Evaluation of Buckwheat Product Properties for Discrete Element Model (DEM) Simulation

Lucie JEZERSKA[1)], Martin ZIDEK[1)], Jiří ZEGZULKA[1), 2), 3)], Barbora PALKOVSKA[2)]

[1)] VŠB-Technical University of Ostrava, ENET Centre, Bulk Solids Centre, 17. listopadu 15, 708 33 Ostrava, Czech Republic
[2)] VŠB-Technical University of Ostrava, Faculty of Mining and Geology, Department of Environmental Engineering, 17. listopadu 15, 708 33 Ostrava, Czech Republic
[3)] VŠB-Technical University of Ostrava, Faculty of Mechanical Engineering, Institute of Transportation, 17. listopadu 15, 708 33 Ostrava, Czech Republic

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Abstract

The paper deals with various types of buckwheat products (Fagopyrum esculentum Moench), which have been determined with mechanical and physical properties in order to provide useful data for engineers to design structures of used equipment, harvesting and other processing technologies. Buckwheat is currently a well-sought-after food in the field of healthy nutrition, especially because of its high fiber content, iron and potassium. Among the tested samples were, for example, buckwheat hazelnuts, chips, flakes and others. In the above mentioned, the parameters of the linear dimensions, the Carrs index, the Hausner ratio and the flow rate were measured and compared. The influence of geometric parameters of buckwheat products was determined on mechanical and physical properties. The first results showed that the set parameters were statistically different for each type of buckwheat. On the basis of measured data, a simulation of the flow of a specific buckwheat sample was performed. The discrete element (DEM) method used for this purpose appears to be an appropriate tool for transporting these agricultural products.

Keywords: agriculture products, buckwheat, DEM simulation, flowability, angle of repose

Introduction

The demand for gluten-free foods is constantly rising due to allergic autoimmune diseases. Usual treatment is a strictly gluten-free diet [1]. Buckwheat is a hit in the field of healthy nutrition, primarily because it is a very important source of fiber, iron, potassium and vitamins. It contains a high percentage of easily digestible, full-fledged proteins. It is an indispensable part of the diet of celiac, vegetarian and vegan [2, 3]. The processing of the buckwheat product line (from flakes to peels) contains a set of partial process modifications in which transport, handling, handling and storage are dominant. In order to predict the behavior of different types of buckwheat along the technological line, their mechanical and physical properties were determined, which are input parameters not only for the calibration of the DEM model [2, 4]. The basic mechanical and physical characteristics were linear grain buckwheat sizes, particle size distributions, bulk and quench density and flow parameters. For sample buckwheat hulls, DEM model calibration was performed based on measured bulk angle data. Simulation of flow of buckwheat hull was created.

Materials and Methods

Tested materials were 4 kinds of buckwheat – buckwheat hops, buckwheat flakes, buckwheat pell and buckwheat flaw (Fig. 1).

Particle size distribution

Particle size distribution was made using a Camsizer particle analyzer, designed to comprehensively characterize dry particles. This analysis determines the size and shape of the particles present in the sample. The principle of measurement is dynamic image analysis. The sample is transported to the measuring area via a vibrating feeder. Particles are further dropped by a measuring device placed between two cameras and a planar source of light. Particles are captured by CCD cameras at speeds of more than 60 frames per second [5].

Flowability measurements

The flowability, based on the angle of repose estimation, was determined using a manual instrument for determining the bulk properties of PF1, Sotax (Fig. 2). The weighed amount of the sample was metered into a precisely defined conical hopper located above the mechanically operable closure [6]. When the hopper was filled, the closure was opened and the test material formed a symmetrical cone on the pad (diameter d). After the material was completely emptied, the height of the cone h was measured and the bulk angle α (equation 1) calculated. The measurement was repeated 10 times.

$$\tan(\alpha) = \frac{h}{0.5.d} \quad (1)$$

Angle of repose

The flow properties of the buckwheat product family were further expressed according to the criteria obtained from the determination of bulk ρ_B and density ρ_T, namely the Hausner ratio HR (equation 2) and Carrs index CI (equation 3).

$$HR = \frac{\rho_T}{\rho_B} \quad (2)$$

$$CI = 100 \cdot \frac{\rho_B - \rho_T}{\rho_B} \quad (3)$$

The tested samples were classified according to HR and CI values into individual flow classes [8].

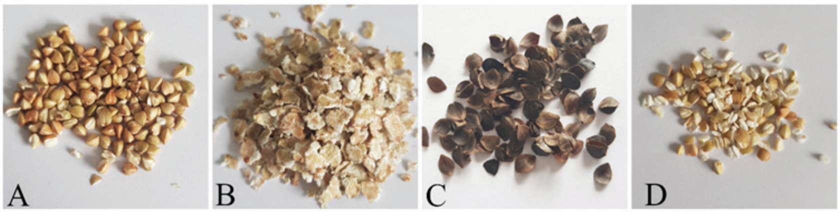

Fig. 1. Tested material. A – buckwheat hops, B – buckwheat flakes, C – buckwheat pell, D – buckwheat flaw
Rys. 1. Badany materiał. A – szyszki gryczane, B – płatki gryczane, C – nasiona gryki, D – uszkodzona gryka

Fig. 2. Device for determining the Powder Flowability PF1 (Sotax) [7]
Rys. 2. Urządzenie do określania płynności proszku PF1 (Sotax) [7]

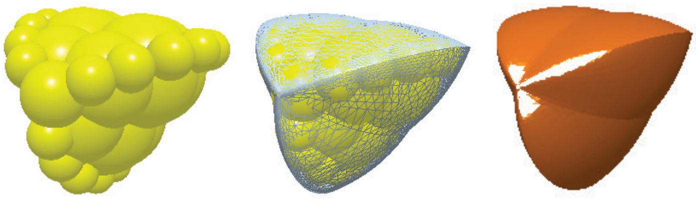

Fig. 3. Create the grain particle bean grains using the DEM method
Rys. 3. Tworzenie ziarna za pomocą metody DEM

Fig. 4. Reading the angle of repose from A) real measurement, B) DEM simulation
Rys. 4. Odczyt kąta spoczynku z A) rzeczywistego pomiaru, B) symulacji DEM

DEM modelling

A Discrete Element Method (DEM) is the most attractive method used for the numerical modelling of particulate materials [9]. Using the DEM, agriculture material is simulated as a set of individual particles interacting with each other or with any other solid object (wall, silo, hopper) within a material transport or handling. The trajectory and velocity of each agriculture particle (rice, soybean, maize etc.) is calculated in discrete time steps, which provide information such as collision frequency and duration of contact with adjacent particles [10]. DEM simulations in this study were done by EDEM Academic software.

Results and Discussion

The results of particle size distributions of the percentage (10, 50 and 90%) of the particles in the sample (d_{10}, d_{50} and d_{90}), b / l (width / length of particle) and sphericity. The test samples are listed in Table 1.

The evaluation of flow characteristics and classification in flow modes is shown in Table 2.

The best flow properties have been established for buckwheat hops, which have been ranked in a class with excellent flow based on HR and CI values. Buckwheat pell has the worst flow properties. The angle of repose was evaluated using direct and indirect methods. The indirect method involves evaluation by calculation from the subtracted h (Chapter Materials and Methods), the second direct method is based on the reading of the angle from the taken photograph of the cone sample. Obviously, the values determined by the indirect and direct method differ. In the case of an indirect method, it is appropriate to use the data as a comparative, relative

Tab. 1. Particle size distribution, b/l ratio and sfericity of buckwheat

Tab. 1. Rozkład wielkości cząstek, stosunek b/l i sferyczność gryki

	d_{10} [μm]	d_{50} [μm]	d_{90} [μm]	b/l [-]	S [-]
Hops	2.55	3.02	3.37	0.79	0.88
Flakes	1.23	3.00	4.91	0.64	0.69
Pell	2.30	3.55	4.22	0.70	0.78
Flaw	1.55	2.29	3.10	0.70	0.83

Tab. 2. Flowability measurements

Tab. 2. Pomiary płynności

Sample	HR [-]	CI [-]	Flow character	Angle of repose, indirect method [°]	Angle of repose, direct method [°]
Hops	1.03	3.29	Excellent	26.19	29.13
Flakes	1.20	16.84	Adequate	29.21	33.76
Pell	1.30	25.07	Average	31.88	42.98
Flaw	1.12	10.33	Good	31.76	23.19

Tab. 3. Mechanical and physical properties of used materials in DEM simulation

Tab. 3. Własności mechaniczne i fizyczne zastosowanych materiałów w symulacji DEM

Parametr	Material	
	Buckwheat	Steel
Poisson constant [-]	0.25	0.30
Bulk density [kg·m^{-3}]	720	7839
Shear Modulus [Pa]	$1\cdot10^6$	$8.1\cdot10^6$

Tab. 4. Parameters of buckwheat particle in DEM simulation

Tab. 4. Parametry cząstek gryki w symulacji DEM

Parameter	Value
Weight [g]	0.0167
Volume [m^3]	$2.32\cdot10^{-8}$

Tab. 5. Setting interactions and contact parameters in DEM

Tab. 5. Ustawianie interakcji i parametrów kontaktu w DEM

Parameter	Material	
	Buckwheat	Steel
Coefficient of restitution [-]	0.5	0.4
Coefficient of static friction [-]	0.3	0.25
Coefficient of rolling friction [-]	0	0

assessment of the flowability of the samples. The method is suitable for a bulk material consisting of fine particles, which repeatedly after filling creates a conical shape of a pile ending with a tip. For the DEM simulation, a hop sample was selected. There are also limitations for determining the input parameters for creating DEM models. The next point of key questions is the representation of the real particle shape [4]. In the EDEM program, the hop particles were made of a ball-shaped parts. Particles based on the entered data were inserted individually, grouped according to the xyz coordinate system. The progressive formation of one hail from several spherical shaped particles is shown in Fig. 3.

The properties of the materials used in DEM simulation are given in Table 3–5.

The simulation data is in agreement with the experiment (both for the direct method and for the indirect method). Setting of the angle of repose was determined by real measurement (Figure 4A) and DEM simulation (Figure 4B). The percentage deviation of real measurement and simulation was 2.6% for the direct method and 3.02% for the indirect method.

Conclusions

The basic mechanical and physical properties of 4 types of buckwheat - buckwheat hops, flakes, pell and flaw were determined. From the evaluation of the flow properties, it was found that the flow of the buckwheat hops is excellent. The individual buckwheat products vary greatly. The geometric parameters of the products showed that the spherical shape of the particle is closest to the buckwheat hops with the sphericality parameter of 0.88. For the DEM model, buckwheat hops were selected. The material was calibrated based on the angle of repose values determined by the indirect method. Experimental and simulated data showed good agreement. The discrete element method can be used to solve the problems of transport, handling and storage of buckwheat hops.

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Ocena właściwości produktów z gryki dla symulacji metodą elementów dyskretnych (DEM)

Artykuł dotyczy różnych rodzajów produktów z gryki (Fagopyrum esculentum Moench), które zostały określone za pomocą właściwości mechanicznych i fizycznych w celu dostarczenia inżynierom przydatnych danych do projektowania struktur używanych urządzeń, zbiorów i innych technologii przetwarzania. Gryka jest obecnie popularnym pożywieniem w dziedzinie zdrowego żywienia, szczególnie ze względu na wysoką zawartość błonnika, żelaza i potasu. Wśród badanych próbek były orzechy laskowe, gryka, chipsy, płatki i inne. Zmierzono i porównano parametry wymiarów liniowych, wskaźnik Carrsa, współczynnik Hausnera i natężenie przepływu. Określono wpływ parametrów geometrycznych produktów z gryki na właściwości mechaniczne i fizyczne. Wyniki wykazały, że zmierzone i założone parametry były statystycznie różne dla każdego rodzaju gryki. Na podstawie zmierzonych danych przeprowadzono symulację przepływu określonej próbki gryki. Zastosowana w tym celu metoda elementów dyskretnych (DEM) wydaje się odpowiednim narzędziem do opisu transportu tych produktów rolnych.

Słowa kluczowe: produkty rolne, gryka, symulacja DEM, płynność, kąt spoczynku