EXPERIMENTAL SUBSTANTIATION OF THE RATIONAL PARAMETERS FOR A REAPING MACHINE OF THE COMB TYPE FOR HARVESTING OIL FLAX SEEDS

This paper reports the results of the experimental study to substantiate the rational structural and regime parameters of a two-drum reaping machine for harvesting flax oilseeds by the method of combing plants on the root. We have confirmed the results of the preliminary mathematical modeling of the process of separating a combed heap in the reaping machine with a predefined curved shape of the casing.

An experimental study of the heap separation process in a reaping machine has established the dependence of the mass fraction of the discharge of husk and stem particles from its region δ_h, the proportion of the release of seeds and capsules with seeds δ_h, and the consumed power P, on the rotation frequency of the beater-reflector n_1, and the combing drum n_2, the position of the air grate L and its width B. The following structural-mode parameters of the comb-type reaping machine for harvesting oil flax seeds have been defined as the most significant ones: the rotation frequency of the beater-reflector, $n_1=892$ rpm; the rotation frequency of the comb drum, $n_2=652$ rpm; the position of the air grate, L=0.62 m, and its width, B=0.56 m. In this case, the mass fraction of the discharge of husk and stem particles is $\delta_h=47.5$ %, the share of the loss of seeds and capsules with seeds from the reaping machine is, respectively, $\delta_h=2.1$ %, and the power consumed to perform the process is P=2.7 kW.

The statistical analysis has demonstrated that the correlation coefficient between the theoretical and experimental data is 0.88–0.95; a relative error in the optimal values is 4.6 %. The actual and statistical comparison of the theoretical and experimental data has confirmed the adequacy of the mathematical models built as a result of the theoretical research.

Based on the results of our experimental research, one can argue about the usefulness of their application for engineering calculations when designing new technical means for harvesting crops by the method of combing plants on the root

Keywords: combing reaping machine, technology of combing plants on the root, oil flax, optimal structural-mode parameters

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1. Introduction

The process of harvesting crops, including oil flax, is an important technological operation of their production in the agricultural sector. The positive dynamics of the growth of oil flax production, due to the growing demand for seeds in the domestic and foreign markets, requires the intensification of technological processes in harvesting equipment.

One of the promising directions of the intensification of technical means for harvesting oil flax is the technology

of harvesting by the method of combing plants on the root. At the same time, timely harvesting of oil flax in optimal agro-technical terms at minimal losses and contamination of the combed heap is one of the most important scientific tasks of improving harvesting equipment. The main feature of a given promising harvesting technology is a significant reduction in the non-grain share in the combed heap compared to the grain-stem mass entering the threshing-separating working bodies in conventional grain harvesters. This leads to the need to improve quality, productivity, and to reduce the energy intensity of the technological harvesting process [1–3]. In this case, the structural and technological parameters of the working bodies, the mode of operation of harvesting machines, as well as the physical-mechanical properties of agricultural crops, exert a significant impact on the effectiveness of the harvesting process [4–6]. The issues relating to using standard reaping machines of the comb type for harvesting include a large variety of agricultural crops, differences in the physical and mechanical properties of plants, structural imperfections, the levels of development of the combing process theory and the design of effective schemes of technical means.

When designing a combing device for harvesting oil flax seeds, an important task is the choice of the rational structural and mode parameters that can minimize seed losses during the process. Therefore, the directions of the scientific search for new technical solutions and technological processes of harvesting should provide for the theoretical aspect of studying the problem and for the practical confirmation of mathematical models built.

The relevance of this work is predetermined by the need to clarify and supplement the theoretical provisions formulated by us in an earlier study of the process of harvesting flax seeds using the method of plant combing.

2. Literature review and problem statement

The comparative analysis [7] of single- and double-drum combing devices proved the advantage of the latter in the process of harvesting by the method of combing plants on the root. The main provisions of the theory of combing of agricultural crops and the development of two-drum structures of technical means for the implementation of the specified process were proposed in works [8, 9]. However, the constructed mathematical models do not provide a comprehensive approach to considering the process of interaction between plants and the working bodies of a combing two-drum reaping machine. The authors did not fully take into consideration the influence of the physical and mechanical properties of plants on the shape formation of the device's fairing. The influence of related processes was disregarded, in particular, an airflow that separates the components of the combed heap and the shape of the reaping machine's casing. Mathematical expressions are complicated or are impractical for the further practical use in order to build new effective technical means for harvesting by the method of combing plants on the root.

A promising direction in the technology development and technical support to the process of combing plants on the root with a two-drum reaping machine can be a comprehensive approach to its implementation. This primarily applies to taking into consideration the properties of the harvested object, the sequence of its interaction with the working bodies of the device, the structural-mode parameters of the reaping machine, and the parameters of the related processes in its area.

This very approach was implemented in works [10–14]. Theoretical studies have established the effect exerted on the process of harvesting oil flax by the developed reaping machine of the comb type by the structural and regime parameters, plant properties, and the components of the combed heap. When building mathematical models, the authors also took into consideration the influence of the accompanying processes that occur in the region of a reaping machine in the implementation of the harvesting process.

When studying processes related to a combing reaping machine, the authors used the following as the physical models for numerical modeling: a k-ε model of the turbulence of the combined current, a field of gravity, the real gas model by Van der Waals, the Navier-Stokes equation averaged by Reynolds equation [15, 16]. The air current was examined using the STAR-CCM+software package, implemented on the basis of a finite-element method [17, 18]. The mathematical models built by the authors involve a comprehensive approach to the process of combing plants on the root by a two-drum reaping machine. They imply calculations in accordance with the sequence of the implementation of the process of interaction between an object (plant stems, the components of the combed heap), and the working bodies of a reaping machine. In this case, the initial parameters of the object are taken into consideration when interacting with the preceding working body of the combing reaping machine. The same consideration applies to the interacting with all subsequent working bodies of the reaping machine. Based on the results of a theoretical study into the process of bending the plant of oil flax under the influence of the reaping machine's fairing, based on the theory of elasticity, the authors of work [10] derived the equation of its shape. The equation is given in the cartesian coordinate system in the form of a second-degree polynomial depending on the biometric parameters of plants and the density of their standing. The resulting shape of the fairing contributes to driving the vegetable mass of the crop to a «state of combing» by tilting the plants forward towards the movement of the reaping machine. This makes it possible to compensate for the tiering of the plant and prepares the stem mass for the next stage of the process-contact with the combing drum.

In works [11, 12], the authors theoretically investigated the process of fluctuations in the plant of oil flax after the interaction with a reaping machine's fairing, assuming the execution of fluctuations in one of the main planes of the plant stem and taking into consideration their biometric characteristics. Based on the results of mathematical modeling of the process of the interaction of a plant with the combing drum, and on the basis of the theory of fluctuations, the authors derived a dynamic function of changing the curvature of the stem depending on its rheological properties. They defined the structural parameters of a reaping machine's drum, which ensure the effective implementation of the process of combing plants.

In another study [13], the authors analytically examined the process of interaction between the unrelated particles of the components of a combed heap of oil flax and the comb of a reaping machine's drum. Based on the laws of dynamics, they solved the differential equation of their movement on the surface of the comb and established the dependence of their overall speed on the rotation frequency of the comb drum. The differential equation suggested in the cited study was used to analyze the movement of the components of a combed heap over the surface of the comb of the device depending on the mode parameters of the comb drum of the

reaping machine. A theoretical study reported in [14] established the impact of the structural and regime parameters on the formation of airflow and maximum speed in its area, which led to the determining the rational shape of the casing and the position of the air grate for the discharge of light impurities. In the numerical modeling of the processes of the separation of the components of a combed heap in the region of a reaping machine with the curved shape of the casing, the authors took into consideration their physical and mechanical properties. They theoretically defined the significant factors of influence on the process: the rotation frequency of the beater-reflector n_1 and the combing drum n_2, the position of the transparent area of the border L of the air grate of the casing and its width B.

The authors solved a compromise problem on maximizing the share of the discharge of impurities δ_h and minimizing the loss of seeds and seed capsules δ_s. They theoretically defined the following rational structural-mode parameters of a combing reaping machine: the rotation frequency of the beater-reflector, $n_1=782$ rpm; the rotation frequency of the comb drum, $n_2=671$ rpm; the position of the transparent zone of boundaries, $L=0.82$ m, and its width, $B=0.45$ m.

Given the results of the analysis reported in works [10–15], based on the technological parameters of the harvester operation, the influence of the structural and regime parameters of a reaping machine and the physical and mechanical properties of the stem mass, as well as an oil flax heap, there is reason to consider it appropriate to conduct experimental research into the rational parameters of the combing reaping machine for harvesting oil flax seeds.

This could confirm and supplement the mathematical models of the harvesting process based on the method of combing plants on the root that we have earlier built and apply them when constructing new effective technical means.

3. The aim and objectives of the study

The aim of this work is to experimentally substantiate the structural-mode parameters for a two-drum reaping machine of the comb type for harvesting oil flax seeds. This would provide an opportunity to design more effective technical means for harvesting by the method of combing plants on the root.

To achieve the set aim, the following tasks have been solved:

– to devise a methodology and technical support to perform an experimental study of the process of harvesting oil flax seeds using a two-drum combing reaping machine;

– to experimentally determine the rational parameters for a reaping machine of the comb type for harvesting oil

flax seeds that would provide for a decrease in the amount of losses in the execution of the process.

4. Experimental substantiation of the rational parameters for a combing reaping machine for harvesting oil flax

4. 1. Methodology and technical support of the study

An experimental laboratory installation [19] was designed to study the technological process of plant combing and to define the rational parameters for a reaping machine of the comb type for harvesting oil flax seeds. The structural-technological scheme and the physical appearance of the designed experimental installation for combing plants are shown in Fig. 1.

In the operational process of the experimental installation, the plants of oil flax are primarily in contact with fairing 1, which contributes to driving them to the «state of combing» by tilting the plants forward in the direction of movement, which makes it possible to compensate for the tiering of the plants and prepares the stem mass for the next stage – a contact with comb drum 3. The simulation of the installation movement in the direction of rows of oil flax plants is carried out by means of moving field 15 whose speed can be chosen in accordance with the working speeds of the machine. After coming off the outer surface of fairing 1, plants enter the combing area, where they come into contact with comb drum 3. The components of the combed heap (seeds, capsules with seeds, husks of capsules, slices of stems, dust impurities), under the influence of the inertia and airflow forces formed by beater-reflector 2 and comb drum 3, are moved along the transporting channel to the zone of tray 6. Small particles of heap and dust are discharged out of the installation through air grate 5. The components of the combed heap are collected in tray 6, the target fraction, and tray 14, losses in the operation of the combing device.

The height of plants relative to the location of the fairing is set by clamps in the moving field (Fig. 2, a). The rotation frequency of beater-reflector 2 and comb drum 3 is changed by changing the gear ratio of the drive by selecting the drive sprockets with a different number of teeth. One installation's wall is transparent, which allowed us to perform visual observation of the process and record a video. The visualization of the trajectories of the movements of the components of the combed heap (Fig. 2, b) helped establish that the particles of stems, husks, and dust fractions have a more inclined motion trajectory compared to the oil flax seeds and capsules with seeds, causing their segregation and removal of the lighter and smaller components through the air grate of casing 5.
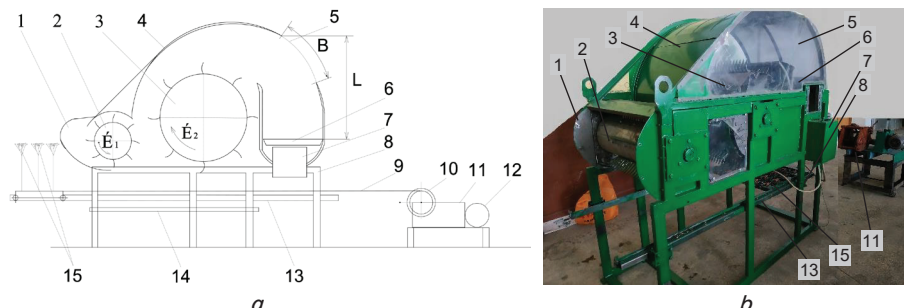

Fig. 1. Laboratory installation to study the parameters and modes of the agricultural crop combing process [18]:
a — structural scheme; b — physical appearance; 1 — fairing; 2 — beater-reflector; 3 — comb drum; 4 — upper casing;
5 — air grate; 6 — tray for discharging combed heap; 7 — control panel; 8 — frame; 9 — flexible cable; 10 — drum;
11 — gearbox; 12 — electric motor; 13 — guides of the moving field; 14 — loss sampling tray; 15 — movable field
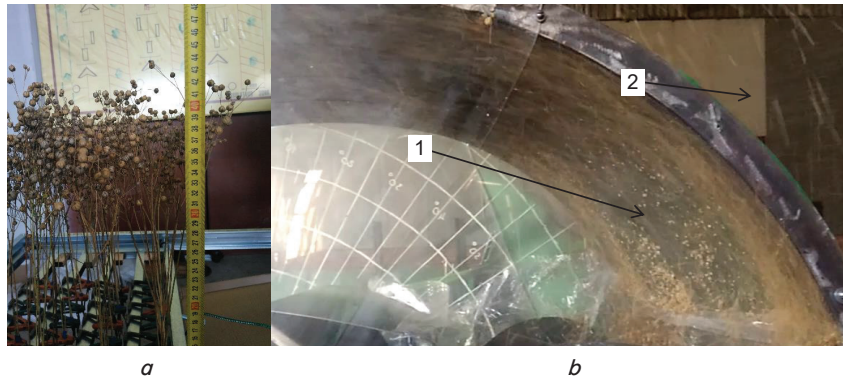
Fig. 2. Preparation of plants and the process of moving heap components in the transporting channel:
a — the preparation of plants for combing; *b* — the visualization of the movement of the components of the combed heap:
1 — target fraction (seeds and capsules with seeds); 2 — non-target fraction (the discharge of husk and stem particles)

Careful observation of the process of simulating the combing of plants at the experimental installation has allowed us to better evaluate the process of harvesting plants based on the specified method.

We studied the process of harvesting oil flax seeds at the laboratory installation for combing plants based on four factors: the rotation frequency of the beater-reflector n_1 and the comb drum n_2, the position of the air grate L, the width of the air grate B. The factors' variance ranges and levels are given in Table 1.

Table 1

The variance levels of factors in experimental research

Factor variance level	Factor			
	The beater-reflector rotation frequency n_1, rpm (x_1)	The comb drum rotation frequency n_2, rpm (x_2)	The air grate position L, m (x_3)	The air grate width B, m (x_4)
Upper level (+)	960	920	1	0.6
Basic level (0)	780	670	0.8	0.4
Lower level (−)	600	180	0.6	0.2
Factor variance interval	180	250	0.2	0.2

Our experimental study employed the D-optimal Box-Benkin plan of the second order for 4 factors with a total number of experiments of 27; repeated three times.

In determining the composition of the components and their quantitative characteristics, we separated from the combed heap the oil flax seeds combed by the combs of the drum at the experimental installation, the uncombed capsules with seeds, the husks of capsules, and the particles of plant stems. The physical appearance of the components of the combed heap of oil flax is shown in Fig. 3.
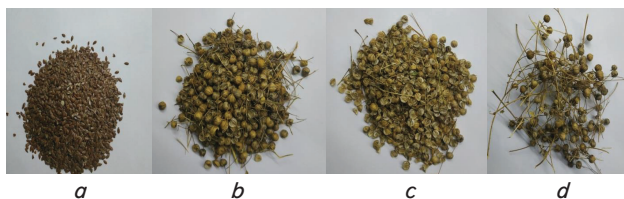

Fig. 3. The physical appearance of the components of the combed heap of oil flax: *a* — seeds; *b* — capsules with seeds; *c* — husks; *d* — stem particles

The following criteria for assessing the process of the separation of a heap in a reaping machine of the comb type were adopted: the mass fraction of the discharge of husks and stem particles from the reaping machine's region δ_h, the mass fraction of the discharge of seeds and capsules with seeds from the region of the reaping machine δ_s. In addition, a process evaluation criterion was the average power P consumed by the experimental installation. The average power P was determined, using an electric meter, as the ratio of consumed electricity to the time of installation operation when combing plants.

4. 2. Results of the experimental substantiation of the rational parameters for a combing reaping machine for harvesting oil flax

To determine the rational structural-mode parameters for a reaping machine of the comb type, we shall solve a compromise problem. The optimization problem, in this case, is reduced to maximizing the mass fraction of the discharge of husk and stem particles from the region of the reaping machine δ_h and minimizing the share of the discharge of seeds and capsules with seeds from the region of the reaping machine δ_s which causes the loss of the target fraction when harvesting.

During the study, we calculated, for each experiment, the mass fraction of the discharge of husk and stem particles from the region of the reaping machine δ_h, and, using the Wolfram Mathematica software package, performed the approximation of data obtained, the result being the dependence on the study factors in the encoded form:

$$\delta_h = 41.5584 + 164{,}012 x_1 + 0.886248 x_1^2 - 6.31347 x_2 -$$
$$- 1.00102 x_1 x_2 - 1.76295 x_2^2 + 3.39003 x_3 +$$
$$+ 0.534828 x_1 x_3 + 0.146541 x_2 x_3 - 1.34309 x_3^2 +$$
$$+ 8.52373 x_4 + 1.48706 x_1 x_4 - 2.7061 x_2 x_4 -$$
$$- 0.387163 x_3 x_4 + 0.389504 x_4^2. \tag{1}$$

The statistical treatment of the resulting equation (1) is consolidated in Table 2. An analysis of Table 2 makes it possible to reduce the insignificant coefficients in equation (1) and represent it in a decoded form:

$$\delta_h = 17.6018 + 60.7155 B + 9.73761 B^2 + 62.9574 L -$$
$$- 9.67908 BL - 33.5772 L^2 - 0.0412674 n_1 +$$
$$+ 0.0413073 B n_1 + 0.0148563 L n_1 + 0.0000273533 n_1^2 +$$
$$+ 0.0920035 n_2 - 0.0751693 B n_2 -$$
$$- 0.0000308956 n_1 n_2 - 0.000054412 n_2^2. \tag{2}$$

Table 2

Statistical treatment of equation (1)

Coeffi-cient	Standard error	t – Student criterion	Error probability at deviation
a_{00}	0.473608	87.7486	$3.08864\cdot10^{-91}$
a_{10}	0.236804	6.92607	$5.52276\cdot10^{-10}$
a_{20}	0.236804	−26.6612	$2.43919\cdot10^{-45}$
a_{30}	0.236804	14.3157	$3.04199\cdot10^{-25}$
a_{40}	0.236804	35.9949	$2.16482\cdot10^{-56}$
a_{12}	0.410157	−2.44058	0.0165579
a_{13}	0.410157	1.30396	0.195465
a_{14}	0.410157	3.6256	0.00047027
a_{23}	0.410157	0.35728	0.721692
a_{24}	0.410157	−6.59771	$2.5226\cdot10^{-9}$
a_{34}	0.410157	−0.94394	0.347646
a_{11}	0.355206	2.49503	0.0143585
a_{22}	0.355206	−4.96317	$3.12638\cdot10^{-6}$
a_{33}	0.355206	−3.78116	0.000275684
a_{44}	0.355206	1.09656	0.275666

Taking into consideration the maximization of the mass fraction of the discharge of husk and stem particles from the reaping machine's region δ_h, we obtain the rational parameters in the first approximation:

$$\delta_h=64.9\ \%,\ n_1=960\ \text{rpm},$$
$$n_2=490\ \text{rpm},\ L=1\ \text{m},\ B=0.6\ \text{m}. \qquad (3)$$

By alternately registering the research factors at a certain level according to (3), the graphical interpretations of dependence (2) are constructed in Fig. 4.
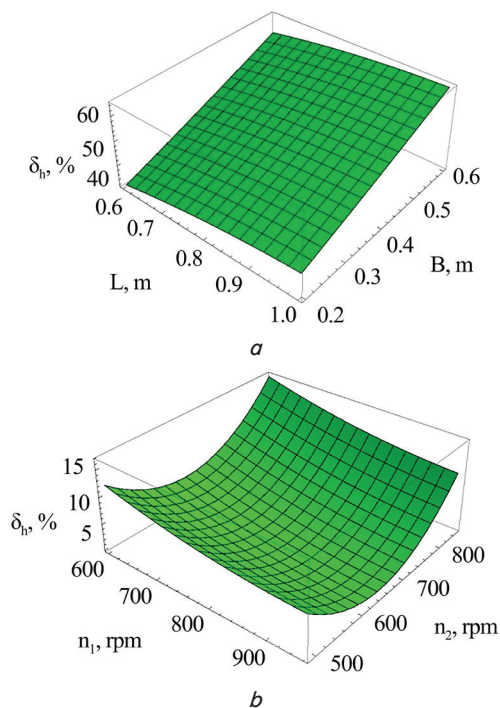

a

b

Fig. 4. Dependence of the mass fraction of the discharge of husk and stem particles from the region of the reaping machine δ_h on: a — the rotation frequency of the beater-reflector n_1 and the comb drum n_2; b — the position of the air grate B and its width L at the fixed values of (3)

Fig. 4 shows that with an increase in the rotation frequency n_1, the position L, and the width B of the air grate, the mass fraction of the discharge δ_s increases. In turn, with the increase in the rotation frequency n_2, the mass fraction of the discharge δ_h decreases.

For each variant of the experiment, we calculated the mass fraction of the discharge of seeds and capsules with seeds from the region of the reaping machine δ_s, and, using the Wolfram Mathematica software package, performed the approximation of data obtained, the resulting being the dependence on the study factors in the encoded form:

$$\delta_h = 3.97364 - 1.283x_1 + 1.13561x_1^2 + 4.10254x_2 -$$
$$- 0.246487x_1x_2 + 8.6198x_2^2 + 0.61405x_3 +$$
$$+ 0.167918x_1x_3 - 0.000607501x_2x_3 -$$
$$- 0.0987031x_3^2 - 1.32029x_4 - 1.2141x_1x_4 -$$
$$- 2.0635x_2x_4 - 0.158931x_3x_4 + 0.0344613x_4^2. \qquad (4)$$

The statistical treatment of the resulting equation (4) is consolidated in Table 3. An analysis of Table 3 makes it possible to reduce the insignificant coefficients in equation (4) and represent it in a decoded form:

$$\delta_h = 105.398 + 61.2868B + 4.96947L - 3.97328BL -$$
$$- 2.46758L^2 - 0.0469495n_1 - 0.033725Bn_1 +$$
$$+ 0.00466438Ln_1 + 0.0000350496n_1^2 - 0.304844n_2 -$$
$$- 0.0573195Bn_2 - 7.60763\cdot10^{-6}n_1n_2 + 0.000266243n_2^2. (5)$$

Table 3

Statistical treatment of equation (4)

Coeffi-cient	Standard error	t – Student criterion	Error probability at deviation
a_{00}	0.174558	22.7619	$8.54305\cdot10^{-40}$
a_{10}	0.087279	−14.7007	$5.45187\cdot10^{-26}$
a_{20}	0.087279	47.0073	$1.30572\cdot10^{-66}$
a_{30}	0.087279	7.03639	$3.2994\cdot10^{-10}$
a_{40}	0.087279	−15.1256	$8.34494\cdot10^{-27}$
a_{12}	0.151172	−1.63073	0.106328
a_{13}	0.151172	1.11132	0.269296
a_{14}	0.151172	−8.03006	$2.93288\cdot10^{-12}$
a_{23}	0.151172	−0.00325929	0.997406
a_{24}	0.151172	−13.6517	$6.15735\cdot10^{-24}$
a_{34}	0.151172	−1.0533	0.294933
a_{11}	0.130919	8.67205	$1.3148\cdot10^{-13}$
a_{22}	0.130919	65.84	$8.07732\cdot10^{-80}$
a_{33}	0.130919	−0.752059	0.453915
a_{44}	0.130919	0.262781	0.793301

Taking into consideration the minimization of the mass fraction of the discharge of seeds and capsules with seeds from the region of the reaping machine δ_s, we obtain the rational parameters in the first approximation:

$$\delta_s=0.47\ \%,\ n_1=960\ \text{rpm},$$
$$n_2=651\ \text{rpm},\ L=0.6\ \text{m},\ B=0.6\ \text{m}. \qquad (6)$$

By alternately registering the study factors at a certain level according to (6), the graphical interpretations of dependence (5) are constructed in Fig. 5.
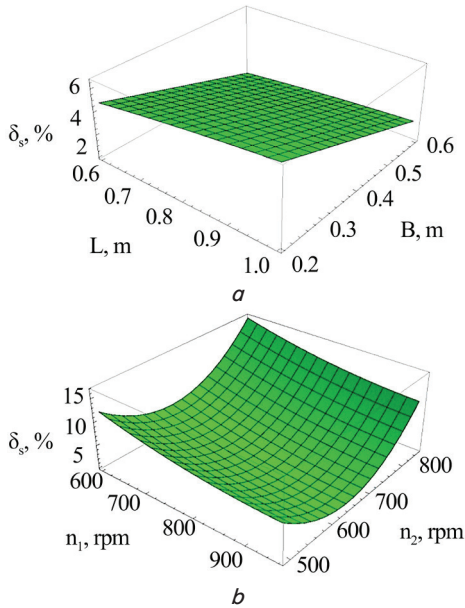
Fig. 5. Dependence of the mass fraction of the discharge of seeds and seed capsules from the region of the reaping machine δ_s on: a — the rotation frequency of the beater-reflector n_1 and the comb drum n_2; b — the position of the air grate B and its width L at the fixed values of (6)

Fig. 5 shows that with an increase in the rotation frequency n_1 and the width of the air grate B, and with a decrease in the value of the position of the air grate L, the mass fraction of the discharge δ_s decreases. In turn, for the rotation frequency n_2 there is an optimum ($n_2=651$ rpm), at which the mass fraction of the discharge δ_s is minimal within the assigned range of factors.

This makes it possible to assert the high-quality progress of the technological process of combing the plants of oil flax at the minimal discharge of the target fraction from the region of the reaping machine.

For each variant of the experiment, we determined the average power consumed by the installation P, and, using the Wolfram Mathematica software package, performed the approximation of data obtained, the result being the dependence on the study factors in the coded form:

$$P = 2.90832 + 0.144157x_1 - 0.0578619x_1^2 +$$
$$+ 0.289464x_2 - 0.05x_1x_2 - 0.0828869x_2^2 -$$
$$- 0.0125x_3 + 6.59195 \cdot 10^{-17} x_1x_3 - 0.04375x_2x_3 -$$
$$- 0.0583333x_3^2 - 0.229583x_4 - 0.0125x_1x_4 -$$
$$- 0.0375x_2x_4 - 0.00625x_3x_4 - 0.00520833x_4^2. \qquad (7)$$

The statistical treatment of the resulting equation (7) is consolidated in Table 4.

An analysis of Table 4 makes it possible to reduce the insignificant coefficients in equation (7) and represent it in a decoded form:

$$P = -3.23992 - 0.45B + 3.14757L - 1.45833L^2 +$$
$$+ 0.00462077n_1 - 1.78586 \cdot 10^{-6} n_1^2 +$$
$$+ 0.00762877n_2 - 0.00104167Bn_2 -$$
$$- 0.00121528Ln_2 - 1.54321 \cdot 10^{-6} n_1n_2 -$$
$$- 2.55824 \cdot 10^{-6} n_2^2. \qquad (8)$$

Table 4

Statistical treatment of equation (7)

Coefficient	Standard error	t – Student criterion	Error probability at deviation
a_{00}	0.043587	66.7245	$2.39512 \cdot 10^{-80}$
a_{10}	0.0217935	6.61468	$2.33345 \cdot 10^{-9}$
a_{20}	0.0217935	13.2821	3.3568910^{-23}
a_{30}	0.0217935	−0.573565	0.567646
a_{40}	0.0217935	−10.5345	$1.52775 \cdot 10^{-17}$
a_{12}	0.0377475	−1.32459	0.188552
a_{13}	0.0377475	$1.74633 \cdot 10^{-15}$	1
a_{14}	0.0377475	−0.331148	0.741278
a_{23}	0.0377475	−1.15902	0.249416
a_{24}	0.0377475	−0.993444	0.323071
a_{34}	0.0377475	−0.165574	0.868852
a_{11}	0.0326903	−1.77	0.0800038
a_{22}	0.0326903	−2.53552	0.0128964
a_{33}	0.0326903	−1.78443	0.0776156
a_{44}	0.0326903	−0.159324	0.873759

Taking into consideration the minimization of the average power consumed by the installation P, we obtain the rational parameters in the first approximation:

$$P=1.98 \text{ W}, n_1=600 \text{ rpm},$$
$$n_2=490 \text{ rpm}, L=0.6 \text{ m}, B=0.6 \text{ m}. \qquad (9)$$

By alternately registering the study factors at a certain level according to (9), the graphical interpretations of dependence (8) are constructed in Fig. 6.
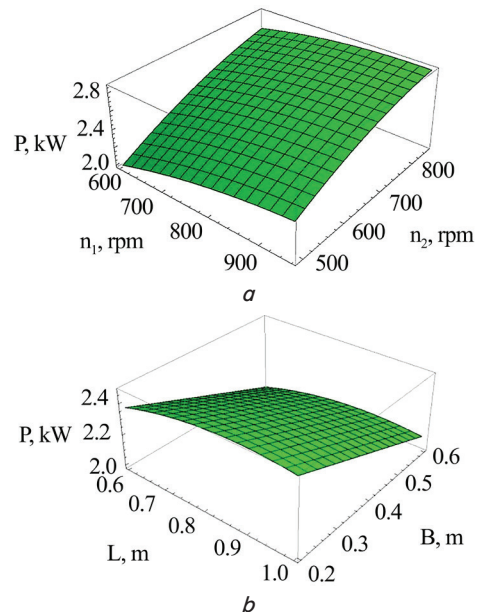

Fig. 6. Dependence of the average power consumed by the installation P on: a — the beater-reflector's rotation frequency n_1 and the comb drum's rotation frequency n_2; b — the position of the air grate B and its width L at the fixed values of (9)

Fig. 6 shows that with an increase in the rotation frequency n_1 and n_2, and with a decrease in the width of the air grate B, the average power consumed by the installation P

increases. In turn, the position of the air grate L has virtually no effect on the specified study criterion.

When solving a compromise problem, namely, maximizing the mass fraction of the discharge of husk and stem particles from the region of the reaping machine δ_h, minimizing the proportion of the discharge of seeds and capsules with seeds from the region of the reaping machine δ_s and minimizing the consumed power P, we have obtained the rational structural-technological parameters for a combing reaping machine: the rotation frequency of the beater-reflector, $n_1=892$ rpm; the rotation frequency of the comb drum, $n_2=652$ rpm; the air grate position, $L=0.62$ m; and it width, $B=0.56$ m. At the same time, the mass fraction of the discharge of husk and stem particles from the region of the reaping machine is $\delta_h=47.5$ %, the share of the discharge of seeds and capsules with seeds from the reaping machine's region is, respectively, $\delta_s=2.1$ %, and the power consumed by the experimental installation is $P=2.7$ kW.

Thus, the experimentally obtained rational values for the structural-mode parameters of a combing reaping machine ensure the high-quality implementation of the process of combing oil flax plants at the minimal losses of the target fraction in the form of seeds and capsules with seeds δ_s and the maximum removal of mechanical impurities in the form of husks of capsules and stem particles δ_h from the region of the reaping machine.

Thus, the results of our study indicate the dependence of the operational quality of a two-drum combing reaping machine on its structural-mode parameters. Namely: the rotation frequency of the beater-reflector $n_1=892$ rpm, the rotation frequency of the comb drum $n_2=652$ rpm, the position of the air grate $L=0.62$ m, and its width $B=0.56$ m. In this case, the mass fraction of the discharge of husk and stem particles from the reaping machine's region is $\delta_h=47.5$ %, the share of the discharge of seeds and capsules with seeds from the reaping machine's region is, respectively, $\delta_s=2.1$ %, and the power consumed by the installation is $P=2.7$ kW.
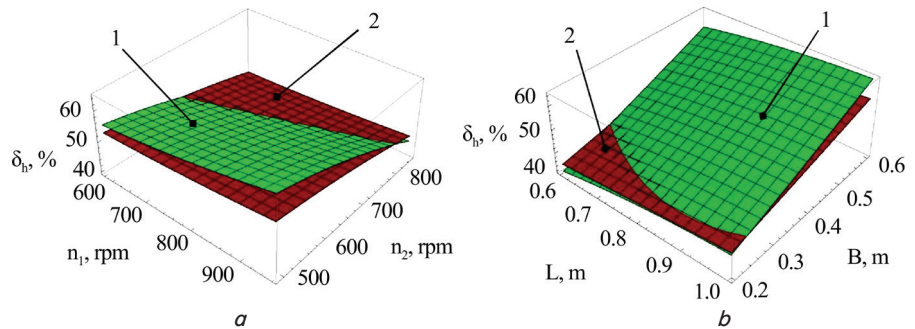

Fig. 7. Dependence of the mass fraction of the discharge of husk and stem particles from the region of the reaping machine δ_h on: a — the rotation frequency of the beater-reflector n_1 and the comb drum n_2; b — the position of the air grate L and its width B; 1 — theoretical; 2 — experimental

5. Discussion of results of experimental substantiation of epy rational parameters for a two-drum combing reaping machine for harvesting oil flax

The qualitative performance of a two-drum reaping machine of the comb type is significant affected by its structural-mode parameters.

The results of our experimental study confirm basic theoretical provisions formulated by us in [10–14] regarding the impact exerted on the mass fraction of the discharge of husk and stem particles from the region of the reaping machine δ_h, the mass fraction of the discharge of seeds and capsules with seeds from the region of the reaping machine δ_s.

The statistical analysis has shown that the correlation coefficient between the theoretical and experimental data is 0.88–0.95, and the relative error in the optimal parameter values is 4.6 %. The actual (Fig. 7, 8) and statistical comparison of the theoretical and experimental data allows us to assert the adequacy of the mathematical models obtained, which are developed as a result of earlier theoretical research. This makes it possible to apply the results of our study when designing new effective combing devices.
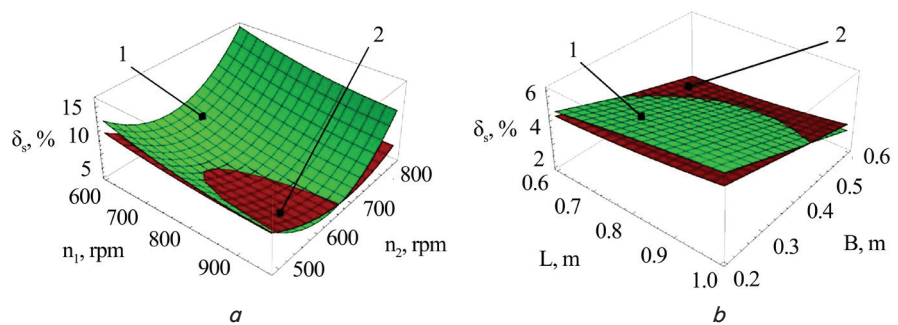

Fig. 8. Dependence of the mass fraction of the discharge of seeds and seed capsules from the region of the reaping machine δ_h on: a — the rotation frequency of the beater-reflector n_1 and the comb drum n_2; b — the position of the air grate L and its width B; 1 — theoretical; 2 — experimental

The above allows us to draw a conclusion about the quality of the developed mathematical model of the process and the effectiveness of its application in the construction of technical means for harvesting crops by the method of combing plants on the root. That predetermines the possibility of their use for engineering calculations when designing new effective combing devices for harvesting crops.

6. Conclusions

1. We have devised the methodology and technical support for the experimental research into the process of harvesting oil flax seeds with a two-drum combing reaping machine; the dependence of the mass fraction of the discharge of impurities δ_h, seeds δ_s, and the consumed power P on the rotation frequency of the beater-reflector n_1 and the comb drum n_2 in

a two-drum reaping machine, the position of the casing's air grate L, and its width B has been experimentally established.

2. Solving the compromise problem on maximizing the mass share of the discharge of impurities δ_h, minimizing the loss of seeds δ_s, as well as consumed power P, produced the rational parameters for the reaping machine. These parameters are: the rotation frequency of the beater-reflector $n_1=892$ rpm, the rotation frequency of the comb drum $n_2=652$ rpm, the position of the air grate $L=0.62$ m, and its width $B=0.56$ m. In this case, the mass fraction of the discharge of husks and stem particles from the reaping machine's region is $\delta_h=47.5$ %, the share of the discharge of seeds and capsules with seeds from the reaping machine's region is, respectively, $\delta_s=2.1$ %, and the power consumed by the installation is $P=2.7$ kW. At the same time, the correlation coefficient between the theoretical and experimental data is 0.88–0.95, the relative error in the optimal values is 4.6 %. The actual and statistical comparison of the theoretical and experimental data allows us to assert the adequacy of the developed mathematical models.

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