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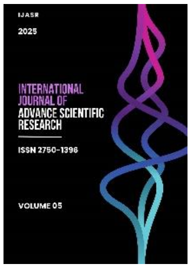

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Research Article

Development of An Improved Device for Separating Bean Seeds from Pods and Optimization of Its Main Structural Dimensions and Operating Modes

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Abstract

The article presents the development of an improved device aimed at increasing the efficiency of the process of separating and cleaning bean seeds from pods, as well as the optimization of its main structural dimensions and operating modes. The results of experimental studies showed that in the proposed device, complete separation of bean seeds from the pods, minimal seed damage, low seed loss, and high seed purity can be achieved when the shaft rotation speed is 450 min^{-1}, the number of beaters is 22, the length of the beaters is 230 mm, and the fan rotation speed is 2000 min^{-1}.

Keywords

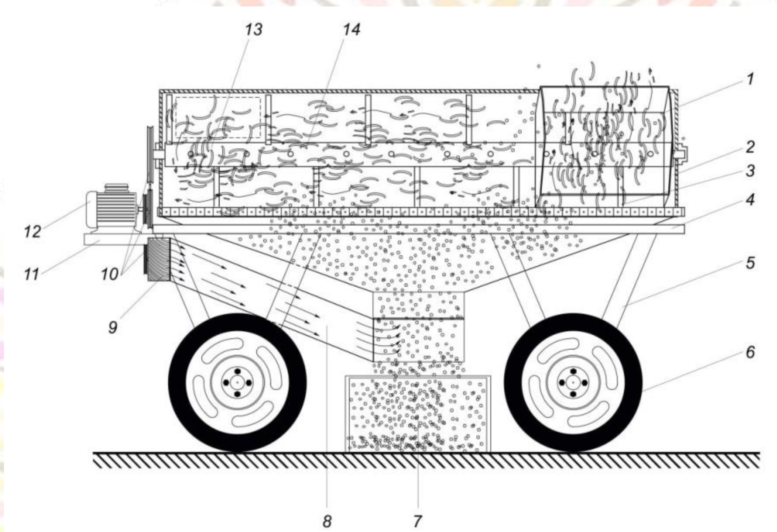
Bean, pod, seed, beater, device, shaft, fan, hopper, cylinder.

Introduction

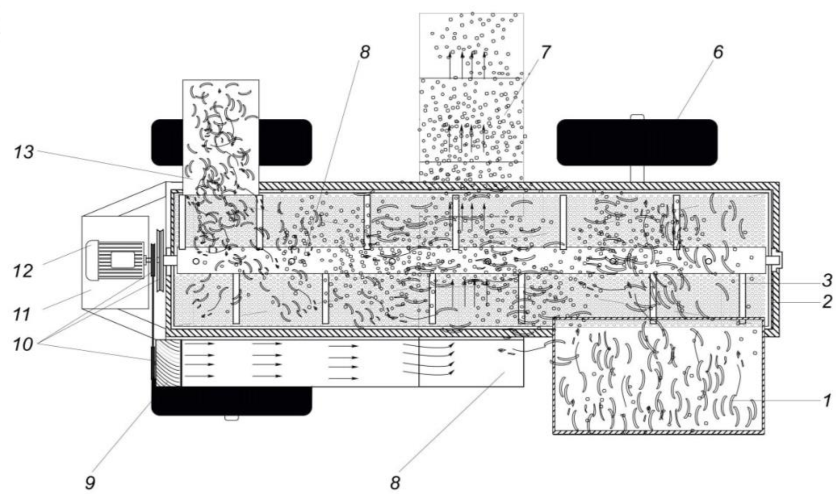
It is well known that the development of technologies and technical means that ensure the high-quality execution of the processes of separating agricultural crop seeds from ears and pods and their initial cleaning, as well as increasing their efficiency, is considered one of the important tasks of scientific research. In this direction, for the proper organization of crop production in farms and reduction of costs, it is important to develop structurally simple devices that can separate seeds from pods in accordance with agrotechnical requirements, while improving energy and resource efficiency — one of the key tasks in agricultural machinery engineering.

Creating improved, energy- and resource-efficient devices to perform the above-mentioned operations on farms is one of the urgent issues of today.

To address this issue, in the course of previous scientific research, a schematic of a newly designed small-scale device for separating and initially cleaning bean seeds from pods was developed (Figure 1)[1–15].



a)



b)

a) side view; b) top view

1 – loading hopper; 2 – cylinder; 3 – beaters; 4 – frame; 5 – support; 6 – wheel;

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7 – hopper for seeds; 8 – air flow; 9 – fan; 10 – pulleys; 11 – base; 12 – electric motor; 13 – discharge outlet; 14 – shaft

Figure 1. Structural and technological diagram of the improved device aimed at increasing the efficiency of the initial cleaning process of separating bean seeds from pods.

Figure 1 illustrates the structural and technological diagram of the device, and its working principle is as follows: when connected to the power supply, the electric motor (12), via pulleys (10), drives the shaft (14) with attached beaters (3) into rotational motion through belt transmissions. At this time, the bean stalks with pods are loaded. When the podded bean stalks fall from the loading hopper (1) into the cylinder (2), the rotating beaters (3) strike them, and due to the impact force, the seeds are separated from the pods. Since the beaters (3) are helically fixed to the shaft (14), they also move the stalks forward in the direction of rotation. The seeds that are not separated on the first strike get hit again by other beaters (3) along the movement path, which ensures complete separation. The separated seeds fall through the sieve-like bottom and enter the airflow path generated by the fan (9) via channels that transfer the seed mixture to the sieve. Depending on their physical and mechanical properties, the seeds and various impurities, including weed seeds, are carried by the fan-generated airflow and are directed to the appropriate fraction section of the receiving hopper (7).

Based on the structural diagram shown in Figure 1, the operating modes and main parameters of the device were theoretically determined. As a result, a prototype of a newly designed small-scale device for separating and cleaning bean seeds from pods was developed (see Figure 2).

Figure 2. General view of the prototype of the improved device for separating and

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cleaning bean seeds from pods.

In order to determine the interrelations among the factors influencing the technological working process of the improved device designed to enhance the efficiency of separating and cleaning bean seeds from pods, as shown in Figure 2, as well as to identify their optimal values, multifactorial experimental studies were conducted.

Based on previous scientific research, literature review, results of theoretical and practical studies, and preliminary experiments, it was determined that the rotational speed of the shaft, the number of beaters, and the length of the beaters most significantly affect the technological process of separating bean seeds from pods. Additionally, the rotational speed of the fan has the greatest impact on the initial cleaning process.

Therefore, in order to optimize the main structural dimensions and operating modes of the improved device aimed at increasing the efficiency of the seed separation and cleaning process, multifactorial experiments were carried out using the B3 experimental design.

As evaluation criteria for the multifactorial experiments, the completeness of seed separation from pods and the degree of seed damage were considered for the separation process, while seed cleanliness and seed loss were used for the initial cleaning process.

Based on preliminary trials and the results of theoretical and practical studies, the variation limits and ranges of the influencing factors were determined.

Table 1 presents the main factors, their variation limits, and intervals.

Table 1

Main factors, their variation limits, and intervals

For the technological process of separating bean seeds from pods				
N	Name of factors	Notation	Variation limits	Vari

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		Actual	Variation Interval	−1	0	+1	ation Interval
1	Shaft rotation speed, r/min	*N*	X_1	400	450	500	50
2	Number of beaters, pcs	Z_k	X_2	20	22	24	2
3	Length of beaters, mm	*l*	X_3	210	220	230	10
For the technological process of separating bean seeds from pods							
1	Fan rotation speed, min^{-1}	n_{ayl}	Y_1	1800	2000	2200	200

The relationship between the factors influencing the technological processes and the resulting outcomes is expressed in the form of the following regression equation [15].

$$y = b_0 + \sum_{i}^{k} b_i x_i + \sum_{i>y}^{k} b_{ij} x_{ij} + \sum_{i=1}^{k} b_{ic} x_i^2 , \qquad (1)$$

there *y* – the optimized criterion of the studied process;

b_o, b_{ij}, b_{ii} – constant regression coefficients;

x_i, x_{ij} – variable factors.

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The factors facilitating the calculations were coded using the following expression.

$$X_i = \frac{X_i - X_{oi}}{\varepsilon}, \qquad (2)$$

there X_i – coded (normalized) value of the factors;

X_i – actual (real) value of the factors;

X_{oi} – actual value of the factors at the zero level;

ε – actual value of the variation interval of the factors.

In the process of determining the significance of the regression coefficients, the Student's t-test was used at the 0.05 significance level.

The adequacy of the process model was tested using the Fisher criterion.

If

$$F_{\max} < F_{жад(0,05)}, \qquad (3)$$

then the model of the technological process is considered adequate.

Three observations were taken for each experiment. To determine the sequence of conducting the experimental studies, a random number table was used. Regression equations were obtained for the completeness of separating bean seeds from pods, the degree of seed damage, seed cleanliness, and seed loss during the initial cleaning process. Based on these equations, the optimal values of the main factors influencing the technological process were determined.

The results obtained from the multifactorial experimental studies on the separation and initial cleaning of bean seeds from pods were calculated and processed using a specialized software program available on the computer. Through this software, the following regression equations were derived, which adequately describe the completeness of seed separation from pods and the degree of seed damage during the separation process, as well as the seed cleanliness and seed loss during the initial cleaning process:

- For the completeness of separating seeds from pods

$$Y_1 = 94{,}758 + 2{,}565 X_1 + 4{,}441 X_2 - 9{,}445 X_3 - 1{,}254 X_1^2 -$$

$$- 8{,}444 X_1 X_2 + 1{,}533 X_1 X_3 - 9{,}311 X_2^2 + 3{,}315 X_3^2, \%; \qquad (4)$$

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- For the degree of seed damage

$$Y_2 = 1{,}43 + 0{,}156X_1 - 0{,}474X_2 - 0{,}869X_3 + 0{,}155X_1^2 +$$
$$+ 0{,}344X_1X_3 + 0{,}657X_2^2 + 0{,}124\,X_2X_3 - 1{,}258X_3^2,\ \% \qquad (5)$$

- For seed cleanliness, (%)

$$U_{toza} = 98{,}136 + 0{,}354X_1 + 0{,}355X_2 + 0{,}366X_3 + 0{,}254X_1X_2 -$$
$$- 0{,}214X_2^2 + 0{,}388\,X_2X_3; \qquad (6)$$

- For seed loss, (%)

$$U_{nob} = 0{,}013 + 0{,}003X_1 + 0{,}002X_2 + 0{,}003X_3 + 0{,}002X_1^2 +$$
$$+ 0{,}001X_1X_2 + 0{,}012X_1X_3 + 0{,}014X_2^2 + 0{,}002X_2X_3 - 0{,}008X_3^2. \qquad (7)$$

Equations (5) and (6) were solved under the conditions of targeting a maximum seed separation completeness of $Y_1 \geq 98\%$ and a seed damage level of $Y_2 < 2\%$, while equations (7) and (8) (not shown in the image) were solved aiming for a minimum seed loss of 0.05% and a maximum seed cleanliness of 98.0%. Based on these optimization conditions, the optimal values of the main factors influencing the technological processes were determined.

Tables 2 and 3 present the results of determining the optimal values of the main factors.

Table 2

Optimal values of the main factors

Indicator Name	Factors and their values		
	n, 1/min	Z_k,	*l*, mm
Coded	+0,121	0	+1
Actual	453,6	22	230
Rounded	450	22	230

Table 3

Optimal values of the main factors

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Indicator Name	Factors and their values
	n_{ayl} min^{-1}
Coded	0
Actual	2000
Rounded	2000

Based on the results presented in Tables 2 and 3, it can be observed that in the proposed device, high completeness of bean seed separation from pods, low seed damage, minimal seed loss, and high seed cleanliness can be achieved when the shaft rotation speed is 450 min^{-1}, the number of beaters is 22, the length of the beaters is 230 mm, and the fan rotation speed is 2000 min^{-1}.

Conclusion

1. High completeness of bean seed separation from pods, low seed damage, high seed cleanliness, and minimal seed loss can be achieved through the correct selection of the shaft rotation speed, length and number of beaters, and fan rotation speed.

2. In the proposed device, high seed separation efficiency, low damage rate, high cleanliness, and minimal seed loss can be ensured when blade-shaped beaters are used with the following parameters: shaft rotation speed of 450 min^{-1}, 22 beaters mounted on the shaft, beater length of 230 mm, and fan rotation speed of 2000 min^{-1}.

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