The object of research is technological processes, seeds of industrial hemp, and working bodies of the dehuller.

A centrifugal-type device for crushing hemp seeds with a closed sector-type working body has been designed. Owing to this, the task related to seed dehulling was solved with a high level of efficiency in separating the seed coat from the kernel.

The rational parameters for the dehuller have been substantiated: the diameter of the impeller is 162 mm, the gap between the impeller and the seed repelling panel is 80 mm, the frequency of rotation of the impeller is 2000 min⁻¹. It was established that with the specified parameters and moisture content of the seeds within the limits of conditional (12.0–13.0 %), it is advisable to carry out dehulling process without preliminary separation of the seeds into fractions by width.

It was established that an increase in seed size leads to a corresponding increase in the weight share of seed kernels. About 58.2 % of the main mass of seeds is the average fraction with a width of 2.5 to 3.0 mm.

It was found that reducing the diameter of the impeller (from 236 mm to 162 mm) at a seed moisture content of 8.8 % improved the efficiency of dehulling. At a rotation frequency of the impeller of 2000 min⁻¹, the highest total number of intact and destroyed kernels (23.23–29.33 %) was achieved for the two studied moistures. With an increase in seed moisture content from 8.8 % to 12.0 %, the number of dehulled kernels in the hempseed cake increased.

It was noted that for seeds with a moisture content of 8.8 %, an increase in the gap led to a decrease in the dehulling efficiency for each of the three investigated seed fractions. The total number of dehulled kernels under such conditions decreased by 2.4–6.8 % and amounted to 16.4–26.9 %. For seeds with a moisture content of 12.0 %, an increase in the gap, on the contrary, increased the dehulling efficiency for each of the three investigated seed fractions. The total number of dehulled kernels for seeds of marked moisture increased within the range of 1.4–3.6 % and amounted to 27.4–31.0 %

Keywords: hemp, seed, seed kernel, separation, separation, cleaning, rotation frequency, centrifugal dehuller

SUBSTANTIATING THE RATIONAL PARAMETERS AND OPERATION MODES FOR THE HEMP SEED CENTRIFUGAL DEHULLER

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1. Introduction

In modern agriculture, three main directions of hemp cultivation are used: for fiber (vegetable direction), bilateral – obtaining fiber and seeds, and for seeds [1]. World experience proves that the bilateral method of growing hemp enables the greatest economic efficiency, as it makes it possible to receive income from the sale of both seeds and hemp fiber or hemp [2].

As of the beginning of 2024, 19 varieties of industrial hemp have been added to the register of plant varieties in Ukraine,

which are recommended for cultivation [3]. Modern varieties developed by Ukrainian specialists are characterized by high productivity, quick ripening, and significant fiber content. The monoecious form of hemp developed by Ukrainian breeders is becoming widespread and popular not only in the lands of Ukraine [4].

Despite the numerous natural characteristics and various uses of the stems of industrial hemp, the seeds of this crop are classified as particularly important products for the human body. Hemp seed is a nut with a hard outer shell, in the middle of which is a soft kernel. Hemp seeds have high value because they are a source of easily digestible plant protein and contain a wide range of phytonutrients important for the health of cells, blood vessels, and internal human organs [5]. In addition, the seeds contain vitamins A, B, D, E, from 30.2 to 38.3 % lipids, 17.6–25.1 % protein, 13.8–26.9 % fiber, 2.5–6.8 % ash. Particularly valuable are the polyunsaturated fatty acids: linoleic Omega-6 (54.31–57.20 %) and linolenic Omega-3 (12.09–14.75 %), which have an ideal ratio for the body. The seeds also contain 20 amino acids, 9 of which are essential [6]. This rich composition makes hemp seeds superior to other «superfoods» such as quinoa, chia, or flax [7].

The demand for products made from industrial hemp seeds is constantly increasing. This is due to the high nutritional value and balance of the main components of food products from hemp seeds [8]. However, the hard seed coat creates significant difficulties for comfortable consumption and effective assimilation of useful substances by the body. That is why research into the justification of rational parameters and modes of operation for centrifugal dehullers of industrial hemp seeds is relevant.

2. Literature review and problem statement

A hulled seed is a seed kernel (grain, fruit) freed from the outer protective shell (husk). Usually, the dehulling operation is carried out to improve the taste of the product or as part of seed preparation for further deep processing.

The process of obtaining a seed kernel free from the shell consists of two independent technological operations: obtaining a hempseed cake (dehulling) and dividing a hempseed cake into fractions (separation of a hempseed cake). The dehulling operation involves the separation of the seed kernel from the shell (husk) [9]. The separation process involves dividing the husk into fractions for the purpose of extracting the basic product – seed kernels, as well as separating waste and whole and intact seeds. Both technological operations, dehulling and separation, are quite complex from the point of view of technological implementation, which is due to the heterogeneity of the properties of both individual seeds and the components of hulled seeds [10].

Separation of kernels from cotton seed shells is carried out with disk cutters due to chipping or cutting [11]. Disadvantages of this principle include repeated impact of knives on seeds, which leads to oiling of seed coats and a corresponding increase in oil losses; the presence of a drive with a flat belt transmission of large dimensions, speed, and power is a dangerous factor for service personnel; changing the speed of rotation of the movable disk due to the rearrangement of pulleys requires considerable time.

The process of separating the shell from kernels is carried out in different ways, depending on the type and shape of the seed: crushing, splitting, cutting, free impact, friction. The main requirement of the seed dehulling process is to obtain a hempseed cake with the maximum content of kernels. The choice of dehulling technique is based on taking into account the mechanical and technological properties of the seed coat, such as strength, elasticity, and plasticity [12]. The effectiveness of the dehulling process largely depends on the degree of ripeness of the seeds. The greater the degree of ripening, the greater the effort required to destroy the seed coat. Seed moisture has a significant impact on the process of separating the seed coat from the kernels. It was noted that an increase in seed moisture leads to a corresponding decrease in the effort to destroy the seed coat [13].

There are scientific studies of mechanisms for cleaning millet, in which abrasive wheels are used to separate the grain from the husk [14]. Abrasive discs rotating at a certain speed are used as a working body. The space between the discs is adjustable. The process of shell separation is based on abrasive friction and occurs when the seeds pass between the disks. The disadvantages of such a mechanism include the impossibility of processing seeds without prior calibration. As a result of the permanent gap between the disks, only the seeds whose dimensions exceed the dimensions of the gap are dehulled. In addition to preliminary seed calibration, such a mechanism requires constant adjustment of the gap according to the size of the seed fractions. It is difficult to dehull hemp seeds by the method of abrasive friction. This is due to a wide range of geometric characteristics of seeds, significant differences in the size of hemp seeds even within the same variety. As a result of wear of the working disks, the probability of contamination of dehulled kernels with abrasive particles increases. The presence of oil in hemp seeds (up to 40 %), as a rule, leads to oiling of the working surfaces, which makes it impossible to carry out dehulling with a high level of efficiency.

In work [15], peeling rollers are used to clean soybean seeds by crushing. The process of destruction of pods occurs under the conditions of their passage between the rollers. The rollers rotate to meet each other and have Archimedean spirals on the surface. There are some caveats to using hemp seeds in the above way. Among them is a long stay of the material in the working area that leads to the dehulling of soft hemp kernels and oiling of the working bodies; a constant working gap between the rollers makes it impossible for seeds to dehull without calibration. It is possible to ensure effective dehulling only under the conditions of constant adjustment of the working parameters (interval) of the mechanism in accordance with the geometric characteristics of seeds.

To separate the fruits of oil camellia from the shell [16], mechanisms based on the principle of splitting are used. The peeling process is based on the principle of soft squeezing and friction during the interaction of the fruit with a dynamic conveyor belt and a flexible friction board. Despite the fact that this principle enables the processing of camellia fruits of different diameters, it cannot be implemented for dehulling hemp seeds. The main obstacle is significant differences in the physical and mechanical characteristics of seeds. In addition, the shell of camellia fruits, unlike hemp seeds, is soft and characterized by a high moisture content. Hemp seeds, on the contrary, have a hard shell and a soft kernel, which is characterized by high oiliness. This method will ensure complete separation of the hard shell of hemp without damaging the seeds.

The dehulling of some grain crops (spelt, emmer) is carried out through the mechanisms of impact principle (the grain hits a hard surface at high speed, which leads to the destruction of the shell). It is worth noting the well-known

mechanisms whose actions are based on the principles of frictional friction. These mechanisms separate the husk from the grain through pressure and friction. Abrasive friction mechanisms function according to principles similar to friction dehullers. The above mechanisms use abrasive surfaces, which improves the efficiency of shell separation [17]. However, the specified technique will not provide the necessary level of efficiency under the conditions of dehulling of hemp seeds.

There are well-known technical solutions [18, 19] that were implemented under the conditions of dehulling sunflower seeds and pistachio fruits. These mechanisms use the impact technique (non-oriented multiple and oriented single-shot) in their work. Corresponding techniques are implemented in whip (multiple impact) and centrifugal (single impact) breakers. It is worth noting that dehulling seeds by a one-shot technique is more effective. The use of the above-mentioned mechanisms for dehulling hemp seeds causes certain difficulties. This is due to significant differences in the physical characteristics of seeds. Hemp seeds, unlike pistachios and sunflower seeds, require more delicate approaches to dehulling.

The choice of principles, equipment, and modes of separation of hempseed cake depends on the properties of its components. Differences in the physical and mechanical properties of individual components in the hempseed cake are used for separation. These properties include shape, linear dimensions, mass, specific gravity, aerodynamic properties and windage, elasticity, coefficient of friction, surface condition, etc. However, the separation of hempseed cake by only one of the properties does not ensure proper separation and does not make it possible to qualitatively separate the mixture into fractions. A combination of several principles is used for qualitative separation. In particular, two-stage separation is applied to separate sunflower seeds: at the first stage, the hempseed cake is separated according to linear dimensions, and at the second stage, according to aerodynamic properties [10].

Our review of the literature [9–22] established the absence of universal technical and technological solutions that would enable the efficiency of dehulling seeds with different physical and mechanical properties. That is, the dehulling of different types of seeds requires special approaches and technical solutions, which take into account differences in the unique properties of the seed (size, hardness of the shell, structure, etc.).

Based on the analysis of [14–22], it was noted that centrifugal dehullers are the most promising mechanisms for dehulling industrial hemp seeds. The seeds in such devices acquire the necessary value of kinetic energy and fall with one targeted impact on the tray. The effective operation of centrifugal dehullers is determined by careful balancing and centering of the rotors. The distance between the rotor and deck should be the same around the entire perimeter. The evenness of seed feed, as well as the speed of rotor rotation are also considered as determining factors of the process. The above is included in the initial requirements for the design of centrifugal dehullers of hemp seeds.

Solving the aforementioned tasks is of great importance for the modernization of technologies and technical means for processing hemp products. Transferring production to highly profitable technologies will ensure its competitiveness.

3. The aim and objectives of the study

The purpose of our study is to justify the rational design parameters and operating modes for the centrifugal dehuller of hemp seeds with a working body of the closed sectoral type. Owing to this, the depth of seed processing has been expanded and the prerequisites for increasing the efficiency of industrial hemp cultivation technologies have been created.

To achieve the goal, the following tasks were set:

– to design a centrifugal-type device for dehulling hemp seeds with a working body of a closed sectoral type;

– to determine the influence of the diameter of the working body of the device on the efficiency of seed dehulling;

– to determine the effect of the distance (gap) between the impeller of the device and the seed repelling panel on the effectiveness of hemp seed dehulling.

4. The study materials and methods

4. 1. Methodology for determining the physical and mechanical properties of seeds

The object of our research is technological processes; seeds of industrial hemp; and working bodies of the dehuller.

The subject of research is the interaction of dehuller's working bodies with industrial hemp seeds, the influence of dehuller's parameters and modes of operation on process indicators.

The scientific hypothesis assumes that there are such technical and technological solutions, the implementation of which will make it possible to carry out the dehulling of industrial hemp seeds with a high level of efficiency.

To study the physical and mechanical properties of seeds, generally accepted procedures and existing techniques were used [23].

The size of hemp seeds was determined by measuring with a caliper. Seed weight was determined by electronic scales by weighing individual samples. Separation of seeds by width into fractions was carried out on laboratory sieves with oblong holes measuring 3.0×20 mm and 2.5×20 mm. Separation was carried out by pouring the seeds on sieves with subsequent reciprocating oscillations of the latter. Under these conditions, three fractions of seeds were obtained: with a width of more than 3.0 mm, less than 3.0 – more than 2.5 mm, less than 2.5 mm. Each of the obtained seed fractions was separately subjected to research.

Seed moisture was determined in accordance with the procedure from [23] using a laboratory drying chamber. The investigated moisture content of seeds was 8.8 %, 12.0 %, 15.2 %, 16.3 %, 21.6 %. The seed humidity was artificially increased by spraying water with subsequent natural drying until it reached a dry state, without traces of water, with signs of free flow.

4. 2. Methodology for determining the effectiveness of dehulling process

The weight of a separate batch of seeds for each of the research options was 5 grams. The batch (hempseed cake) obtained after passing through the experimental device for dehulling was divided into components. To this end, sieves (with oblong and round holes) of different sizes (from 1.1 to 3.5 mm) were used. Hempseed cake was divided into 6 fractions: whole kernel, broken kernel, whole seed, intact seed, waste, dust.

The effectiveness of the process of dehulling hemp seeds was determined by the fractional composition of the pulp and by coefficients identical to the coefficients used to evaluate the performance of centrifugal sunflower seed dehullers [24]:

1) efficiency;

2) dehulling;

3) kernel integrity (3).

The fractional composition of hempseed cake was determined as the percentage content of each of the above fractions in the sample.

The efficiency of the process of seed dehulling was determined by the coefficient η as:

$$\eta = \frac{k_{deh} - k_{k.i.}}{100}, \%, \qquad (1)$$

where k_{deh} is the coefficient of seed dehulling, %; $k_{k.i.}$ – kernel integrity coefficient, %.

The coefficient of seed dehulling was determined according to the dependence:

$$k_{deh} = \frac{m_2 - m_1}{m} \cdot 100 \%, \qquad (2)$$

where m_1 is the mass of whole and intact seeds, g; m_2 is the mass of a hempseed cake, g.

The coefficient of kernel integrity was determined according to the dependence:

$$k_{k.i.} = \frac{m_3}{m_4} \cdot 100 \%, \qquad (3)$$

where m_3 is the mass of the whole kernel in a hempseed cake, g; m_4 is the mass of the entire kernel, taking into account the whole kernel, destroyed kernel, and oil dust, g.

Sorted seeds of industrial hemp of different batches from the production crops at the Institute of Bask Crops of the National Academy of Sciences of Ukraine were used for research.

Research into the operation of dehulling hemp seeds was carried out using the designed experimental centrifugal device. The electric motor with the impeller of the device made it possible to provide the necessary level of speed (kinetic energy) to the seeds. The device provided for a smooth change in the rotation frequency of the electric motor in the range of 100–3000 min^{-1}. The seeds were fed from above through the structural hole in a free-flowing state into the loading hole of the impeller. Freely falling seeds from above during contact with the impeller, which had a certain frequency of rotation, changed the direction of movement and hit the walls of the seed repelling panel with some force.

Research was carried out by conducting a series of experiments. The number of repetitions in one experiment is fivefold. The results of experimental studies were processed using the methods of mathematical statistics according to the generally accepted methodology.

In the process of research, the variable design parameters were the diameter of the impeller and the gap between the impeller and the seed repelling panel. To study the influence of the diameter of the working body on the efficiency of seed dehulling, two versions of it were designed (Fig. 1). The working bodies noted above, which are identical in structure, have different diameters – 236 and 162 mm. The frequency of rotation of the impellers was studied in the main range of 1500–2500 min^{-1} with a step of 500 min^{-1}. In addition, the change in the characteristics of hempseed cake at the rotation frequency of the impeller of 1600 min^{-1} and 1750 min^{-1} was investigated.

The effect of the size of the gap between the impeller and seed repelling panel on the efficiency of the hemp seed dehulling was studied by using seed repelling panels identical in structure (metal ring) but different in diameter. The size of the gap for each impeller was chosen individually. For a diameter of 236 mm, 15 and 40 mm were chosen, for a diameter of 162 mm – 50 and 80 mm, respectively.
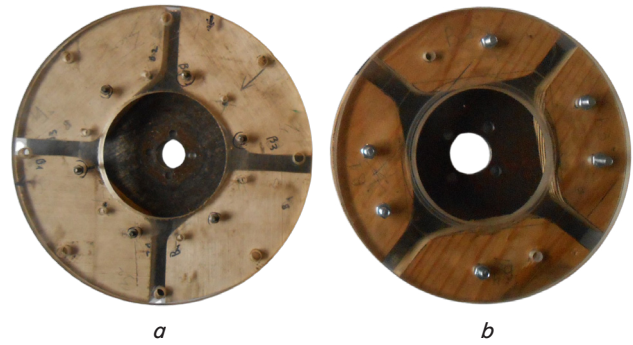

Fig. 1. Impellers of the closed sectoral type that were investigated: *a* — wheel diameter, 236 mm; *b* — wheel diameter, 162 mm

The basic processing of experimental data results was performed according to [26] using the Microsoft Excel software environment.

5. Results of investigating the parameters and modes of operation of the centrifugal dehuller

5. 1. Designing a device for dehulling hemp seeds

According to the research results, an experimental sample of the centrifugal dehuller device was designed [25]. The device for dehulling hemp seeds contains a body, an impeller with channels fixed on the shaft of an electric motor, a working chamber, a seed repelling panel, and a discharge tray.

A characteristic difference of the proposed structure of the impeller is that it contains two disks, the upper one of which has a loading hole. There are four sectors between the disks, which together form four radial profile channels with hyperbolic side surfaces. The seed repelling panel is made in the form of a cylinder with a smooth inner surface. The discharge tray has a W-shaped cross-section.

The closed design of the impeller prevents the formation of unwanted excess air flow in the working chamber, provides the necessary trajectory of the seeds, reduces the time of the components of hempseed cake in a suspended state in the working chamber.

The hyperbolic shape of the side surfaces of the sectors enables the unhindered passage of seeds through the channels and allows dehulling hemp seeds with a moisture content of up to 13 %, which contains up to 15 % of organic waste impurities.

The smooth inner surface of the deck combined with the rational angular speed of the impeller ensures satisfactory separation of the seed coat from the kernels for seeds of all sizes. Owing to this, the need to separate hemp seeds into several size fractions before processing is eliminated.

Due to the W-shape of the unloading tray, the components of hempseed cake cannot move uncontrollably after falling. This avoids unwanted destruction of its fragments.

The essence of the mechanism is shown in Fig. 2.

The experimental device for dehulling hemp seeds (Fig. 2) consists of hopper 1, nozzle 2, impeller 3, seed repelling panel 4, unloading tray 5, electric motor 6. Impeller 3 consists of upper disk 7 with a loading hole, lower disk 8, and four sectors 9 forming profile channels 10.

The device works as follows. Seed 11 from hopper 1 through nozzle 2 and the loading hole in upper disk 7 falls on lower disk 8. As a result of contact with lower disk 8,

the seed, under the action of centrifugal forces, begins to move in the horizontal plane along profile channels 10 in the direction of seed repelling panel 4. At the moment of contact of seed 11 with seed repelling panel 4, the seed coat is destroyed, and the seed kernel is released. The resulting mass falls on discharge tray 5 and is removed from the device under the influence of vibration.
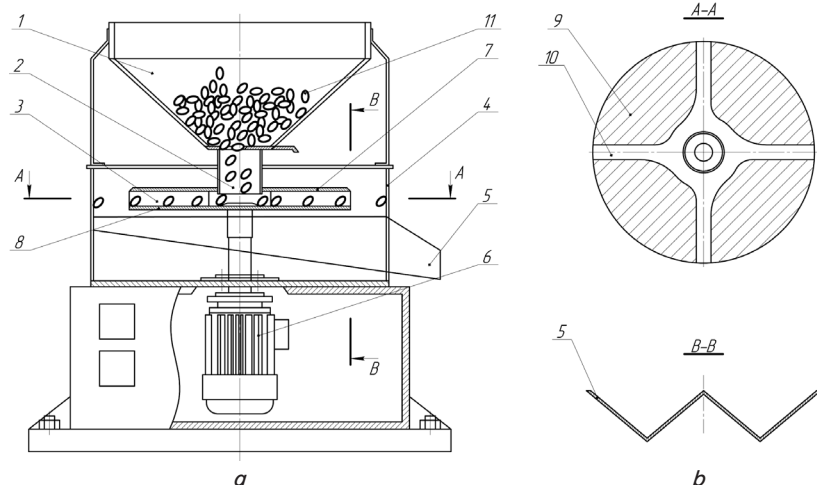

Fig. 2. Schematic of the experimental device for dehulling hemp seeds: *a* − general scheme, *b* − structure of the impeller (A−A) and the shape of the unloading tray (B−B)

The process of separation of the seed kernel and shell takes place at the moment of an approximate one-time impact of the seed against the seed repelling panel. The device makes it possible to obtain hempseed cake from hemp seeds, with a moisture content of 8.8 % to 13.0 %, which contains 3–15 % of organic waste impurities. There is no need to separate hemp seeds into several size fractions before processing. Owing to this, the process of dehulling hemp seeds is greatly simplified and time and labor costs are reduced.

Fig. 3 shows a general view of the experimental sample of the device for dehulling hemp seeds.
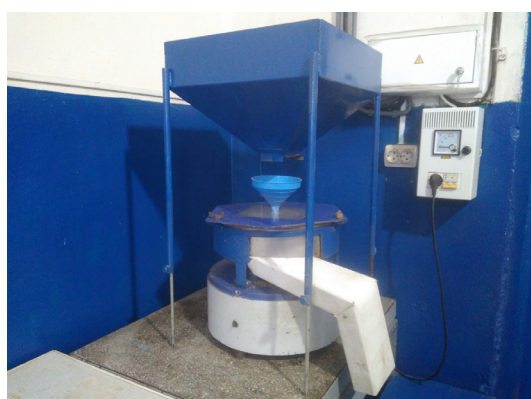

Fig. 3. General view of the experimental sample of the device for dehulling hemp seeds

The basis of the work of the experimental device is the principle of a one-time oriented impact of the seeds against a seed repelling panel. The use of a closed sector-type impeller eliminates excessive air flow in the working chamber, preventing unwanted crushing of seeds. Effectively matching the angular speed of the impeller with the distance to the seed repelling panel eliminates the need for complex preparation, such as detailed sorting of seeds by size. However, it should be noted that 41.2–76.4 % of the seeds remain intact during one pass through the dehuller. Three cycles are used to dehull a batch of hemp seeds. According to the first cycle, up to 26.7 % of ready-to-use kernels from the initial mass of the batch are released, according to the second cycle – up to 9.7 %, according to the third – 1.1 % of the initial mass of the batch, respectively. That is, a full cycle of dehulling makes it possible to obtain about 37.5 % of ready-to-use hemp kernels.

5. 2. Results of research on the influence of the diameter of the device's working body on the efficiency of seed dehulling

Hemp seeds, like the seeds of other oil crops, consist of a seed kernel covered with a film and a protective shell (husk), between which there is an air layer. A feature that directly complicates the process of dehulling is the shape of hemp seeds. The shape of the seed is close to elliptical, round-ovoid, slightly compressed from the sides [4]. Hence, the size of the seed is determined by three parameters (Fig. 4): length, width, thickness, which vary significantly even within the same variety.
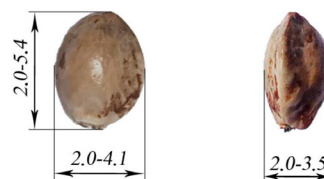

Fig. 4. Geometric dimensions of hemp seeds

In order to establish the influence of physical and mechanical properties of hemp seeds on the process of dehulling, they were divided into fractions. The width of the seed was chosen as the basic parameter, according to which the fractionation was carried out. Owing to laboratory sieves with holes of an oblong shape measuring 3.0×20 mm and 2.5×20 mm, respectively, three fractions of seeds were obtained: width greater than 3.0 mm (>3.0), greater than 2.5 mm – less than 3 .0 mm (2.5–3.0), less than 2.5 mm (<2.5).

The results of the analysis of seeds by fractions are given in Table 1 and shown in Fig. 6.

Table 1

Characteristics of seeds by fractions*

No. of entry	Seed fraction by width, mm	Weight of 10 seeds, g	Seed components, %	
			Kernel	Shell
1	>3.0	0.24	58.3	41.7
2	2.5–3.0	0.18	55.6	44.4
3	<2.5	0.13	53.9	46.1

*Note: * – moisture content 8.4–9.0 %*

The average statistical value of the weight of 10 seeds (Table 1) for the fraction larger than 3.0 mm was 0.24 g, fraction 2.5–3.0 mm – 0.18 g, fraction less than 2.5 mm – 0.13 g with a root mean square deviation of 0.007 g, 0.008 g, 0.004 g for each of the fractions noted above, respectively.

Table 1 demonstrates that the size of the fraction is a determining factor that affects both the weight of the seed and the weight of the kernel. For all three fractions, more than half of the seed weight is in the kernel. As the seed fraction decreases, the kernel weight fraction also decreases. Larger seeds have a correspondingly larger seed kernel.

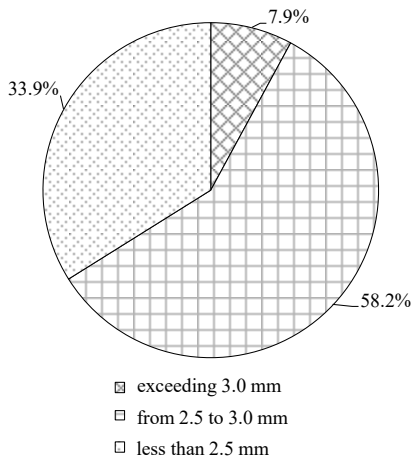The percentage content of each fraction in the total mass of seeds is shown in Fig. 5.

Fig. 5. The ratio of fractions in hemp seeds

- exceeding 3.0 mm
- from 2.5 to 3.0 mm
- less than 2.5 mm

Fig. 5 demonstrates that more than half of the seeds (58.2 %) consisted of the average fraction with a size of 2.5 to 3.0 mm.

Each obtained fraction of seeds was separately subjected to dehulling. Under such conditions, the influence of seed moisture and the frequency of rotation of the impeller on the efficiency of the dehulling process was studied (Table 2). In the process of research, the seeds were fed in a non-oriented loose state into the loading hole of the impeller.

According to the results of our review of the literature [12–15], it was noted that the humidity of both the seed coat and the kernel has a significant influence on the effectiveness of dehulling. Thus, an increase in seed moisture increased the moisture not only of seed coats but also of seed kernels. The humidity was increased for two days by spraying water on the seeds, followed by natural drying. This made it possible to increase the moisture content of seeds from 8.8 to 21.6 %.

The results of the research are shown in Fig. 6 and given in Table 3.

Table 2

Parameters under study

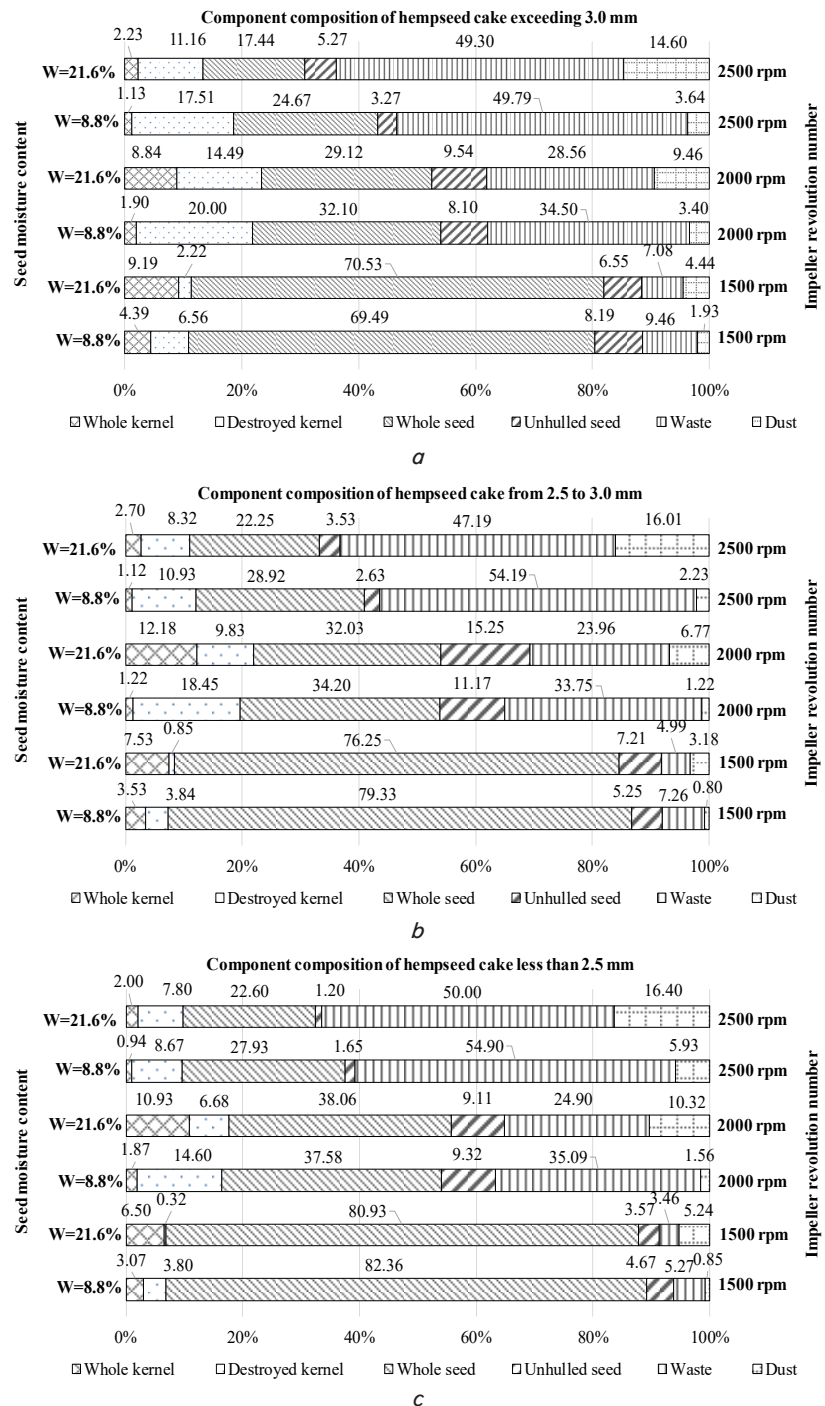| No. of entry	Parameters	Variables		
1	Diameter of the impeller, mm	236		
2	Clearance between the seed repelling panel and impeller	40		
3	Seed fraction (by width), mm	>3.0	2.5–3.0	<2.5
4	Seed moisture, %	8.8	21.6	
5	The number of revolutions of the impeller, min^{-1}	1500	2000	2500

a

b

c

Fig. 6. Fractional composition of hempseed cake based on the studied parameters (impeller diameter, 236 mm; gap between deck and impeller, 40 mm): a — fraction of seeds larger than 3.0 mm; b — seed fraction greater than 2.5 — less than 3.0 mm; c — fraction of seeds less than 2.5 mm

Table 3

Effectiveness of hemp seed dehulling based on the studied parameters (impeller diameter, 236 mm; gap between the deck and impeller, 40 mm)

Impeller speed, min⁻¹	Seed fraction (width), mm	Dehulling coefficient, $K_{deh.}$	Kernel integrity factor, $K_{k.i.}$	Dehulling efficiency factor, η
Humidity 8.8 %				
1500	>3.0	29.41	35.00	10.29
	2.5–3.0	17.85	45.45	8.11
	<2.5	15.90	46.67	7.42
2000	>3.0	61.00	8.66	5.28
	2.5–3.0	57.88	6.00	3.47
	<2.5	57.35	11.36	6.51
2500	>3.0	75.51	7.34	5.54
	2.5–3.0	70.90	8.82	6.25
	<2.5	71.57	6.94	4.97
Humidity 21.6 %				
1500	>3.0	27.18	58.82	15.99
	2.5–3.0	17.83	66.67	11.89
	<2.5	18.45	61.54	11.35
2000	>3.0	68.28	34.69	23.69
	2.5–3.0	56.47	42.64	24.08
	<2.5	52.83	39.13	20.67
2500	>3.0	77.28	7.97	6.16
	2.5–3.0	74.22	10.00	7.42
	<2.5	76.20	7.63	5.81

Among the three fractions, according to the analysis of research results (Fig. 6), the fraction of seeds with a width of less than 2.5 mm dehulled the least. The best is the fraction of seeds with a width of less than 3 – more than 2.5 mm.

Based on the results of experimental data processing (Table 3) with Statistica10.0 software, regression equations (4) to (6) were built and graphical dependences were constructed (Fig. 7):

$$\eta = 10.7724 + 0.6009\,W - 0.0048n, \qquad (4)$$

$$\eta = 88.009 + 0.6009\,W - 0.8517C, \qquad (5)$$

$$\eta = 106.7756 - 0.8517C - 0.0048n, \qquad (6)$$

where η is the dehulling efficiency coefficient; C – seed fractions by width, mm; W – seed moisture content, %; n is the number of revolutions of the impeller, min⁻¹.

The graphic dependences shown in Fig. 7 make it possible to establish the relationship between the investigated parameters and their influence on the value of the dehulling efficiency coefficient.

It should be noted that an increase in seed moisture and a decrease in the number of revolutions increases the value of the coefficient of dehulling efficiency (Fig. 7).

Fig. 8 and Table 4 demonstrate the results of studies into the influence of the gap between the impeller and seed repelling panel (impeller diameter, 236 mm; the gap between the deck and impeller, 15 mm) on the indicators of hemp seed dehulling.
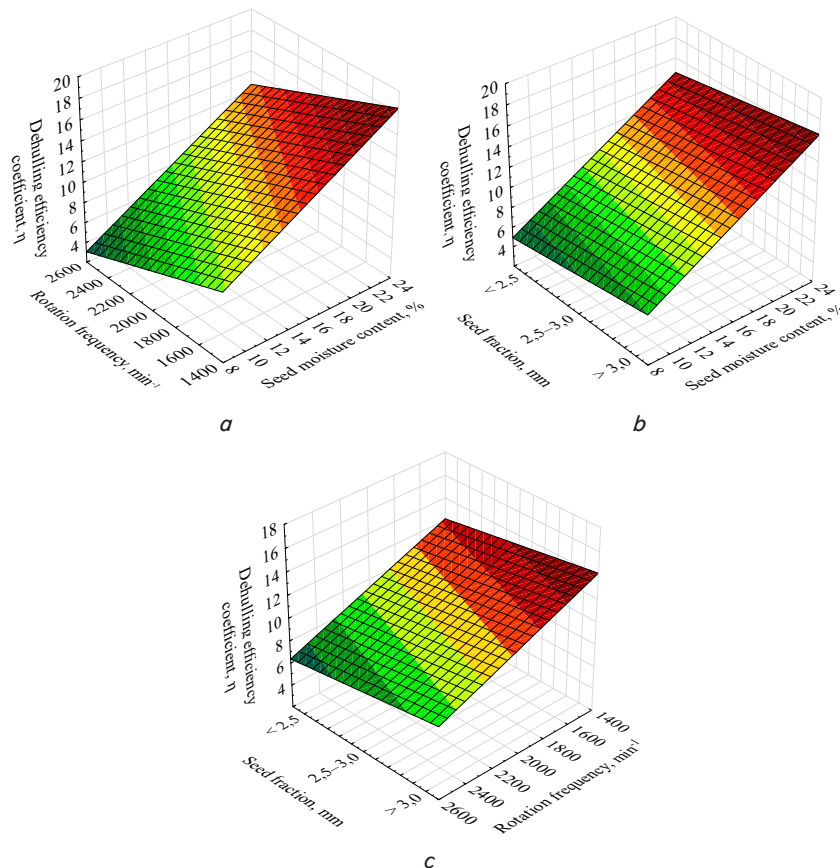

Fig. 7. Dependences of change in the dehulling efficiency coefficient on the fraction of the seed by width, seed moisture, and the number of revolutions of the impeller (impeller diameter, 236 mm; the gap between the deck and impeller, 40 mm): a – rotation frequency/seed moisture content; b – seed fraction/seed moisture content; c – seed fraction/rotation frequency

It is worth noting (Fig. 8) that at a seed moisture content of 8.8 %, the reduction of the gap between the seed repelling panel and impeller (from 40 to 15 mm) with a impeller diameter of 236 mm reduced the effectiveness of hemp seed dehulling. For all three investigated fractions, at a given impeller rotation frequency, the number of whole and destroyed kernels in the hempseed cake decreased. A decrease in seed moisture from 21.6 to 16.3 % led to a corresponding decrease in the number of seed kernels in the hempseed cake. The best results in terms of the number of intact and destroyed kernels were obtained at an impeller rotation frequency of 2000 min^{-1}. According to the results of experimental data processing (Table 4) with Statistica10.0 software, regression equations (7) to (9) were built and graphic dependences were constructed (Fig. 9):

$$\eta = 3.8384 + 0.2542W - 0.0025n, \qquad (7)$$

$$\eta = 50.5584 + 0.2542W - 0.5067C, \qquad (8)$$

$$\eta = 58.7089 - 0.5067C - 0.0025n, \qquad (9)$$

where η is the dehulling efficiency coefficient; C – seed fractions by width, mm; W – seed moisture content, %; n is the number of revolutions of the impeller, min^{-1}.
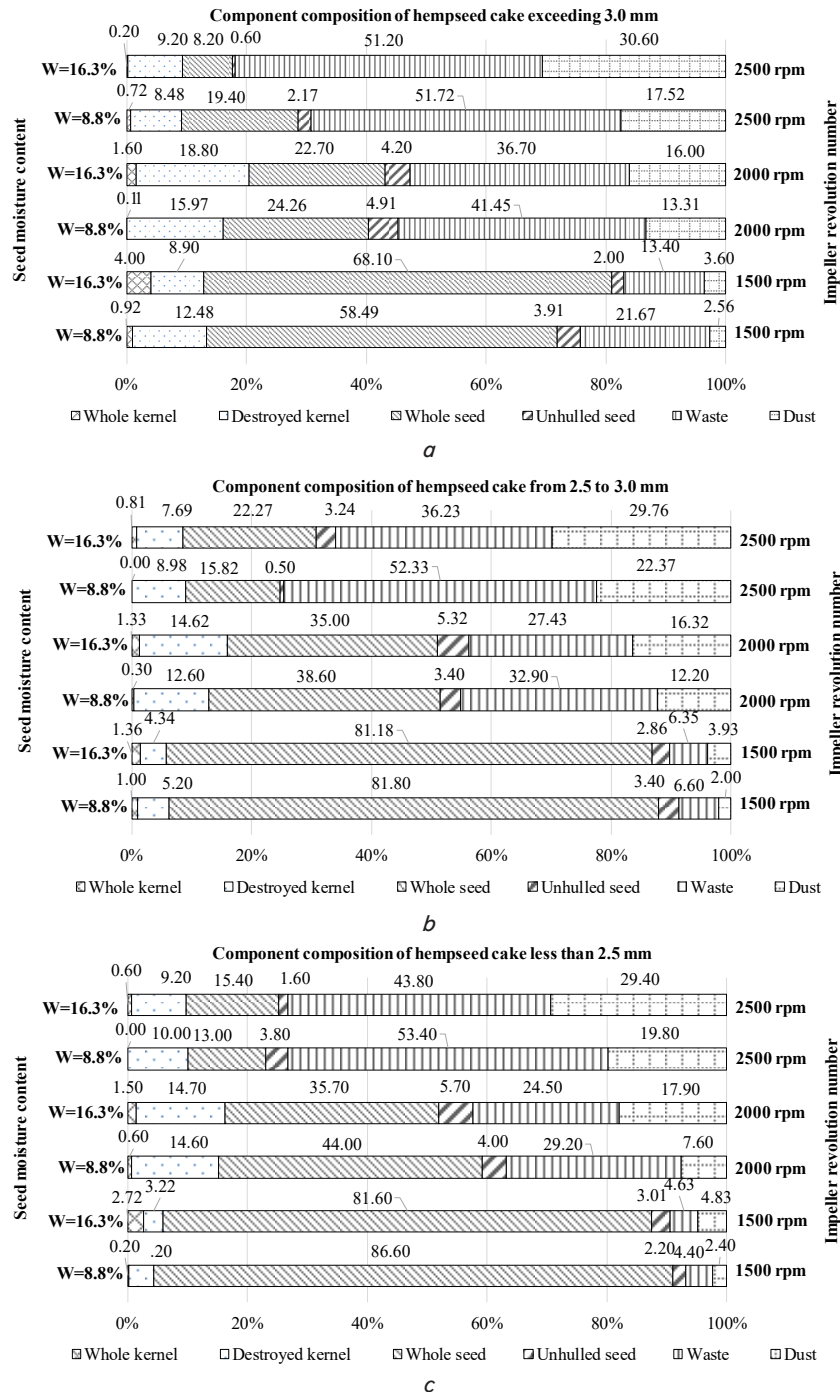

Fig. 8. The fractional composition of hempseed cake based on the studied parameters (diameter of the impeller, 236 mm; gap between the deck and impeller, 15 mm): *a* — fraction of seeds larger than 3 mm; *b* — seed fraction greater than 2.5 — less than 3.0 mm; *c* — fraction of seeds less than 2.5 mm

Table 4

Effectiveness of hemp seed dehulling based on the studied parameters (impeller diameter, 236 mm; gap between the deck and impeller, 15 mm)

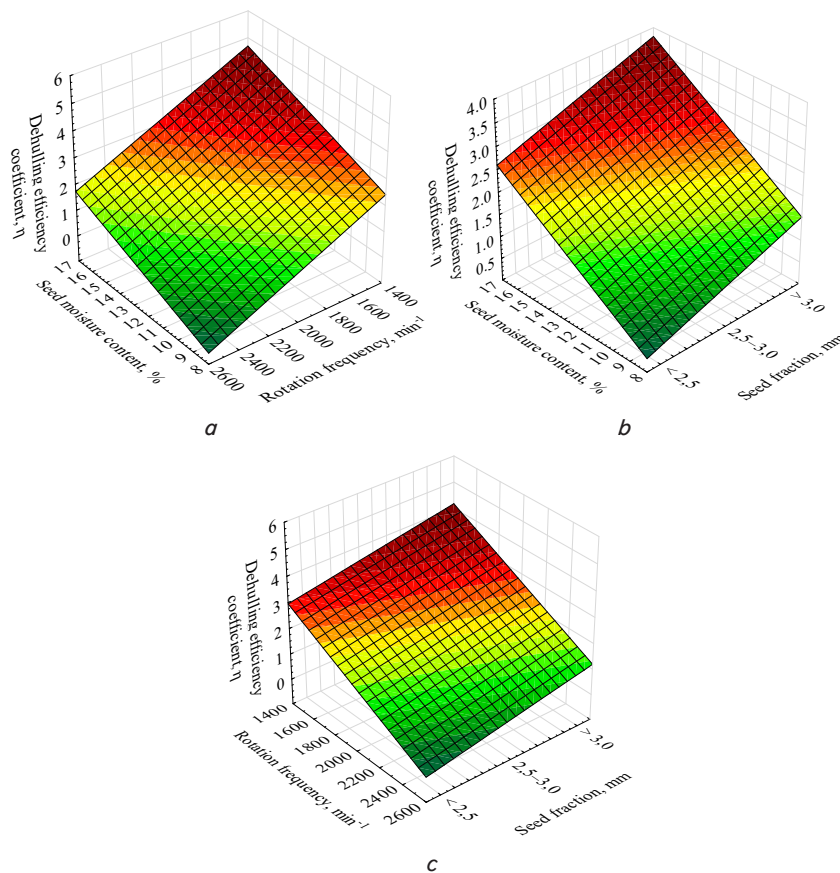| Impeller speed, min^{-1}	Seed fraction (width), mm	Dehulling coefficient, $K_{deh.}$	Kernel integrity factor, $K_{k.i.}$	Dehulling efficiency factor, η	Impeller speed, min^{-1}	Seed fraction (width), mm	Dehulling coefficient, $K_{deh.}$	Kernel integrity factor, $K_{k.i.}$	Dehulling efficiency factor, η
Humidity 8.8 %					Humidity 16.3 %				
1500	>3.0	38.57	7.59	2.93	1500	>3.0	33.00	23.40	7.72
	2.5–3.0	14.80	12.20	1.80		2.5–3.0	17.71	14.04	2.49
	<2.5	11.20	2.94	0.33		<2.5	18.18	29.23	5.31
2000	>3.0	70.84	0.66	0.47	2000	>3.0	75.20	4.02	3.03
	2.5–3.0	54.60	1.57	0.86		2.5–3.0	61.59	4.61	2.84
	<2.5	52.00	2.63	1.37		<2.5	59.00	4.05	2.39
2500	>3.0	78.48	2.88	2.26	2500	>3.0	91.20	0.50	0.46
	2.5–3.0	84.96	0.01	0.01		2.5–3.0	74.49	2.12	1.58
	<2.5	83.20	0.01	0.01		<2.5	90.20	1.53	1.38

Fig. 9. Dependences of change in the dehulling efficiency coefficient on the fraction of the seed by width, moisture of the seed, number of revolutions of the impeller (diameter of the impeller, 236 mm; gap between the deck and impeller, 15 mm): *a* — moisture content of the seed/rotation frequency; *b* — seed moisture content/seed fraction; *c* — rotation frequency/seed fraction

Based on the dependences shown in Fig. 9, it is worth noting the coincidence of the nature of their change with Fig. 7 (for a gap between the impeller and deck of 40 mm).

In order to study the influence of the impeller rotation frequency on the efficiency of seed dehulling, additional studies were conducted. With an impeller diameter of 236 mm and a gap between the deck and impeller of 15 mm, the frequency of rotation of the impeller of 1600 and 1750 min^{-1} was additionally investigated.

The results of research on determining the influence of the rotation frequency of the impeller on the efficiency of seed dehulling with an impeller diameter of 236 mm, a gap between the deck and impeller of 15 mm, and rotation frequencies of 1600 and 1750 min^{-1} are shown in Fig. 10.

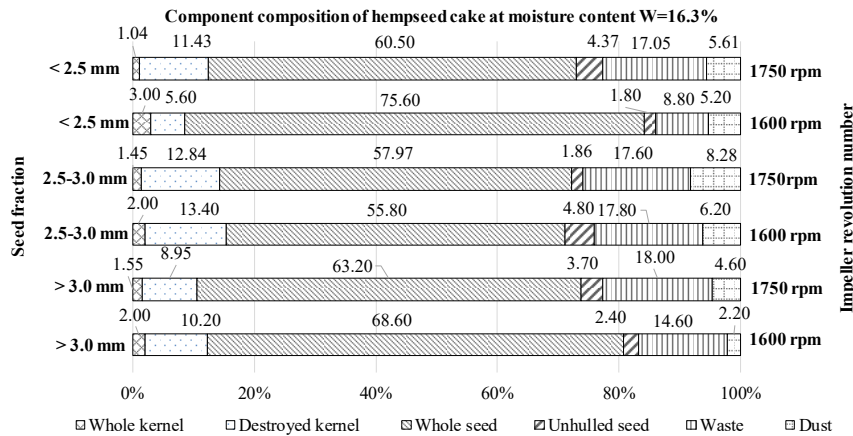**Component composition of hempseed cake at moisture content W=16.3%**

Fig. 10. The fractional composition of hempseed cake based on the studied parameters (impeller diameter, 236 mm; gap between the deck and impeller, 15 mm)

It was established (Fig. 10) that the number of dehulled kernels in hempseed cake was within 15 %, which is lower than the previous results. The coefficients evaluating the dehulling efficiency were also characterized by a low level.

Taking into account the results obtained at high seed humidity (21.6 % and 16.3 %), further research was carried out with seeds whose humidity did not exceed the standard for hemp, i.e., 12–13 %. Since the normalized humidity is ensured in the processes of primary processing of the seed before its storage, the implementation of the dehulling significantly simplifies the technological scheme of the process. The operation caused by the need to regulate the moisture content of the seeds is excluded from the technological chain of preparation of hemp seeds for dehulling. Subsequently, seeds with a moisture content of 12–13 % were used for research.

5. 3. Results of studies on the influence of the distance (gap) between the impeller of the device and the seed repelling panel on the effectiveness of hemp seeds dehulling

The results of investigating the operation of the device, the impeller of which had a diameter of 162 mm and a gap between the deck and the impeller of 50 mm, are given in Table 5.

According to the data in Table 5, reducing the diameter of the impeller (from 236 mm to 162 mm) at a seed moisture content of 8.8 % increased the efficiency of dehulling. To some extent, this is a consequence of the increased clearance between the impeller and deck (50 mm vs. 15 mm). It is worth noting that at an impeller rotation frequency of 2000 min^{-1}, the highest total number of whole and destroyed kernels (23.23–29.33 %) was achieved for the two humidities studied. With an increase in seed moisture content from 8.8 % to 12.0 %, the number of dehulled kernels in the hempseed cake increased, which once again confirmed the previously established regularity. Based on the results of experimental data processing (Table 5), regression equations (10) to (12) were built with the Statistica10.0 software and graphical dependences were constructed (Fig. 11).

$$\eta = 15.6919 + 0.8163W - 0.0093n, \qquad (10)$$

$$\eta = -21.0864 + 0.8163W + 0.1775C, \qquad (11)$$

$$\eta = 6.0767 + 0.1775C - 0.0093n, \qquad (12)$$

where η is the dehulling efficiency coefficient; C – seed fractions by width, mm; W – seed moisture, %; n is the number of revolutions of the impeller, min^{-1}.

It should be noted that the dependences shown in Fig. 11 demonstrate the coincidence of the nature of their change with Fig. 7, 9 (for a gap between the impeller and deck of 40 mm and 15 mm, respectively).

The generalization of our results of dehulling efficiency, taking into account the physical and mechanical properties of the seeds, structural dimensions and technological parameters of the impeller, made it possible to establish rational values that provide for the highest number of dehulled kernels in the hempseed cake (Table 6).

The results of research based on the established rational values of the parameters and operating modes for the device are shown in Fig. 12 and given in Table 7.

Table 5

Effectiveness of hemp seed dehulling according to the studied parameters (impeller diameter, 162 mm; gap between the deck and impeller, 50 mm)

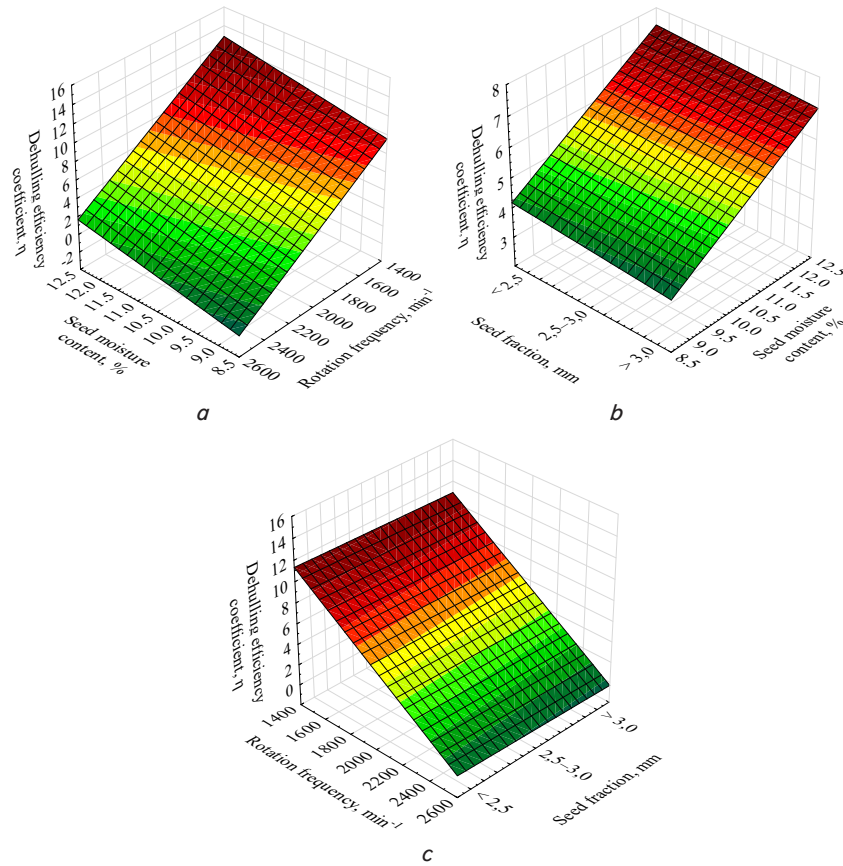| Impeller speed, min^{-1}	Seed fraction (width), mm	Dehulling coefficient, $K_{deh.}$	Kernel integrity factor, $K_{k.i.}$	Dehulling efficiency factor, η
Humidity 8.8 %				
1500	>3.0	36.60	28.41	10.40
	2.5–3.0	34.20	22.37	7.65
	<2.5	31.26	26.92	8.42
2000	>3.0	86.57	4.49	3.89
	2.5–3.0	85.57	1.92	1.65
	<2.5	87.17	3.57	3.11
2500	>3.0	86.20	0.68	0.58
	2.5–3.0	83.10	1.00	0.83
	<2.5	87.60	1.47	1.29
Humidity 12.0 %				
1500	>3.0	40.40	25.74	10.40
	2.5–3.0	29.60	47.13	13.95
	<2.5	31.60	33.33	10.53
2000	>3.0	84.60	7.70	6.58
	2.5–3.0	56.80	10.88	6.18
	<2.5	75.20	14.71	11.06
2500	>3.0	89.20	1.35	1.21
	2.5–3.0	84.00	0.76	0.64
	<2.5	80.60	0.96	0.78

Fig. 11. Dependences of change in the dehulling efficiency coefficient on the fraction of the seed by width, moisture of the seed, number of revolutions of the impeller (diameter of the impeller, 162 mm; gap between the deck and impeller, 50 mm): a — moisture of the seed/rotation frequency; b — seed fraction/seed moisture content; c — rotation frequency/seed fraction

Table 6

Parameters under study

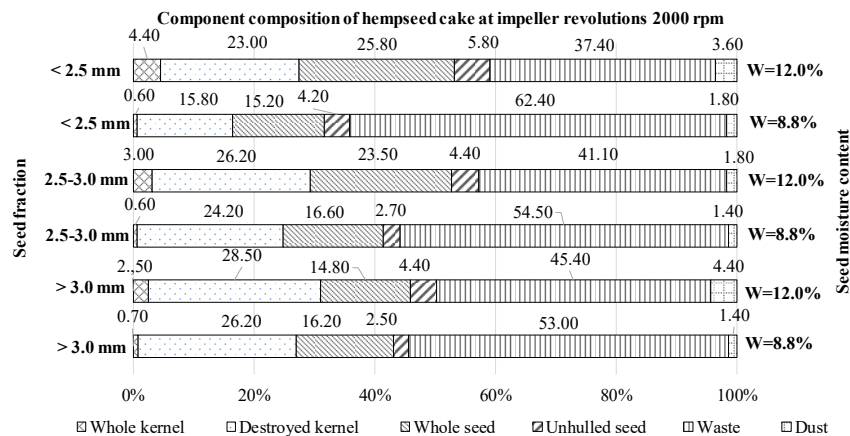| No. of entry	Parameters	Variables		
1	Diameter of the impeller, mm	162		
2	Clearance between the seed repelling panel and impeller	80		
3	Seed fraction (by width), mm	>3.0	2.5–3.0	<2.5
4	Seed moisture, %	8.8	12.0	
5	The number of revolutions of the impeller, min^{-1}	2000		

Fig. 12. The fractional composition of hempseed cake at an impeller revolution of 2000 min^{-1} in accordance with the established rational values of parameters for the device for dehulling hemp seeds (impeller diameter, 162 mm; gap between the deck and impeller, 80 mm)

Table 7

Effectiveness of hemp seed dehulling at an impeller revolutions of 2000 min^{-1} in accordance with the studied parameters (impeller diameter, 162 mm; gap between the deck and impeller, 50 mm)

Impeller speed, min^{-1}	Seed fraction (width), mm	Dehulling coefficient, $K_{deh.}$	Kernel integrity factor, $K_{k.i.}$	Dehulling efficiency factor, η
Humidity 8.8 %				
2000	>3.0	85.80	3.27	2.80
	2.5–3.0	84.40	2.33	1.96
	<2.5	80.60	3.30	2.66
Humidity 12.0 %				
2000	>3.0	80.20	7.26	5.82
	2.5–3.0	75.40	9.09	6.85
	<2.5	68.40	14.19	9.71

Based on the results shown in Fig. 12 and given in Table 7, it can be noted that for seeds with a moisture content of 8.8 %, an increase in the gap led to a decrease in the dehulling efficiency for each of the three seed fractions studied.

6. Discussion of results of research on designing a centrifugal hemp dehuller

At a rotation frequency of 1500 min^{-1} in each of the three fractions (Fig. 6) at the humidity (8.8 and 21.6 %) that were studied, we obtained a hempseed cake with a high content of whole seeds (69.49–82.36 %). As the size of the fraction decreased, the number of whole unbroken seeds increased. Under such conditions, the total number of dehulled whole and destroyed kernels was in the range of 6.8–11.4 %.

Under the conditions of increasing the rotation frequency to 2000 min^{-1} at humidity levels of 8.8 and 21.6 %, the number of whole seeds decreased to 29.12–38.06 %. This led to an increase in the total number of dehulled whole and destroyed kernels – up to 17.61–23.33 %. It is worth noting that an increase in humidity for each of the three fractions increases the percentage of whole kernels while simultaneously decreasing the percentage of destroyed kernels. Compared to the rotation frequency of 1500 min^{-1}, the share of waste increased significantly – from 3.46–9.46 % to 23.96–35.09 %, respectively.

Increasing the rotation frequency of the impeller to 2500 min^{-1} for all three fractions significantly increased the percentage of waste (47.19–54.90 %). There was a decrease in both the number of whole unhulled seeds (17.44–28.92 %) and the number of dehulled whole and destroyed kernels (9.61–18.64 %). Under such conditions, the number of whole kernels in the hempseed cake decreased, and the number of destroyed ones increased accordingly. The percentage of dust increased significantly compared to other options, up to 16.4 %.

Analyzing the results of Table 3, it is worth noting that at the lowest values of rotation of the impeller (1500 min^{-1}) the greatest preservation of the integrity of the dehulled kernels was achieved for each of the three fractions (35.0–66.67 %). Under such conditions, the reduction of the seed fraction increases the coefficient of integrity of kernels both at a moisture content of 8.8 % and at a moisture content of 21.6 %. However, low values of the dehulling coefficient (15.9–29.41 %) and the dehulling efficiency coefficient (4.42–15.99 %) were noted for each of the three fractions at the studied humidity.

Increasing the rotation frequency of the impeller to 2500 min^{-1} for the moisture content of the studied seeds significantly increased the dehulling coefficient for each of the studied fractions (70.90–77.28 %). However, the coefficient of integrity of the kernels decreased (6.94–10.0 %) and, accordingly, the coefficient of dehulling efficiency decreased (4.97–7.42 %) for each of the fractions.

The best results were obtained for the frequency of rotation of the impeller of 2000 min^{-1} at a seed moisture content of 21.6 %. The highest efficiency coefficient (24.08 %), kernel integrity coefficient (42.64 %), and dehulling coefficient (56.47 %) was established for the fraction of seeds with a width of less than 3 – more than 2.5 mm.

It is worth noting that the highest values of indicators of whole and destroyed seed kernels were established at the frequency of rotation of the impeller of 2000 min^{-1}.

At a seed moisture content of 8.8 %, a portion of crushed kernels and shells that were in a free (loose) state fell into the waste. At a humidity of 21.6 %, the marked particles stuck together, forming lumps. At high humidity, the fractions of crushed kernels are larger in size, and their number in the hempseed cake is much smaller.

At a seed moisture content of 8.8 %, all constituent parts of the seeds (shells, film, kernels) were easily separated into parts in the process of dehulling and were separated from each other in the hempseed cake. An increase in humidity to 21.6 % made the process of separating the film from the seed kernels more difficult.

An increase in the moisture content of seed kernels reduced their crushing during the process of dehulling. At a seed moisture content of 21.6 %, after passing through a centrifugal dehuller, it was established that the kernels were destroyed (cracked, split into several particles), but all the particles that formed the kernel itself were together. Due to the increased humidity, the seed kernels had significant plasticity, and the bond strength in the kernels increased. As a result, the resulting hempseed cake did not have free flow, and was mainly in lumps. Lumps were a mixture of seed kernels with particles of destroyed kernels, shells, and film stuck to the outside. This led to the complication of further separation of the hempseed cake.

At a humidity of 21.6 %, an increase in the revolutions of the impeller to 2500 min^{-1} led to the sticking of the components of the hempseed cake (destroyed kernels, dust) on the seed repelling panel of the dehuller, which caused oiling of the dehuller parts.

It should be noted that the increase in humidity to 21.6 % had a significant impact on the process of storing dehulled kernels (whole and destroyed). Under such conditions, the process of storing hulled kernels of industrial hemp requires additional special studies.

At an impeller rotation frequency of 1,500 min^{-1} for each of the three fractions (Fig. 8), at the moisture content (8.8 % and 16.3 %) that were studied, we obtained a hempseed cake with a high content of whole seeds (58.49–86.60 %). As the size of the fraction decreased, the number of whole unbroken seeds increased. Under such conditions, the total number of dehulled whole and destroyed kernels was in the range of 4.2–13.4 %.

With an increase in the rotation frequency to 2000 min^{-1} at humidity levels of 8.8 and 16.3 %, the number of whole seeds decreased to 22.7–44.0 %, and the total number of dehulled whole and destroyed kernels increased significantly – to 12.9–20.4 %. Increasing moisture for each of the three fractions increased the percentage of whole kernels. Compared to the

rotation frequency of 1500 min^{-1}, the share of waste increased significantly – from 4.4–21.67 % to 24.5–41.45 %, respectively.

Increasing the rotation frequency of the impeller to 2500 min^{-1} for all three fractions significantly increased the percentage of waste (36.23–53.4 %). Both the number of whole unhulled seeds (8.2–22.27 %) and the total number of dehulled whole and destroyed kernels (8.5–10.0 %) decreased. Compared to other options, the percentage of dust increased significantly (up to 30.6 %).

Analyzing the results in Tables 3, 4, the following should be noted: the reduction of the gap between the impeller and seed repelling panel, the reduction of the moisture content of the seeds significantly worsened the calculated indicators of dehulling efficiency. At humidity levels of 8.8 and 16.3 %, according to some research options, we note such an indicator as the dehulling coefficient, which reached a value of 91.20 %. However, the kernel integrity coefficient and the dehulling efficiency coefficient were at a low level – 0.01–29.23 and 0.01–7.72, respectively.

It should be noted that at a seed moisture content of 8.8 %, the characteristics of the components of hempseed cake corresponded to the previously established results. A portion of the crushed kernels and shells that were free from each other (loose) fell into the waste. All constituent parts of the seeds (shells, films, kernels) were easily separated into parts during the dehulling process and were separated from each other in the hempseed cake. The seed kernels had significant brittleness, which reduced the particle size of the destroyed kernels.

The characteristics of the components of hempseed cake with increased seed moisture also remained unchanged. An increase in the humidity of the seed kernel reduced its crushing during the dehulling process, and the fraction of crushed kernels increased in size.

At a rotation frequency of the impeller of 2000 min^{-1}, both at a humidity of 8.8 % and 12.0 %, a high total content of whole and destroyed kernels in the hempseed cake was established (Table 5) for all three fractions of the studied seeds. For the fraction of seeds with a width of more than 3 mm, the observed indicators were 29.33 % (W=8.8 %) and 29.0 % (W=12.0 %), fractions less than 3 mm and more than 2.5 mm – 26.10 % (W=8.8 %) and 27.80 % (W=12.0 %), fractions smaller than 2.5 mm – 23.23 % (W=8.8 %) and 23.80 % (W=12 .0 %), respectively. It is also worth noting that with optimal technological and design parameters of the device and moisture content of seeds in the range of 8.8–12.0 %, the dehulling process can be implemented without preliminary fractionation of seeds by size. This is another factor that simplifies the technological scheme of the dehulling process: the operation of fractionating seeds by size is excluded from the technological chain.

In accordance with the analysis of the fractional composition, up to 30 % of the hempseed cake consists of dehulled seed kernels (Table 5). Separate experiments at an impeller rotation frequency of 1500 min^{-1} have established relatively high dehulling coefficients, kernel integrity, and dehulling efficiency. The dehulling coefficient reached the level of 89.20 % at a relatively low value of the kernel integrity coefficients and dehulling efficiency – 0.68–47.13 and 0.64–13.95, respectively.

The composition of seed hempseed cake with a moisture content of 12.0 % is identical to the composition of seed hempseed cake with a moisture content of 8.8 %: loose, the components of the seeds (shell, film, kernel) are not connected to each other and are easily divided into fractions. The main particles of the shell are large, in some places there

were also finely crushed particles. The free seed kernels had a complete shape, 88–90 % of the kernels are covered with a seed film, 25–30 % do not have a fruit stalk. A majority of the destroyed kernels were 1/2, 1/4 of the size of the entire kernel and could be separated satisfactorily. The existing destroyed kernels of a smaller size were difficult to separate and ended up in the waste. Under the conditions of establishing an effective separation of the hempseed cake into fractions, it is possible to separate the marked destroyed kernels of small size, owing to which the result of the dehulling could increase by 2–3 %. Almost 50 % of the destroyed kernels are covered with particles of the seed film.

Analyzing the research results (Fig. 12, Table 7), it should be noted that the total number of dehulled kernels under such conditions decreased by 2.4–6.8 % and was 16.4–26.9 %. For seeds with a moisture content of 12.0 %, increasing the gap, on the contrary, increased the efficiency of dehulling for each of the three seed fractions. The total number of dehulled kernels for seeds of marked moisture increased in the range of 1.4–3.6 % and amounted to 27.4–31.0 %.

Analyzing the fractional composition of the hempseed cake (Fig. 12), it is worth noting that increasing the gap to 80 mm reduced both the number of damaged and whole seeds and the percentage of dust present in the hempseed cake. Thus, increasing the gap between the impeller and seed repelling panel increased the efficiency of the dehulling process.

Analyzing the research results (Table 7), it is worth noting that the calculated values of the dehulling efficiency maintain the previously established trend – a relatively high dehulling coefficient and low coefficients of the integrity of the kernels and the efficiency of the dehulling process. It is noted that the estimated values for seed moisture content of 12.0 % are higher than for seed moisture content of 8.8 % (Table 7).

Comparing the obtained results for dehulling hemp seeds with normalized indicators for dehulling sunflower seeds, where the total content of dehulled kernels in the hempseed cake is 60 %, it can be concluded that the efficiency of this centrifugal dehuller is low. However, if, for comparison, we take one of the techniques of processing hemp seeds, in particular the process of obtaining oil [1], then the result is not so low. Under the conditions of obtaining hemp oil, the efficiency of the PSH-250 screw press used in the oil and fat industry is within 16–20 %, and in the best cases it reaches 23 %. Under such conditions, the processing efficiency of 23.8–29.0 % provided by the centrifugal dehuller is much higher.

It is worth noting certain contradictions between the results of the analysis of the fractional composition of hempseed cake and the calculations of the efficiency of the process. It should be taken into account that the methodology for calculating the coefficients of the effectiveness of hemp seed dehulling is borrowed from a similar methodology for determining the efficiency of sunflower seed dehulling. Naturally, these crops differ significantly in the assessment of such an indicator as «whole kernel». The hemp seed kernel is significantly different from the sunflower kernel: it is more fragile, plastic, and has a different shape. And as it was established, the technique of dehulling with an oriented impact does not ensure sufficient preservation of the integrity of the dehulled kernel. Therefore, even with a total content of dehulled kernels up to 30 %, the dehulling efficiency remains low.

It is worth noting the characteristics of the components of hempseed cake, which was obtained from seeds with a moisture content of 8.8 %, and which fully corresponded to the results established earlier and given above.

It is well known that the effectiveness of dehulling is determined both by the perfection of the device designed for this, and by the principles, equipment, and methods of separating the seed coat. At the stage of separation, the differences in the physical and mechanical properties of individual components of the hempseed cake are used. These properties include shape, linear dimensions, mass, specific gravity, aerodynamic properties and windage, elasticity, coefficient of friction, surface condition, etc. Practical experience proves the low efficiency of separating the hempseed cake by only one of its properties. Qualitative separation involves a combination of several principles, the application of which makes it possible to solve the tasks set.

Despite the variety of properties, differences in size, mass, and windage are mainly used in practical separation. These features are the basis of air-sieve separation, which occupies the largest volumes in the separation of seed-grain mixtures. However, the process of separation of industrial hemp seeds has not been sufficiently studied. Future research in this direction requires more flexible approaches and original technical solutions. A separate paper will report the results of research on the substantiation of the principles, equipment, modes of separation and analysis of the separation of the seed coat of industrial hemp depending on the properties of its components.

Integrated technologies for hemp seed processing are promising. Owing to the use of all processing components, these technologies minimize production waste. Integrated technologies should provide areas for the production of hulled seeds, oil, loose hemp products, fodder pellets, or fuel briquettes. Technological chains are composed sequentially or in parallel, depending on the quality and quantity of one or another raw material.

7. Conclusions

1. The rational parameters for the centrifugal dehuller, which take into account differences in mechanized technological processes, have been systematically substantiated. A centrifugal-type device for dehulling hemp seeds with a closed sector-type working body has been designed. The rational parameters for the dehuller were substantiated: the diameter of the impeller is 162 mm, the gap between the impeller and seed repelling panel is 80 mm, the frequency of rotation of the impeller is 2000 min^{-1}. It was established that with the specified parameters and moisture content of the seeds within the limits of conditional (12.0–13.0 %), it is advisable to carry out the dehulling process without preliminary separation of the seeds into fractions by width.

2. It was established that the reduction of the diameter of the impeller (from 236 mm to 162 mm) at a seed moisture content of 8.8 % increased the efficiency of dehulling. At a ro-

tation frequency of the impeller of 2000 min^{-1}, the highest total number of intact and destroyed kernels (23.23–29.33 %) was achieved for the two studied moistures. With an increase in seed moisture content from 8.8 % to 12.0 %, the number of dehulled kernels in the hempseed cake increased.

3. It was noted that for seeds with a moisture content of 8.8 %, an increase in the gap led to a decrease in the dehulling efficiency for each of the three investigated seed fractions. The total number of dehulled kernels under such conditions decreased by 2.4–6.8 % and amounted to 16.4–26.9 %. For seeds with a moisture content of 12.0 %, an increase in the gap, on the contrary, increased the dehulling efficiency for each of the three investigated seed fractions. The total number of dehulled kernels for seeds of marked moisture increased within the range of 1.4–3.6 % and amounted to 27.4–31.0 %.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

Data availability

The data will be provided upon reasonable request.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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