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ANALYSIS OF COLLISIONS BETWEEN WHITE MUSTARD SEEDS OR RAPESEEDS AND DISKS OF A HULLING MACHINE EQUIPPED WITH CYLINDRICAL BLADES

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K e y w o r d s: hulling, disk of a hulling machine, seeds, mustard, rape.

A b s t r a c t

The aim of the study was to analyze collisions between seeds and disks of a hulling machine during the removal of the coats of white mustards seeds and rapeseeds. The theoretical analysis was based on the existing models and experimental tests. The husking process was described using the results of theoretical computations, which enabled to determine the contact surface area between seeds and the working elements of a hulling machine. The difference in the surface area on a disk where collisions take place, resulting from the use of blades with a minimum or maximum diameter, is 17.5%. Due to their similar dimensions and morphological structure, seeds of white mustard and rape can be successfully hulled through collisions with cylindrical blades.

ANALIZA ZDERZEŃ NASION GORCZYCY BIAŁEJ ORAZ RZEPAKU Z TARCZAMI OBŁUSKIWACZA WYPOSAŻONYMI W CYLINDRYCZNE WYPUSTKI

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S ł o w a k l u c z o w e: obłuskiwanie, tarcza obłuskująca, nasiona, gorczyca, rzepak.

S t r e s z c z e n i e

Analizowano zderzenia między nasionami a tarczą obłuskującą zachodzące podczas usuwania okrywy owocowo-nasiennej z nasion gorczycy białej oraz rzepaku w obłuskiwaczu tarczowym. Analizę teoretyczną przeprowadzono na podstawie znanych modeli oraz badań eksperymentalnych. Opis procesu obłuskiwania oparto na obliczeniach teoretycznych, które pozwoliły ustalić powierzchnię kontaktu nasion z częścią roboczą obłuskiwacza. Różnica wielkości pola na tarczy, na którym dochodzi do zderzeń w przypadku zastosowania wypustek o minimalnej średnicy i zastosowaniu wypustek o maksymalnej średnicy, wynosi 17,5%. Obłuskiwanie nasion gorczycy białej i rzepaku, ze względu na ich podobne wymiary oraz zbliżoną budowę morfologiczną, może się odbywać przez poddawanie ich zderzeniom.

Introduction

In order to increase the nutritive value of white mustard seeds and food products obtained from rapeseeds, they are hulled or fractionated. Fractionation involves mechanical division of seeds into fractions differing in the content of seed coats and – in consequence – the concentrations of protein, fiber and energy (BALKE, DIOSADY 2000, NIEWIADOMSKI 1983, SUVENDU BHATTACHARA, VASUDHA, KRISHNA MURTHY 1999, VELISEK, MIKULCOVA, MIKOVA, WOLDIE, LINK, DAVIDEK 1995). The design of machines and devices for mechanical seed processing requires thorough knowledge of the phenomena that occur in the working space. Such knowledge is also indispensable in the case of mechanical seed coat removal (ANDERS 2003, GRZELAK 1996, SZWED, LUKASZUK 2004). Numerous authors have analyzed the phenomena taking place during mechanical seed hulling and seed coat breaking (KWIETNIAK, KWIETNIAK 1989, LASKOWSKI, LYSIAK 1993, MIESZKALSKI 1999, SARNIAK 1997). In the case of rapeseeds, mechanical coat separation allows to eliminate harmful glucosinolates and improve the quality of oil used for dietary purposes, whereas hulled white mustard seeds can be used for the production of seasonings and spices.

Aim of the study

The aims of the study were to analyze a collision-based method of coat removal from seeds of white mustard and rape, and to calculate the surface area on a disk where seeds come into contact with cylindrical blades in the working space of a disk-type hulling machine.

Methods

Experimental tests were conducted to remove the coats of white mustard seeds and rapeseeds. The experimental materials comprised seeds of white mustard and rape var. Sponsor, stored indoor in plastic bags at a constant temperature of 18°C and air humidity of about 85%. Prior to tests the seeds were separated on a pneumatic separator with a vertical aspiration airtrunk, to eliminate impurities and broken seeds. The moisture content of seeds ranged from 6.5 to 8.5%, and was determined according to the Polish Standard PN-EN ISO 665:1999. The working space of a hulling machine is composed of a top cover, a cylindrical casing and a hulling disk. The disk is equipped with cylindrical blades, ϕ = 2, 3, 4 mm, placed radially (Fig. 1). The seeds were gravitationally supplied to the working space through a feed hopper in the top

a ***b***

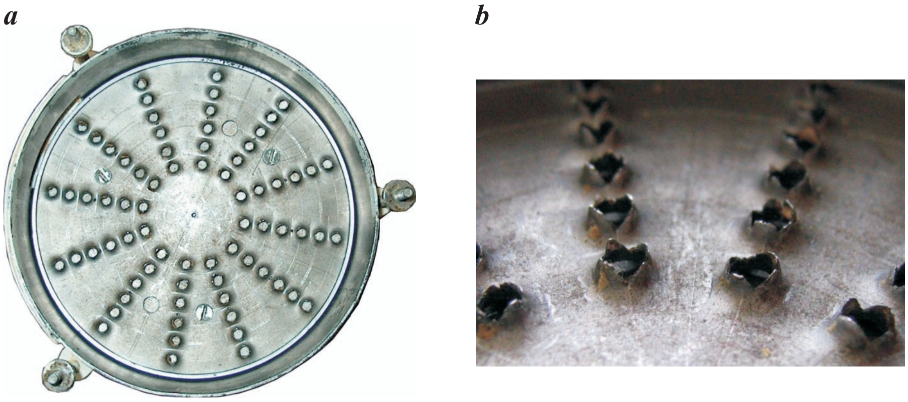

Fig. 1. Working disk of a laboratory disk huller: *a* – view of a disk, *b* – upper edges of the blades of a hulling disk

cover. The disk, 140 mm in diameter, was rotating at a constant angular velocity of ω = 738 rad/s. A detailed description of the experimental methods and results is given elsewhere (Mieszkalski, Anders 2002, 2003). The size of seeds of white mustard and rape, adopted for theoretical calculations, was 1.4 mm to 2.8 mm (Niewiadomski 1983). In order to perform a more detailed theoretical analysis of collisions between seeds and the hulling disk, the following simplifications were made: the seeds were treated as homogenous spheres, the interactions between seeds and the aerodynamic drags of seed motion in the working space of a hulling

Table 1

Construction parameters of a hulling disk

Disk no.	Disk diameter *D* (mm)	Number of rows of blades placed radially	Number of blades placed radially in a row	Blade height h_w (mm)	Outer diameter of a cylindrical blade d_w (mm)	Distance between blades *m* (mm)
1	140	12	10	1.8	2	5
2	140	12	8	2.3	3	6
3	140	12	6	2.5	4	7

machine were ignored. It was also assumed that the surface areas of seeds and working elements are smooth and that the seeds supplied to the working space form an ordered layer. Strains of the working elements of a hulling machine were disregarded.

In order to determine similarities in the morphological structure of the seeds used in the experiment, 20 mustard seeds and 20 rapeseeds were selected from the samples prior to hulling. Right sections along cotyledons were made, and photographs were taken using a digital camera and a microscope, at 60x magnification.

Results

Seeds fall into the working space of a hulling machine under the influence of gravitational force, through a slot (length b = 5 mm) in the feed hopper. Length b permits continuous seed feeding to the disk. The seeds rebound against the blades and the top cover of the working space. It was assumed that the seeds falling down can come into contact with the blades at various points on the disk

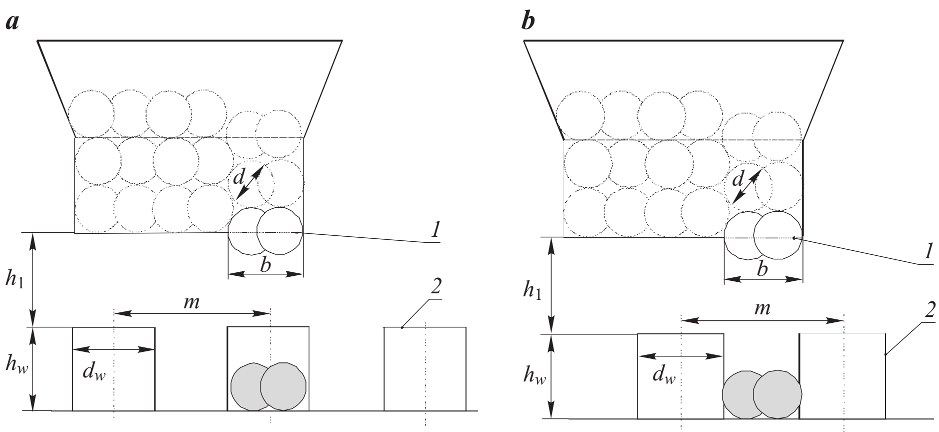

Fig. 2. Seeds falling down onto the cylindrical blades of a disk: *1* – outlet of the feed hopper, *2* – blade; b – outlet length, d_w – blade diameter, h_1 – distance between the feed hopper and the upper edge of a blade, h_w – blade height, m – distance between blade axes

(Fig. 2). Seed falling takes place within segment h_1, and then the seeds touch upon the working elements.

Various outer diameters of blades and distances between blades on a disk provide conditions for different types of contact between blades and seeds during the hulling process (Fig. 3). Blade diameters affect the contact surface area

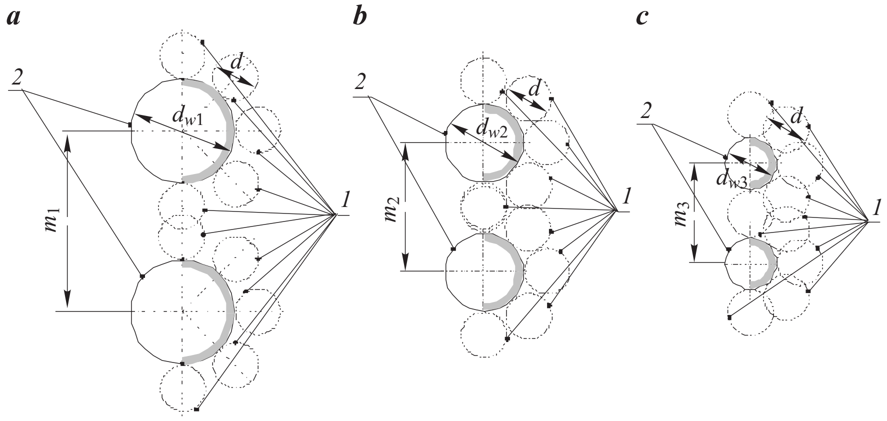

Fig. 3. Contact between seeds and cylindrical blades with different outer diameters (top view): *a* – d_{w1} = 4 mm, *b* – d_{w2} = 3 mm, *c* – d_{w3} = 2 mm; m_1, m_2, m_3 – distance between blades, *1* – seeds, *2* – cylindrical blades

between seeds and blades as well as stresses within seed coats. The greatest stresses are observed when seeds are struck centrally by rotating blades.

The total surface area of a hulling disk, over which contact between seeds and blades occurs, varies depending on the instantaneous position of the working element and a seed (Fig. 4). This area can be calculated using formulas 1, 2 and 3.

The area over which a seed strikes against the disk blade is:

$$A = \frac{\pi \cdot d_w}{2} \cdot \overline{AB}, \qquad \overline{AB} = h_w - \frac{d}{2} \tag{1}$$

where:

d_w – outer diameter of a blade (mm),
h_w – blade height (mm),
d – seed diameter (mm).

It was assumed that the area over which a seed strikes against the disk base corresponds to a circular sector diminished by the areas of orthogonal projections of the contours of disk blades:

$$B = \frac{\varphi \cdot \pi}{360} \cdot \left(R^2 - (R-b)^2\right) - 2 \cdot \frac{\beta \cdot \pi}{360} \cdot \left(\frac{1}{4} \cdot (d_w^2 + 2 \cdot d_w \cdot d + d^2)\right) \tag{2}$$

where:

φ =30° – angle between two neighboring rows of blades,
R – radius of the hulling disk (mm),
b – length of the feed hopper slot (mm),
b = 180° – angle at which seeds come into contact with blades.

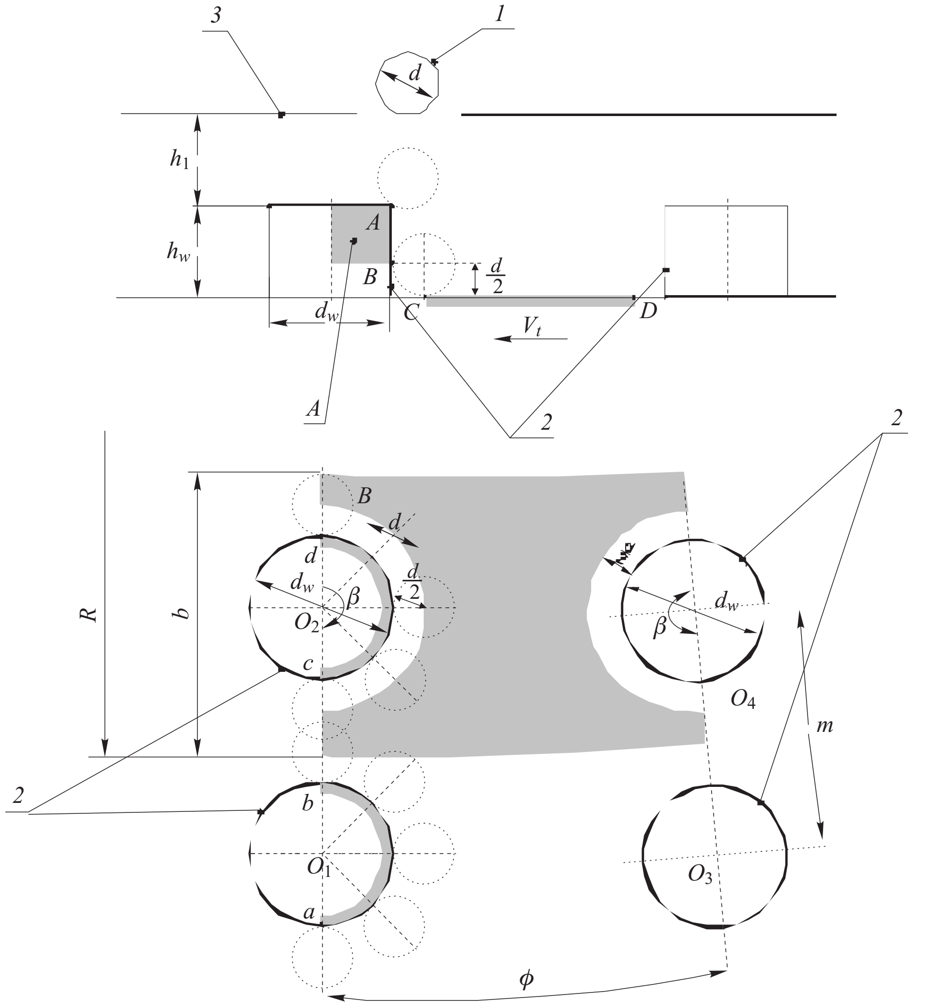

Fig. 4. Area of contact between seeds and cylindrical blades of a hulling disk: *1* – seed, *2* – blades, *3* – cover: $\overline{AB}$ – segment representing contact between a seed and the lateral surface of a blade, $\overline{CD}$ – segment representing contact between a seed and the surface area of a disk

The total surface area between neighboring rows of blades placed radially, where seeds strike against the hulling disk, is:

$$O = A + B \tag{3}$$

When actual dimensions of the hulling disk and seeds are substituted into the above formulas, we obtain the surface area of a disk where seed collisions take place (Fig. 5).

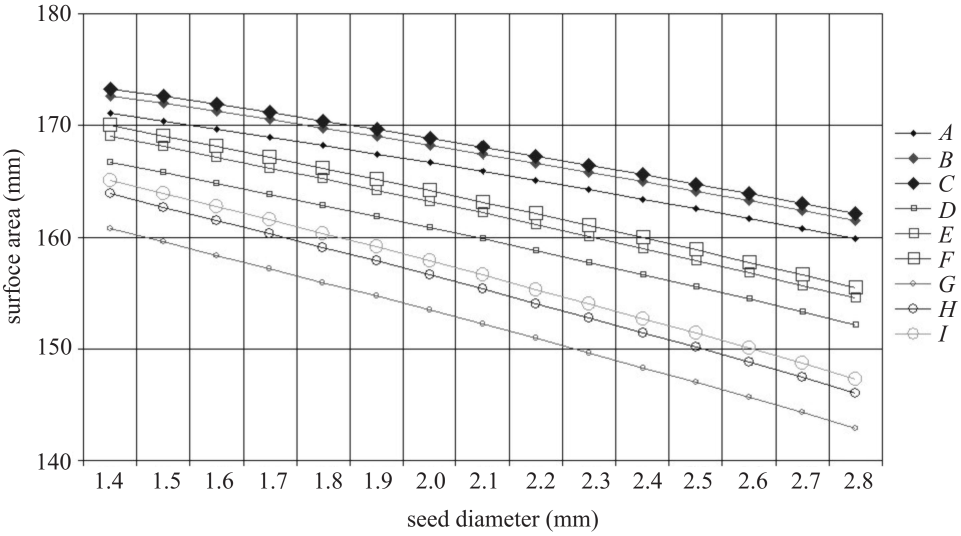

Fig. 5. Contact surface area between seeds and the hulling disk: $A - d_w = 2$ mm, $h_w = 1.8$ mm, $B - d_w = 2$ mm, $h_w = 2.3$ mm, $C - d_w = 2$ mm, $h_w = 2.5$ mm, $D - d_w = 3$ mm, $h_w = 1.8$ mm, $E - d_w = 3$ mm, $h_w = 2.3$ mm, $F - d_w = 3$ mm, $h_w = 2.5$ mm, $G - d_w = 4$ mm, $h_w = 1.8$ mm, $H - d_w = 4$ mm, $h_w = 2.3$ mm, $I - d_w = 4$ mm, $h_w = 2.5$ mm

An analysis of Figure 5 shows that the difference in the surface area on a disk over which collisions take place, resulting from the use of blades with a diameter of 2 mm and 4 mm and seeds with a diameter of 1.4 mm and 2.8 mm respectively, is 17.5%. During the hulling of white mustard seeds and rapeseeds, 1.4 mm to 2.8 mm in diameter, on a disk equipped with blades 2 mm in diameter, the surface area over which seeds strike against disk elements is 173.3 mm^2 and 162.0 mm^2 respectively.

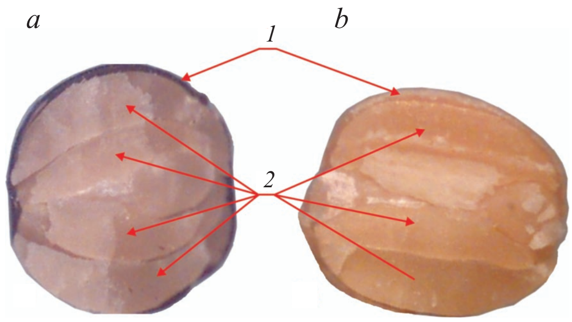

Fig. 6. Seed sections: *a* – rapeseed, *b* – white mustard seed, *1* – seed coat, *2* – cotyledons

Photographs of seed sections taken under the microscope show that seeds of white mustard and rape have similar structure. The seeds are covered by coats inside which there are four cotyledons and an embryo, loosely connected with each other (Fig. 6). The seed coat is not permanently connected with the inner morphological parts of a seed. Seed sections and photographs taken under the microscope reveal places where the coat comes off the inner cotyledons.

Conclusions

1. A theoretical analysis of the size of the areas on a hulling disk over which seeds strike against blades enabled to design a disk permitting a high number of collisions necessary to remove the coats of white mustard seeds and rapeseeds.

2. Due to their similar dimensions and morphological structure, seeds of white mustard and rape can be hulled through collisions with the working elements of a disk (cylindrical blades).

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