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Methodological aspects of development of a 3D model of a broad bean seed huller. Part I. The broad bean seed hulling concept

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Abstract: *Methodological aspects of development of a 3D model of a broad bean seed huller. Part I. The broad bean seed hulling concept.* The article provides an analysis of the internal structure of the seed coat and seed leaf of broad bean on the basis of microscope photographs. The methodological aspects of development of the broad bean seed hulling process concept have been presented. Removal of the seed coat from broad bean seeds (hulling) takes place by hitting the seeds many times – as a result, the coat fragments are torn off, and about 1/3 of the coat is removed from the seed leaf. The hulling concept served as a basis for development of the broad bean huller design concept and for the 3D model of the design. The huller design concept and the 3D model have been described in Part II of the article, in the same issue of this scientific journal.

Key words: broad bean seed, microstructure, hulling concept

INTRODUCTION

Broad bean seeds, containing 32–34% proteins can be used as a substitute for imported soybeans. The coat seed of broad bean contains protease inhibitors, hemagglutinins, tannins, alkaloids [Pastuszewska 1985, Laskowski et al. 1993, Meijer and Ognik 1994]. Rational use of broad bean seeds as a fodder raw material is possible after meeting the nutritional requirements, reducing to a minimum the content of anti-nutritional compounds that are found mainly in the seed coat. Market trade requires compliance with the applicable standards in this regard [Waszkiewicz et al. 2012]. Broad bean seeds without the seed coat are characterized by a better chemical composition, as a substantial quantity of tannings and protease inhibitors are removed along with the seed coat [Laskowski et al. 1993, Mieszkalski 1993, 1999, Mejer et al. 1994, Flis 1996] Klocek [1985], Kwiatkowski and Golec [1987] found that removal of the seed coat from the broad bean seeds reduced the *in vitro* activity of trypsin inhibitors by about 40%, tannins – by about 60%, and tanning agents – by about 80%. One of the methods of reduction of antinutritional compound content is to remove the external layers of the seed in the hulling process [Reichert 1982, Mwasaru et al. 1988, Reichert et al. 1988]. During hulling, the seed coat is removed in a manner, which is aimed at minimizing damage to the seed leaf. After hulling, the raw material is characterized by higher concentration of protein and starch and lower fiber content.

The hulling process, using various types of hullers [Yamamoto 1986, Satake 1989, Salete 1990, Savage 1995, Thakor et al. 1995, Vimala 1996] – is used in many technological processes, such as production of flour, groats, hulling of common pine cones [Aniszewska 2012] and fodder production [Mustafa et al. 1997]. The research team of the Faculty of Agricultural Machines of Mashhad University in Iran [Khodabakhshien et al. 2010] has proposed the method of systematic designing of hullers on the basis of the theory, developed by Pahl and Beits in 1988. In this method, searching for the concept has been divided into the following stages: defining of the problem, defining of the device function, alternative principles for each function, formulation of structural solutions, assessment of the solution concept on the basis of the criteria defined. Pahl and Beitz [1988] accept the intuitive approach at each stage of systemic design. They believe that the systemic and intuitive approach are not mutually exclusive, but complementary. When designing hullers, it is necessary to meet the following requirements: the machine must be characterized by high performance and work efficiency and low unit energy consumption.

Searching for the huller design concept, it is necessary to take into account the physical characteristics of the seeds, which are of significance for the hulling process, and their morphological structure, and, first of all, their anatomy.

The objective of the study was to design a broad bean seed hulling concept on the basis of analysis of the broad bean seed internal structure.

ANALYSIS OF THE PROCESS OF HULLING OF BROAD BEAN SEEDS

During hulling, seeds are subjected to external loads. The seed moisture content should be appropriate to make sure that the seeds subjected to loads behave like relatively brittle materials. The moisture content in the seeds should thus reach about 13% [Mieszkalski 1992]. At this moisture level, the broad bean seeds were damaged by stress of 38–59 $N \cdot mm^{-2}$. Loads exceeding the ultimate strength must be limited to the seed coat area. Loads applied to the seed during hulling should be selected to reduce to a minimum the mechanical damaging of the seed leaf. In the hulling process, one of the possible variants is to cause loading by hitting the seed against the working components of the huller. According to Mieszkalski (1993), getting familiar with the course of changes in the value of the impact energy within the limits of macro damage to the broad bean seed cover provides the basis for calculation of the speed, at which the seed should be hitting the working components of the huller in order to cause breaking of the seed cover without damaging the seed leaf. The highest impact energy, amounting to 10–11 J, is recorded as the seed is hit in the thickness direction, and the lowest (3–4.5 J), when it is hit in the longitudinal direction, in the space left after the rachis (Fig. 1). When hitting the seeds against the working component of the huller at a defined speed, the seed mass is of importance.

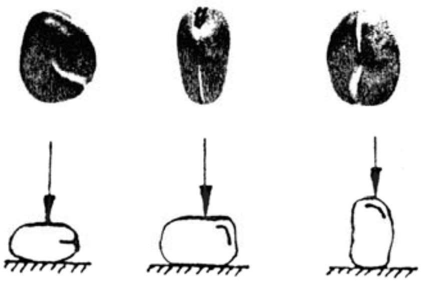

FIGURE 1. The place of impact of the broad bean seed, as shown by the arrow in the direction of thickness, length and the place after the rachis (own eleboration)

The broad bean seed mass in the air-dried state ranges from 0.35 to 1.1 g. When choosing the concept of structure of the huller working unit, it is also necessary to take into account the basic seed dimensions. The broad bean seed length ranges between 6.8 and 12.1 m, its width – from 6.6 to 10.4 mm, and thickness – from 5.6 to 8 mm. The seed shape is associated with its dimensions. Figure 2 presents the geometric model of the broad bean seed shape [Mieszkalski 2014a, b], which is of significance for the computer simulation of the hulling process and selection of the huller working space parameters. A sensitive spot on the seed cover is the place left after rachis removal (Fig. 2). The magnification

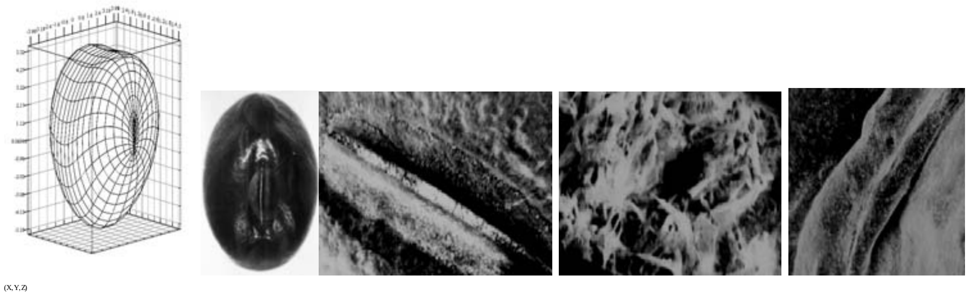

FIGURE 2. The broad bean seed shape and the place left after rachis removal and unevenness of the seed surface (own materials and elaboration)

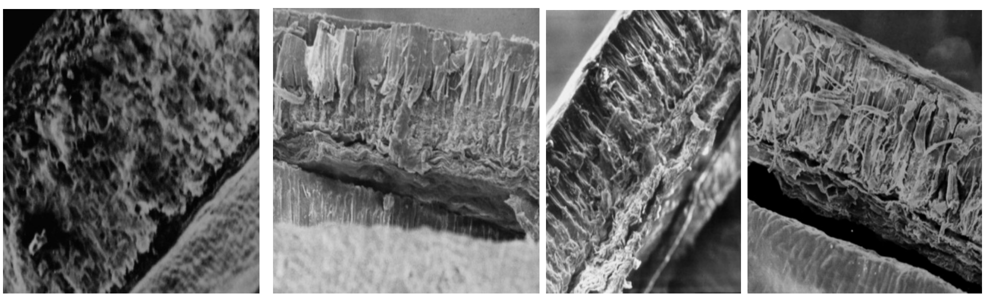

FIGURE 3. Cross-sections of the seed cover and the seed leaves (magnification 500 times), (own elaboration)

image of this location (magnified 60 and 1,500 times) suggests that the working component that the seed is supposed to hit should have a sharp-edged surface.

Anatomy of the broad bean seeds indicates that the seed cover is not integrated with the seed leaves (Fig. 3), and the hulling process should be conducted in a different manner than in the case of hulling of caryopses of basic cereals.

CONCEPTUAL ASSUMPTIONS OF THE HULLING PROCESS

Analysis of the microscopic image (electron microscope JEOL JSN 5310 LW) of the broad bean seed cross section indicates that the seed cover consists of many layers: the epidermis with the epithelium, palisade cells, support cells and parenchymal cells (Fig. 4). The palisade cells are strongly elongated and they adhere tightly to one another. Under the palisade cell layer, there are the short, thick-walled support cells, and underneath – the parenchymal cells. In the process of hulling of the broad bean seeds, adherence of the seed cover to the seed leaves and the shape of the palisade cells are of significance.

Cracking of the seed coat as a result of hitting of the seed during measurement of the impact energy within the limits of macro damage [Mieszkalski 1992] takes place along the palisade fibers (Fig. 5). This observation, concerning the mode of cracking of the seed coat, was used when developing the broad bean seed hulling process concept. The working component of the huller may lean with its sharp edges against the unevenness of the surface (Fig. 5). Removal of the seed cover of the broad bean seed can be effected by perpendicular cutting of the palisade cells or by causing cracking

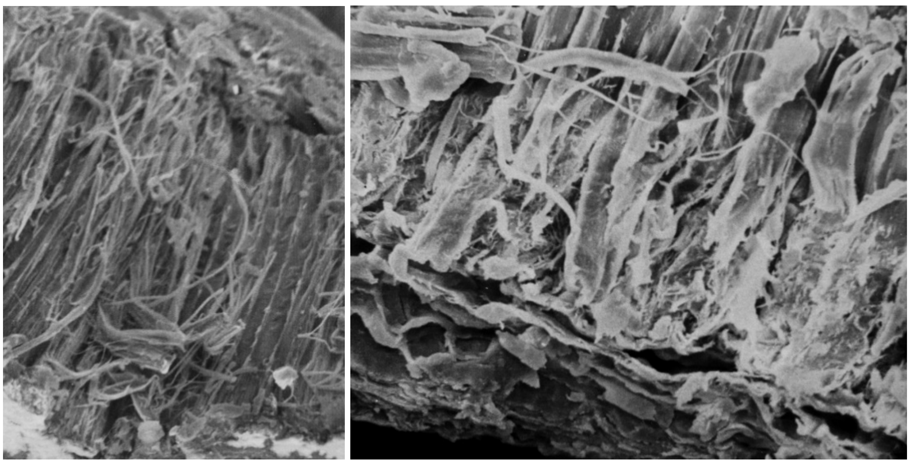

FIGURE 4. Microscopic image of cross-section of the broad bean seed cover (magnification 500 times), (own materials)

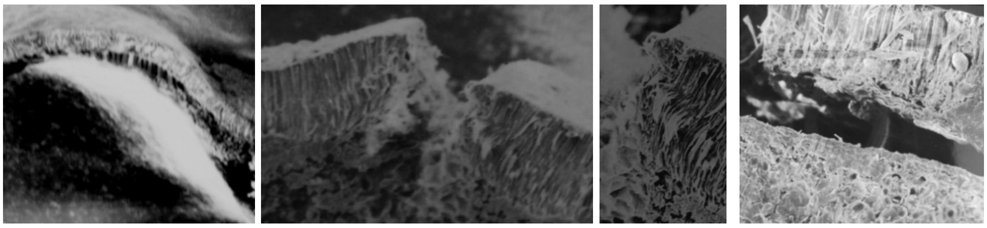

FIGURE 5. Damaging of the seed cover of the broad bean seed resulting from impact (own materials)

along the palisade cell fibers (Fig. 6). The seed in the working space of the huller must be subjected to complex stress (shearing and compressing stress). The broad bean seed in the working space of the huller should be subjected to multiple hits against the grinding wheel with the protruding sharp edges and the huller casing, in order to lead to cracking along the fibers of the internal structure of the seed cover. Between the grinding wheel and the casing, the seed will be relocated by complex motion (Fig. 7), enforced by the huller working components (rebounding against the revolving grinding wheel and the fixed casing), as well as the seed shape [Mieszkalski 2014a, b].

In the broad bean seed hulling process, the force that causes breaking off of the cover is of great significance. Its fragments are torn off by the protruding parts of the revolving grinding wheel (Fig. 7).

Resistance of seeds to mechanical damage depends on elastic properties, depending on cohesion forces of the basic parts of the anatomic internal structure. External load exceeding the cohesion forces results in dislocation of a part of the internal structure, exceeding the acceptable value, which results in cracking. Individual parts of the internal structure vary with regard to their size, shape

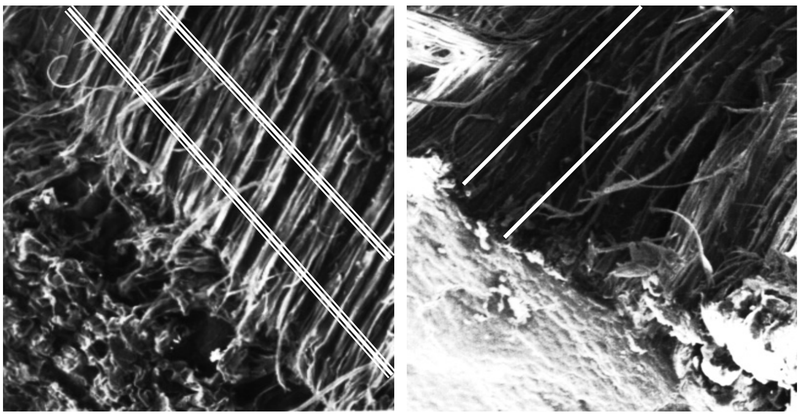

FIGURE 6. Cross-section of the seed coat. The white lines indicate the mode of its removal through perpendicular cutting of fibers or cracking along fibers (own materials)

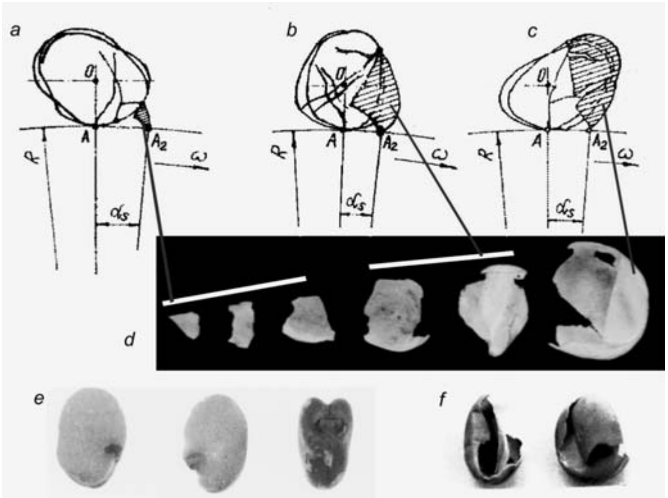

FIGURE 7. The stages of releasing of seed leaves from the broad bean seed: a – first phase of hulling, b – second phase of hulling, c – third phase of hulling, d – seed cover fragments, e – seed leaves, f – seed cover, R – grinding wheel radius, ω – angular velocity of grinding wheel, α_s – angle of rotation of grinding wheel, A – seed impact point, A_2 – point of tearing off of the seed cover fragment (own materials and elaboration)

and cohesion force values. The broad bean seed as an anisotropic material changes its rheological state depending on moisture content. A change in state from moist to dry results in a change of the rheological state of the seed from plastic towards elastic and then brittle. Tearing off of a small fragment of the seed cover (about 4 mm^2) requires force of 3 N at moisture content of 14% to 7 N at moisture content of about 10%. Falling of fragments of the cover takes place until it is removed from the area constituting about 0.62 of the entire cover. The cover from the remaining seed surface is removed using the force of 0.2–0.6 N [Mieszkalski 1993].

In the process of hulling of the broad bean seeds, the seed leaves should not be subjected to mechanical damage (broken). Small damaging is allowed, caused by cutting with sharp edges of the grinding wheel. If the seed must cover an excessive distance, falling and hitting many times against the grinding wheel and the casing in the working space of the huller, after hulling, the seed leaf surface is cut by the rotating grinding wheel. As a result of such cutting, small parts of seed leaves emerge (Fig. 8).

In the hulling process, implemented through multiple hitting of the seed against the working components of the huller, microdamages in the internal leaf seed structure can emerge (Fig. 9). As a result of such microdamage inside the seed leaf, upon subsequent impact, cracking and fragmentation of the seed leaf takes place.

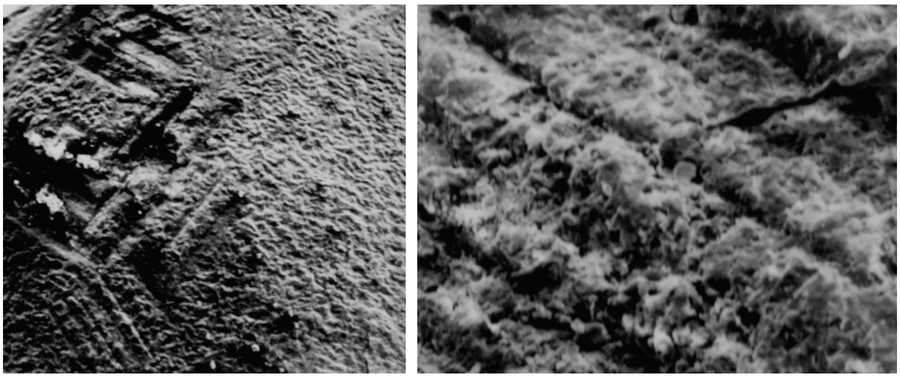

FIGURE 8. The visible macrodamage in the microscopic image of the seed leaf surface (magnification 60 and 500 times), (own materials)

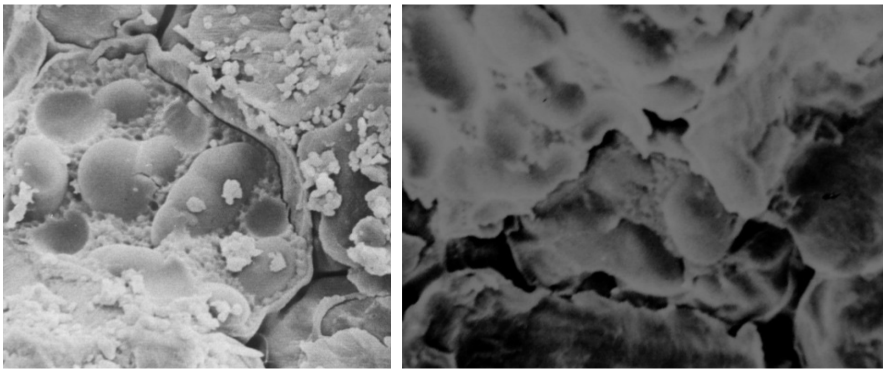

FIGURE 9. The visible microcracks in the microscopic image of the seed leaf cross-section (magnification 1,500 times), (own materials)

CONCLUSIONS

Analysis of the microstructure of the seed cover of the broad bean seed shows that it is not integrated with the seed leaves, but adherent to it. It is made of palisade cells of elongated shape, support cells and parenchymal cells. Removal of the seed cover from the broad bean seed can be implemented by causing cracking along the fibers of palisade cells. Removal of the cover will be implemented by breaking of its fragments until removal of about 0.62 of the entire cover area. The cover will be then torn off the remaining seed area. The height, linear velocity of the rotating grinding wheel, length of the falling distance of the seeds and the number of hits of the seeds against the grinding wheel and the casing in the working space of the huller should be selected so that after hulling, the seed leaf surface is not subjected to cutting by the rotating grinding wheel.

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Streszczenie: *Metodyczne aspekty tworzenia modelu bryłowego 3D obłuskiwacza do nasion bobiku. Część I. Koncepcja obłuskiwania nasion bobiku.* W artykule dokonano analizy struktury wewnętrznej okrywy owocowo-nasiennej oraz liścienia nasiona bobiku na podstawie zdjęć mikroskopowych. Przedstawiono metodyczne aspekty opracowania koncepcji procesu obłuskiwania nasion bobiku. Usuwanie okrywy owocowo-nasiennej z nasiona bobiku (obłuskiwanie) odbywa się podczas wielokrotnych uderzeń nasiona, w wyniku których okrywa jest fragmentami odrywana, a około 1/3 okrywy zostaje ściągnięte z liścieni. Koncepcja obłuskiwania stanowiła podstawę opracowania zarówno koncepcji konstrukcji obłuskiwacza do nasion bobiku, jak i jego modelu bryłowego. Koncepcję konstrukcji obłuskiwacza i jego model bryłowy opisano w części II artykułu, w tym samym numerze tego zeszytu naukowego.

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