Bulgarian Journal of Agricultural Science, 28 (No 2) 2022, 362–366

Mathematical model of the separation process of sunflower seeds in innovative air-sieve grain-cleaning machine

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Abstract

Priporov, I. E. (2022). Mathematical model of the separation process of sunflower seeds in innovative air-sieve grain-cleaning machine. *Bulg. J. Agric. Sci., 28 (2)*, 362–366

To develop grain-cleaning machines with high technical and economic indicators, there is a need to solve the problem by optimizing a rational set of certain operations and parameters of grain-cleaning machines, which determine sequential or stagewise highly efficient cleaning circuits. They must ensure the fulfillment of the preset parameters while minimizing the total reduced costs for cleaning and obtaining seed and product material. Experimental studies, carried out by the author, to determine the movement speed of sunflower seed heap along the tray when it is delivered into the pneumatic channel of the final aspiration of an air-sieve grain-cleaning machine, for example, MVU-1500 type, made of fluoroplastic-4, makes it possible to increase pneumatic channel operation by 20%, compared to series-produced one (12%). The disadvantages of secondary cleaning machines are considered, as well as the device of the developed air-sieve grain-cleaning machine. To study the process of motion of sunflower seed heap along the tray, the factors, affecting the movement speed of sunflower seed heap, have been determined. To obtain the regression equation, the second order Box-Behnken design has been generated. The optimal movement speed of sunflower seed heap along the tray was 0.5439 m/s at angle of 42.09^0, which should be made of fluoroplastic-4 and 0.0968 m long. The proposed air-sieve grain-cleaning machine makes it possible to determine the seed material quality in real time through the use of innovative device, consisting of a multimedia device with a personal computer.

Keywords: air-sieve grain-cleaning machine; material movement speed; fluoroplastic-4; multimedia device; regression equation; mathematical model; separation process

Introduction

The replacement of physically and morally obsolete grain-cleaning machines with new ones has been continuing for many years, since there is no noticeable progress in the creation of new domestic and efficient grain-cleaning machines, skilled methods of cleaning grain. In this regard, farms are lack of high-performance grain-cleaning machines (Elchyn et al., 2019; Aliev et al., 2018; Rogovskii et al., 2020; Bulgakov et al., 2020; Kharchenko et al., 2021). As a result, even with a high yield, farms incur severe grain losses during post-harvest processing.

The most important task, facing the constructors of competitive grain-cleaning machines and units today, is to substantiate rational schemes and technical means for in-line technologies for cleaning and sorting grain seeds, providing high performance with minimal reduced costs, which will further ensure the development and production of high-performance agricultural machinery for post-harvest grain crops processing.

Currently, design of new equipment is mainly along the path of improving the traditional principles and complicating the basic structures, increasing their metal consumption and energy saturation, which did not lead to a significant improvement in their technological reliability and specific indicators of technical level. This is explained by the fact that the existing traditional methods of development and design of technological processes and technical means (grain-cleaning machines and in-line systems) are based on the traditional sequence of technological operations and the use of existing basic machines. Without implementation of advanced technologies and construction of new generation grain-cleaning machines, the improvement of post-harvest grain cleaning and sorting, is impossible.

In this regard, for grain-cleaning machines development (Ismaylova, 2018) with high technical and economic performance, there is a need to solve the problem by optimizing a rational set of certain operations and parameters of grain-cleaning machines, which determine sequential or stagewise highly efficient cleaning circuits. They must ensure the fulfillment of the preset parameters while minimizing the total reduced costs for cleaning and obtaining seed and product material (Baishugulova, 2016; Pavlyuchenko, 2016).

Materials and Methods

Researches, conducted by V. S. Paltsev, M. N. Letoshnev, A. Ya. Malis and A. R. Demidov, on the study of input rate effect of the source material into the pneumatic channel of the air-sieve grain-cleaning machine on the separation quality of seed material, showed, that it is of great importance for its quality (Titz et al., 1967).

Analysis, carried out by A. S. Matveev, showed that the process of separating the components of seed heap in air flow at low input speeds, takes place on a very short path in pneumatic channel and does not depend on the location of sieves in the sieve boot. At the same time, considering the low injection rates, the process of separating the components in air flow is not rational (Matveev, 1964).

One of the possible options for increasing the speed of the injection of components into pneumatic channel is to install a stationary chute between the pneumatic channel and the sieve boot.

The purpose of the research is to optimize the design parameters of the tray on the modernized air-sieve grain-cleaning machine of MVU-1500 type.

The modernized air-sieve grain-cleaning machine 1 (Figure 1) contains pneumatic channels for preliminary and final aspiration, a sieve system (not shown in the figure). Machine 1 has a device 2 for determining the seed cleaning quality, which has weighing batchers 3, multimedia devices 4, conveyors 5, machines 6 for additional seed cleaning, tanks 7 for storing seeds, a personal computer 8. In this case, a pneumatic channel (not shown) of final aspiration is connected to a device 2 for determining the seed cleaning quality, using a conical seed distributor 9 with a shutter 10. Device 2 contains a conical truncated hopper 11, outlet channels 12, the outer channels of which are made in the form of a hyperbola, and the central one has a straight-flow cylindrical shape. Moreover, on the inner surface of all channels 12 along the entire length and along the perimeter, there are protrusions 13 made in the form of petals at one end, fixed on the inner surface, and with the other end – lowered down in the direction of sunflower seed motion. The distance between adjacent protrusions 13 horizontally is equal to the seed width and between them vertically to the seed length and is made of rubber. At the outlet of the discharge channels 12 at angle of 40-45°, there are trays 14 for withdrawing seeds into the weighing batchers 3 and are made of a material with low friction coefficient, for example, from fluoroplastic, and have dampers 15. With that, the outlet openings of the weighing batchers 3 are located above the conveyors 5, which are connected to machines 6 for additional seed cleaning and above each conveyor 5, there are multimedia devices 4, commu-

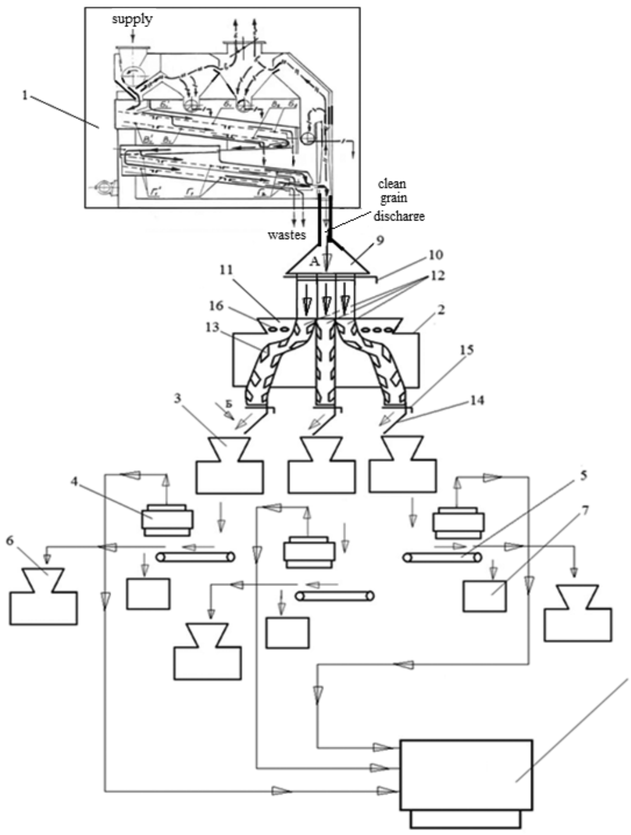

Fig. 1. Air-sieve grain-cleaning machine design

nicated with a personal computer 8. In the upper part of the conical truncated hopper 11 of the device 2 for determining the seed cleaning quality, an automatic sensor 16 of the level of its loading is installed, electrically connected with a gate 10 located at the outlet of the conical seed distributor 9.

To study the process of sunflower seed heap motion along the tray, the factors, affecting the movement speed of sunflower seed heap, have been determined: X_1 – the angle of tray location, deg. (α); X_2 – the material of tray surface (*f*); X_3 – the tray length (*L*), m.

To determine the optimal material for the tray, the following materials have been selected: nylon (polyamide), teflon and fluoroplastic-4.

The natural value of the factor variation interval has been determined by the formula (Melnikov S.V. et al., 1980):

$$\varepsilon = \frac{X_i^u - X_i^l}{2}, \tag{1}$$

where x_i^u – the factor value at the upper level; x_i^l – the factor value at the lower level.

Variation levels of the factors and their designations are given in Table 1.

Table 1. Variation levels of the factors and their designations

Factor	Factor level			Variation interval
	upper	base	lower	
Angle of tray location, deg.	44	42	40	2
Friction coefficient of components on tray surface	0.0	0.07	0.04	0.03
Tray length, m	0.13	0.10	0.07	0.03

To obtain the regression equation, the second order Box-Behnken design has been generated.

To check the homogeneity of variances, we will use the Cochran's criterion, which is defined as the ratio of the maximum variance to the sum of all variances (Melnikov et al., 1980):

$$G_{opt} = \frac{\sigma_{imax}^2}{\sum_1^N \sigma_i^2}, \tag{2}$$

where σ_{imax}^2 – the largest row variance, $\sum_1^N \sigma_i^2$ – the sum of variances along the row.

The value, calculated by the expression (2) is compared with the table value. If the G_{opt} calculated value of the Cochran's criterion is less than the G_{table} tabular, then the variances are homogeneous.

The procedure for calculating the homogeneity of variances is as follows (Melnikov et al., 1980):

Variance in parallel experiments is determined by the formula:

$$\sigma_i^2 = \frac{\sum_1^m (y_{ii} - \bar{y}_i)^2}{m - 1}, \tag{3}$$

where $\bar{y}_i$ – the average value of the optimization criterion in the i-th row of the planning matrix for *m* parallel experiments;

Variance of a single measurement is determined by the formula:

$$\sigma_y^2 = \frac{\sum_1^N \sum_1^m (y_{ii} - \bar{y}_i)^2}{N(m-1)}, \tag{4}$$

where *N* – the number of series in the plan.

After obtaining the adequate mathematical model of the second order (5), the coordinates of the optimum have been determined and the properties of the response surface in its vicinity have been studied:

$$Y_s = b_0 + \sum^k b_i x_i + \sum_{i<j}^k b_{ij} x_i x_j + \sum^k b_{ii} x_i^2. \tag{5}$$

After the canonical transformation and determination of the response surface type, its analysis has been carried out by two-dimensional sections (Melnikov et al., 1980).

Construction of two-dimensional sections of the response function has been performed in the following sequence (Melnikov et al., 1980). The coded (optimal) values of all factors, except for the two studied, have been substituted into the model (5). Further, in the obtained expression, the center of the response surface has been determined by taking partial derivatives for each factor and equating the obtained expressions to zero. Canonical transformation of the resulting second-order model has been carried out. After the canonical transformation, the response surface type in the section has been determined. By assigning different values to the optimization criterion in the canonical equation, a series of curves of equal yield have been constructed in the range of admissible variation values of independent variables.

Results and Discussion

Having calculated results, the regression equation has been obtained in the form:

$$\begin{aligned} y_s = {} & 0.514 + 0.063x_1 + 0.029x_2 - 0.006x_3 - 0.05x_1x_2 \\ & - 0.005x_1x_3 - 0.04x_2x_3 - 0.035x_1^2 - 0.065x_2^2 - 0.031x_3^2. \end{aligned} \tag{6}$$

The "+" sign in front of b_i in equation (6) indicates that the change in x_i causes an increase in the movement speed of sunflower seed heap along the tray, and conversely, the "–" sign means a decrease in the speed. The value of the coefficients of pair interactions b_{ij} suggests that the action of one of the factors under consideration, depends on the factor level, since b_{ij} has a negative sign, the movement speed of sunflower seed heap along the tray, decreases in cases, where both factors x_i and x_j are at lower levels. Analyzing the coefficients b_i of the regression equation, it can be concluded that the greatest influence (Melnikov et al., 1980) on the movement speed of sunflower seed heap is exerted by the tray angle (regression coefficient 0.063), then – the tray material (regression coefficient – 0.029) and, to a lesser extent, the tray length (regression coefficient – 0.006).

Based on the performed experiment, the value of the Cochran criterion as a result of calculations was G_{opt} = 0.525, and the tabular value at f_1 = 1 and f_2 = 4 – G_{tab} = 0.907. The hypothesis about the homogeneity of dispersions is verified.

Calculation of the coefficients of the canonical equation showed that B_1 = – 0.035; B_2 = – 0.073; B_3 = – 0.0227.

The equation in canonical form is:

$$Y - 0.5439 = -0.035X_1^2 - 0.073X_2^2 - 0.023X_3^2. \qquad (7)$$

After substituting different values of the optimization criterion in the equation (7), the equations of the second degree have been obtained in standard form, with the help of which a system of contour curves of equal displacement velocity, which are ellipses, has been constructed (Melnikov et al., 1980) (Figure 2).

Consideration of the two-dimensional section shows that the joint interaction of factors (x_1 and x_2), (x_1 and x_3), (x_2 and x_3) in the experimental area has an extremum in terms of the indicator (Melnikov et al., 1980) of the motion speed at the point υ = 0.5439 m/sec with the values of the factors, respectively, α = 42.090, f = 0.0666, L = 0.0968 m. The friction coefficient f = 0.0666 corresponds to the fluoroplastic-4 material.

Conclusions

Experimental studies, carried out by the author to determine the motion speed of sunflower seed heap along the tray, when it is supplied into the pneumatic channel of the final aspiration of an air-sieve grain-cleaning machine, for example, of MVU-1500 type, made of fluoroplastic-4, makes it possible to increase the pneumatic channel operation by 20%, compared to series-produced one (12%).

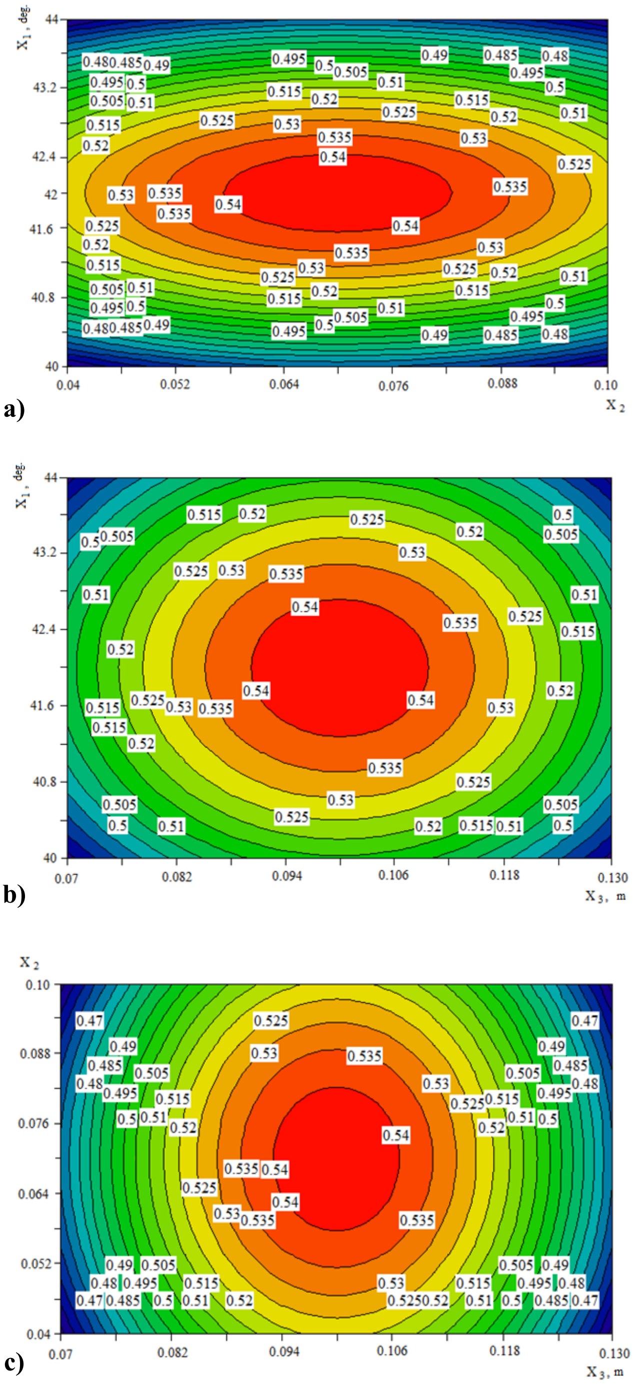

Fig. 2. Two-dimensional sections of the response surfaces, characterizing the motion speed of sunflower seed heap at:
a) -x_1 = 0.048 and x_2 = -0.112;
b) -x_1 = 0.048 and x_3 = -0.106;
c) -x = -0.112 and x_3 = -0.106

The optimal sunflower seed heap motion speed along the tray was 0.5439 m/sec at angle of 42.09^0, which should be made of fluoroplastic-4 and 0.0968 m long.

The proposed air-sieve grain-cleaning machine makes it possible to determine the seed material quality in real time through the use of innovative device, consisting of a multimedia device with a personal computer.

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Received: July 11, 2021; *Accepted:* October 22, 2021; *Published:* April, 2022