correlation coefficients, however, were obtained when the grinding energy as well as energy utilisation index were related to the reciprocal of the modulus *dF/dl*. Lower seed elasticity results in higher specific energy requirements and is the reason of lower surface created values in reference to comparable energy inputs during the grinding process (Fig. 4 and 5).

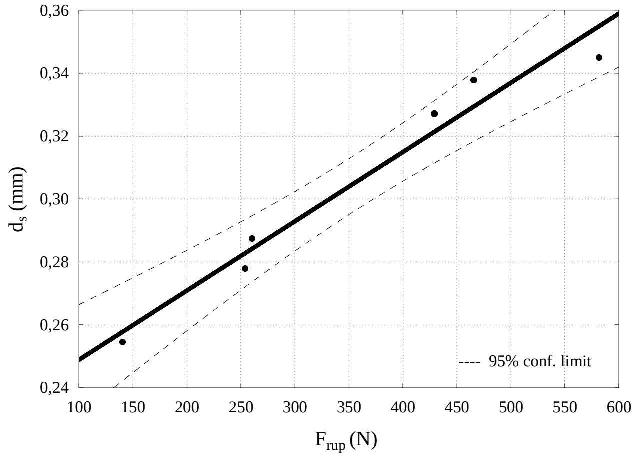

Fig. 2. Particle mean size of ground faba bean as a function of seeds strength

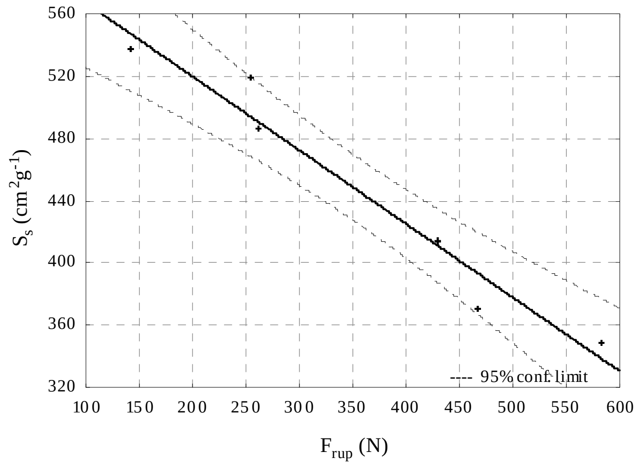

Fig. 3. Specific surface of ground faba bean as a function of seeds strength

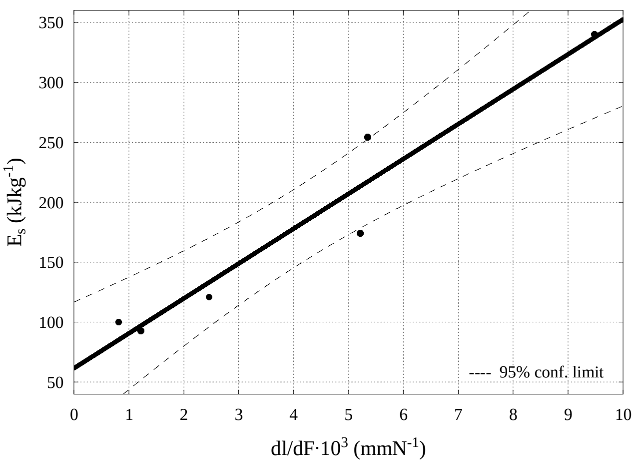

Fig. 4. Specific grinding energy as a function of seeds elasticity

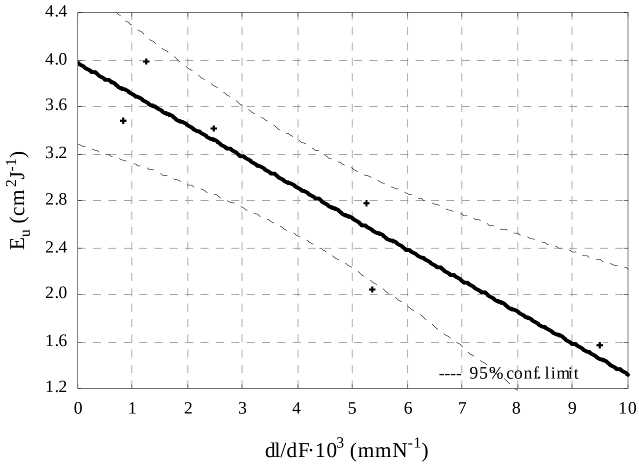

Fig. 5. Grinding energy utilisation index as a function of seeds elasticity

CONCLUSIONS

1. The mechanical properties of faba bean seeds allowed the grinding energy requirements as well as the product properties prediction.
2. The particle size was strongly related to the seeds strength. Higher seeds rupture force values are characteristic for more brittle behaviour, with a tendency to produce particles of smaller sizes.
3. The specific grinding energy values were strongly related to the material elasticity. The decrease in grain elasticity is one of the reasons of higher energy requirement values.
4. The results of uniaxial testing showed distinct behaviour of seeds in regard to their moisture. Fracture mechanisms, brittle in nature for dry seeds and ductile for wet ones, were observed. More profound distinction between these two mechanisms is needed for grinding process evaluation.

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BADANIA WŁAŚCIWOŚCI MECHANICZNYCH NASION BOBIKU DLA OCENY PRZEBIEGU PROCESU ROZDRABNIANIA

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S t r e s z c z e n i e. W pracy przedstawiono wyniki badań nad wpływem właściwości mechanicznych nasion na przebieg procesu rozdrabniania. Materiał do badań stanowił bobik odmiany Nadwiślański o wilgotności od 8 do 18%. Pojedyncze nasiona ściskano na maszynie wytrzymałościowej Zwick. Na bazie uzyskiwanych krzywych zgniatania określono wartości sił, odkształceń oraz energii zgniatania charakteryzujących cechy materiału. Badania procesu rozdrabniania zrealizowano na laboratoryjnym rozdrabniaczu bijakowym Polymix Micro Hammermill. Określono jednostkową energochłonność rozdrabniana oraz skład granulometryczny uzyskiwanych produktów. Ocenie poddano wpływ wilgotności nasion na charakter zależności obciążenie-odkształcenie i energochłonność procesu rozdrabniania. Dla niższych poziomów wilgotności obserwowano wyraźne pękanie nasion w wyniku oddziaływania obciążeń. Zwiększony udział odkształceń o charakterze plastycznym dla nasion wilgotnych wpływał na odmienny mechanizm ich uszkodzeń. Wraz ze wzrostem wilgotności zmniejszała się odporność nasion na oddziaływanie obciążeń wyrażająca się relatywnie większymi deformacjami w wyniku przyłożonych sił. Proces rozdrabniania materiału bardziej wilgotnego cechował się zwiększonym jednostkowym zużyciem energii rozdrabniania. Wskazano na istotne zależności pomiędzy jego przebiegiem a wilgotnością i właściwościami mechanicznymi nasion.

S ł o w a k l u c z o w e: właściwości mechaniczne, rozdrabnianie, bobik