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Methodology for conducting an optimization experiment for harvesting dry short-stalked grain crops

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Abstract. The article raises the issue of climate warming without loss of harvesting dry short-stalked crops will increase, and requires an urgent technological and technical solution. Research aimed at the development of a device installed in an inclined chamber, providing a reduction in grain losses during harvesting of dry short-stalked grain mass, is relevant and of great economic importance. The aim of the study was to increase the efficiency of harvesting dry short-stalked crops due to the uniform distribution of threshed grain mass supplied to the combine harvester. And the scientific hypothesis of the study was to increase the efficiency of a single-drum combine harvester by threshing dry short-stalked breads, by ensuring a uniform layer of grain mass entering the local government. The results showed that the threshing of grain increases due to the uniform distribution of mass depending on the length of the discrete part of the corrugation. The results of the experiment are obtained.

1. Introduction

Grain production in the modern world is presented as one of the priority areas of any state where it takes place. Grain production not only reflects the state and level of development of all agricultural production, but also determines its effectiveness and competitiveness by qualitative and quantitative, price characteristics, being a powerful locomotive of the entire agricultural industry.

In the grain production system, the most responsible and stressful stage is the harvesting. In the southern regions of the republic, due to the dry climate, cereal crops ripen quickly, the plants are short-stemmed and have low humidity, which causes significant (up to 15%) wheat losses during harvesting. The use of well-known technical solutions for direct combining of dry short-stalked grain crops due to the mismatch between the length of the stems and the optimal parameters for arranging the corrugations reduces the degree of delamination and the orientation of short stems along the width of the grind, which causes grain loss during threshing, and this is significant from the total crop [1].

In this regard, research aimed at developing a device installed in an inclined chamber, providing a reduction in grain loss during harvesting of dry short-stalked grain mass, is relevant and of great economic importance.

The purpose of the study is to increase the efficiency of harvesting dry short-stalked crops due to the uniform distribution of threshed grain mass supplied to the combine harvester.

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2. Research Methodology

The research methods were carried out using standard and particular techniques using mathematical modeling and mathematical statistics, modern instruments and computers [2]. A considerable amount of work has been devoted to the description of the process of movement of the cereal mass in the inclined chamber of the combine harvester, but no studies have been carried out on the degree of uniform distribution of dry short-stalked cereal mass in this process [3].

It has been established that in direct combining, the initial state of the density of dry short-stalked bread mass has a minimum thickness in the middle of the stream and a maximum along the edges. The screw feeds the mass (when harvesting, we consider the height of the mowed mass to be the same) to the window of the inclined chamber. In the central part of the window, the height of the mass layer is h_0. Closer to the edges of the window, the layer height will change due to the density coming from the edges of the header; here, due to additional turns on the auger, the mass equalization does not completely occur (Figure 1) [4].

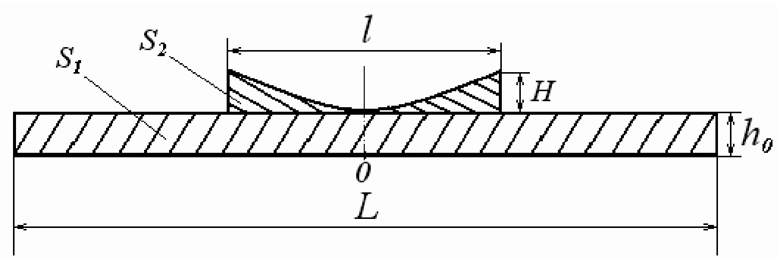


Figure 1. The estimated shape of the cross section of the mass flow

where l is the width of the input window of the inclined camera; L is the width of the reaper; H - the height of the window of the inclined camera.

Ideally, the areas S_1 and S_2 should be equal to:

$$S_1 = \frac{(L-l)h_0}{2} \quad \text{and} \quad S_2 = \frac{a \cdot l_0^3}{24} \tag{1}$$

because $S_1 = S_2$, then

$$\frac{a \cdot l_0^3}{24} = \frac{(L-l)h_0}{2} \geq a = \frac{12((L-l)h_0)}{l_0^3} \tag{2}$$

Due to the flexibility of the mass, compression is assumed, therefore, the areas S_1 and S_2 are unequal. Suppose that the compression along the l axis is inversely proportional to the coordinate l [5]:

$$S_1 = S\left(\frac{1}{l}\right) = \frac{\hat{a}}{l} \geq S_1^{/} = S_2 \geq \frac{\hat{a}}{l} = \frac{l_0^3}{24} \geq \hat{a} = \frac{a \cdot l_0^4}{24}. \tag{3}$$

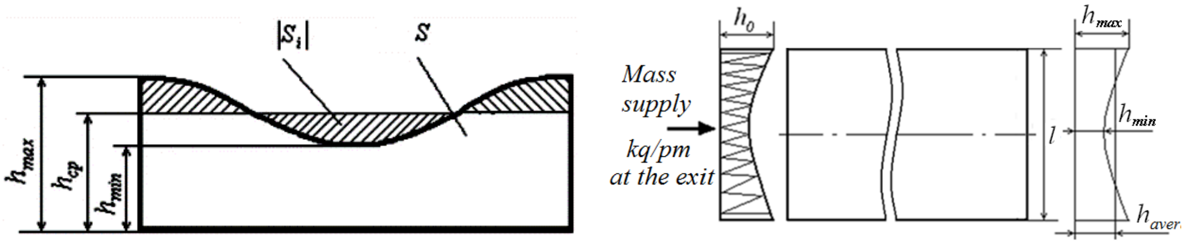
At $l_1 = L$
$$S_1^{/} = S_1 \geq \frac{\hat{a}}{L} = \frac{(L-l)h_0}{2} \geq \hat{a} = \frac{(L-l)L \cdot h_0}{2}; \tag{4}$$

$$\frac{(L-l)L \cdot h_0}{2} = \frac{a \cdot l_0^4}{24} \geq a = \frac{12(L-l)L \cdot h_0}{l_0^4}. \tag{5}$$

That is, the height of the grain mass along the edge of an unlimited window

$$H = a \cdot l_0^2 + h_0 = \frac{3(L-l)L \cdot h_0}{l_0^2 + h}. \tag{6}$$

The window height of the tilt chamber is limited by the value of h H, the edges will undergo vertical compression.



a b

Figure 2. The initial state of the grain mass (a) and to the transformation of the mass across the width of the thresher of the combine harvester (b)

where h_0 is the height of the inclined chamber; h_{max} is the maximum thickness of the bread mass; hmin is the minimum thickness of the bread mass; h_{av} - the average thickness of the bread mass. Where the thickness of the cereal mass at the points of contact of the scourges of the drum, large specific pressures occur, leading to damage to the grains.

In order to increase the degree (coefficient) of leveling δ_k, which leads to minimization of losses of dry short-stalked cereal mass, we proposed a device for normalizing cereal mass mounted on the bottom of an inclined chamber (Figure 3).

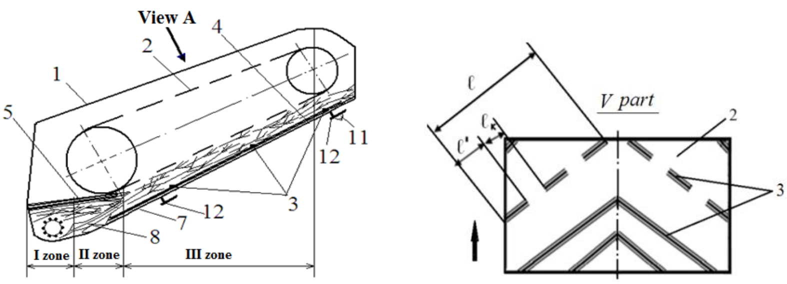


Figure 3. The scheme of the inclined chamber with the device (left image) and V - shaped profile for the distribution of the flow of grain mass (right image): a) 1- inclined camera; 2 - straps of the conveyor; 3 - corrugations; 4 - discreteness of the corrugation; 5 - grater and separation grill; 7 - trough; 8 - collection; 11- nut; 12 - guide groove; b) ℓ - the total length of the stretching branch of the corrugations; $\ell_к$ - arithmetic mean value of the length of ears; ℓ'- the length of the discrete part of the corrugations

A device for normalizing grain mass, contains an inclined chamber 1 located in a combine harvester, a body with a bottom 5, a working surface that is corrugated, and the corrugations have a V-profile 3, a slatted conveyor 2, a receiving beater 6 and one stretching branch made discrete 4 .
The total length of the stretching branch of the corrugations is determined by the formula [6]:

$$\ell = n\,(\ell_к + \ell')\,, \tag{7}$$

where ℓ is the total length of the stretching branch of the corrugations, mm; n is the number of discreteness, units .; $\ell_к$ - arithmetic mean value of the length of ears, mm; ℓ'- the length of the discrete part of the corrugation, mm.
To search for optimal conditions for the interaction of dry short-stalked bread mass with the device, the method of experiment planning is used.

At the first stage, the UNK-1 laboratory unit was used (certificate No. VA 03-082 / 06, Figure 4).

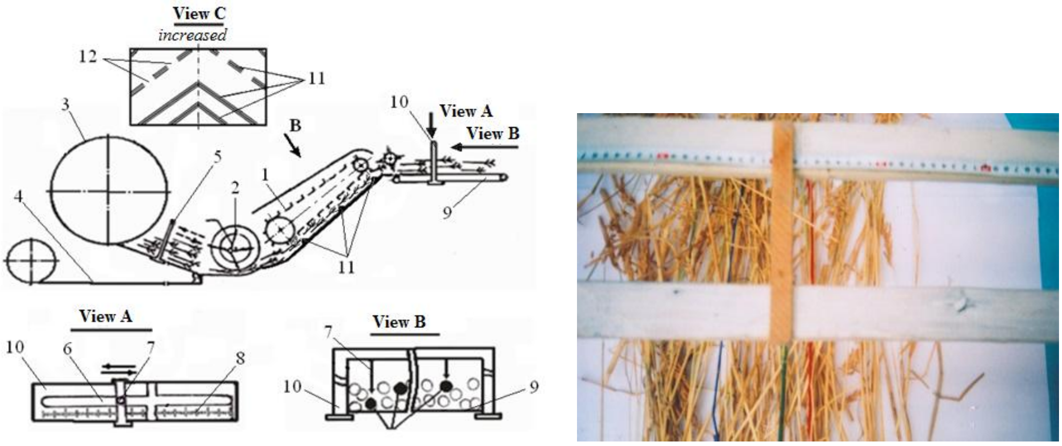


Figure 4. The technological scheme of the device with the bread mass of dry short-stemmed: 1-conveyor; 2-auger; 3 reel; 4-conveyor feeder; 5-U-shaped measuring frame; 6-slot frame; 7-clamp 8-meter ruler; 9-discharge conveyor; 10-frame; 11-corrugation device; 12 - discreteness of the corrugation

The installation includes an inclined chamber with a device, feeding and receiving conveyors, a measuring device with a metric ruler for measuring the initial and offset coordinates of the stalks of dry short-stalked bread masses (patent No. 23913) [7]. The drive of the working bodies of the installation makes it possible to adjust the speed mode. In the course of research, the coefficients, physical quantities, and rational parameters of the device elements were determined. The design allowed changing the angles of attack and the height of the guiding corrugations. To substantiate the optimal parameters and operating modes of the device for dry short-stalked bread masses, the methods of statistical planning of a multivariate experiment were used. For this, a complete four-factor experiment was performed at three levels of variation in triplicate (Table 1) [8, 9]:

Table 1. Regulated factors and their levels of variation

Regulated factors: natural (coded)	Coded levels				
	-α	–1	0	+1	α
x_1 – supply of grain mass (q, kg / pm)	1.2	1.5	2.0	2.5	2.8
x_2 – amount of discreteness of the corrugations in the device (n, units)	1	2.0	3.0	4.0	5
x_3 – angle of attack of V-shaped corrugations (α, degrees)	25.6	29.0	37.0	40.0	45.4
x_4 – the gap between the conveyor and the working surface of the device (δ, mm)	3.2	10.0	20.0	30.0	36.8
Note - Star Leverage α = 1.682					

The degree of uniform distribution, the deformation of the ears and free grain are taken as optimization criteria. When determining the distribution coefficient of the stem mass of dry short-stalked bread in a weighed portion, the initial coordinates of the colored stems were found relative to the central axis of the inclined chamber. Bread mass was supplied by the feeding conveyor to the inclined chamber, passed through the working bodies under investigation and entered the receiving conveyor, where the coordinates of the displaced stems were measured relative to the same reference system. Calculation of the average deviation of the colored stems made it possible to estimate the coefficient of the uniform distribution of the grain mass of dry short-stalks according to the formula:

$$\mu = \frac{(X_{max} - X_{min})}{X_{max}} , \tag{8}$$

where X_{max} - the maximum displacement of the colored stems, mm; X_{min} - the minimum displacement of the colored stems, mm; μ is the coefficient of uniform distribution of the layer of bread mass [10, 11].
At the second stage, the device parameters were checked and refined. Multivariate planning methods determined the effect on the indicators of uniform mass distribution: deformed ears and free grains and second mass supply, the amount of discreteness of the corrugations, the angle of attack of the V-shaped corrugations and the speed of the conveyor. Using a JEOL electron microscope (Japan) JEM, macro- and microdamage to the grain mass of dry short-stalked grain was determined [12].

3. Results and Discussion

Based on the results of a multivariate experiment, the coefficients of the regression equation are found:
for the distribution of grain mass of dry short-stemmed,%

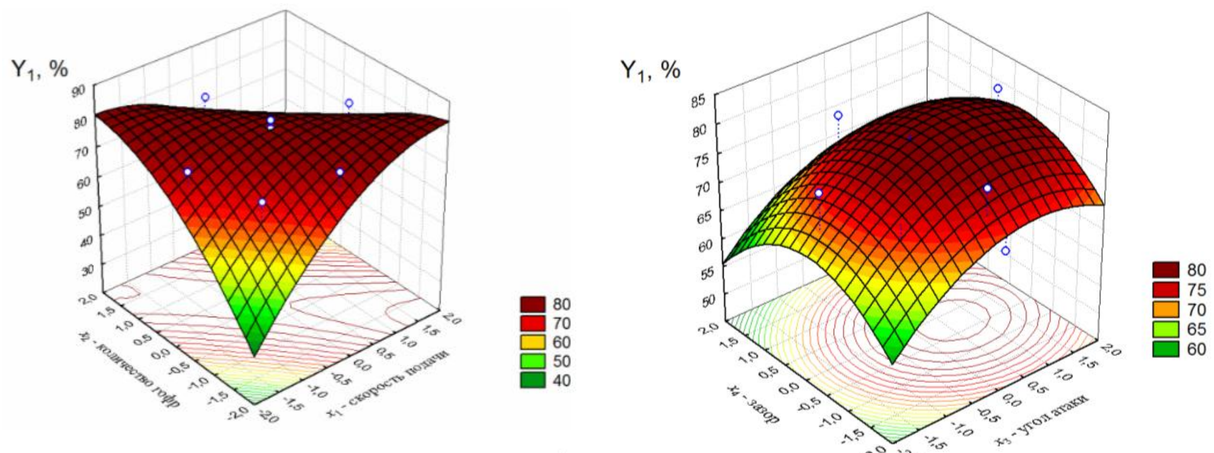
$$\begin{aligned} Y_1 = {} & 79,783 - 0,02973\, x_1 - 2,86924\, x_1^2 - 0,80262\, x_2 - 2,48042\, x_2^2 + \\ & + 2,47276\, x_3 - 1,86186\, x_3^2 - 0,95125\, x_4 - 2,53344\, x_4^2 - 5,93875\, x_1 x_2 - \\ & - 1,1125\, x_1 x_3 + 0,70988\, x_1 x_4 - 0,4375\, x_2 x_3 + 1,80777\, x_2 x_4 - 0,0375\, x_3 x_4; \end{aligned} \tag{9}$$

for deformed ears,%

$$\begin{aligned} Y_2 = {} & 1,963 - 0,029727\, x_1 + 0,767313\, x_1^2 + 0,208086\, x_2 + 0,767313\, x_2^2 - \\ & - 0,095517\, x_3 + 0,767313\, x_3^2 - 0,118906\, x_4 + 0,997066\, x_4^2 - 0,293906\, x_1 x_2 + \\ & + 0,05\, x_1 x_3 + 0,333086\, x_1 x_4 + 0,175\, x_2 x_3 + 0,570273\, x_2 x_4 - 0,075\, x_3 x_4; \end{aligned} \tag{10}$$

for free grain,%

$$\begin{aligned} Y_3 = {} & 7,385 + 0,05945\, x_1 - 1,10025\, x_1^2 - 0,02973\, x_2 - 0,90584\, x_2^2 + 0,11583\, x_3 - \\ & - 0,57005\, x_3^2 - 0,20809\, x_4 - 0,55238\, x_4^2 - 0,22059\, x_1 x_2 + 0,0375\, x_1 x_3 + \\ & + 0,13277\, x_1 x_4 - 0,1375\, x_2 x_3 + 0,14695\, x_2 x_4 + 0,13750\, x_3 x_4. \end{aligned} \tag{11}$$

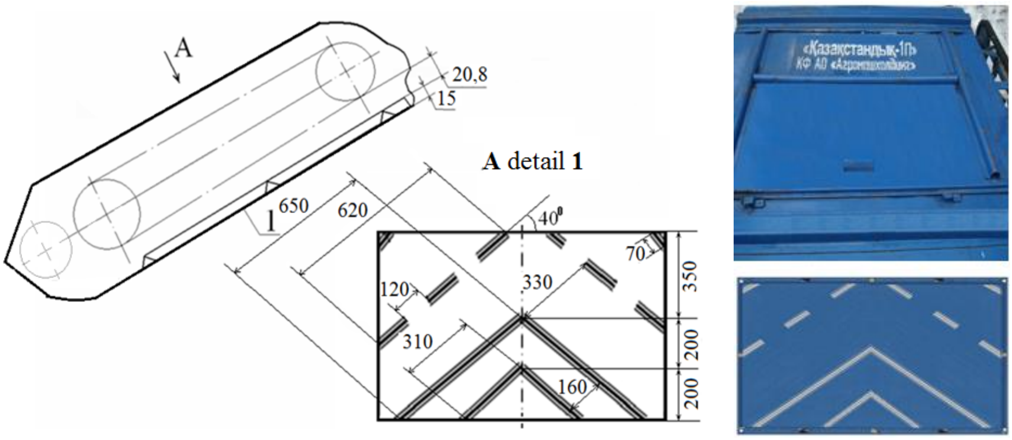


a)

Figure 5. Response and contour of threshing grain of dry short-stalked wheat

The obtained second-order regression models (9) - (11) are an adequate process for the uniform distribution of the grain mass of dry short-stemmed and threshing quality depending on the parameters of the device, fully characterize the process and have a 95% certainty [13].

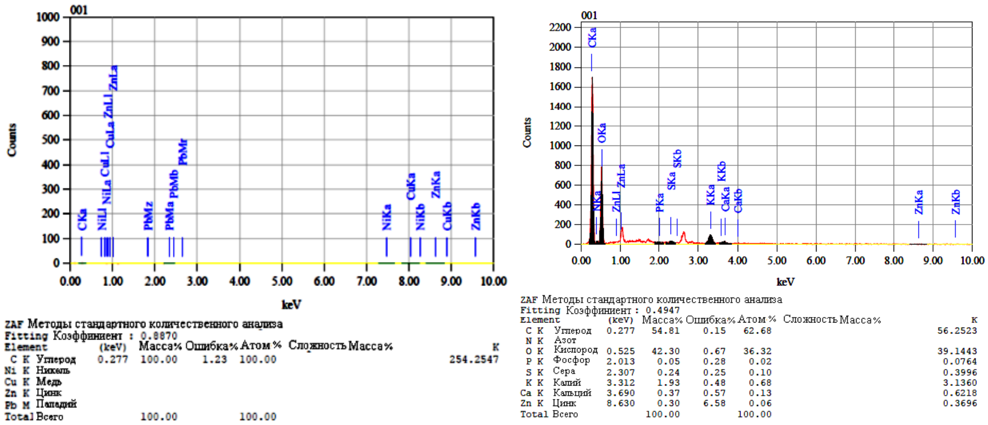
The volumetric graph in Fig. 5 gives a clear idea of how the indicator Y_1 - the degree of optimal distribution of the grain mass of dry short-stalks is related to the supply of masses (x_1) and the amount of discreteness in the corrugations (x_2) with V-shaped corrugations fixed at the main level of attack (x_3 = 0) and the gap between the conveyor and the edges of the working elements (corrugation) of the device (x4 = 0). The color marks or gray tones in this figure show, by means of intensity, the degree of optimal distribution of the grain mass of dry short-stemmed Y_1.
The problem was solved in Excel 2003. The optimal device parameters were obtained [14-17].
According to the research results, an inclined chamber with a device for harvesting short-stalked dry cereal masses was developed and manufactured according to the drawings developed by the design bureau of the same "AgromashHolding" factory (Kostanay city) (Fig. 6).



a b

Figure 6. Structural-technological scheme (a) and experimental sample of an inclined chamber with device (b)

Using a JEOL electron microscope (Japan) JEM-1011, the coefficient of damage of spring wheat Qazaqstandyq 10 was calculated by standard quantitative analysis (Figure 7 a, b).



a) b)

Figure 7 a, b. The results of studies of damaged grains: a) the internal epidermis and the germ of grain with traditional harvesting technology; b) the outer layer of grain with advanced harvesting technology.

A serial harvester for dry short-stalked bread masses does not create conditions for threshing without injuries, in which the embryo is wholly or partially knocked out, the embryo and endosperm simultaneously have macro-injuries. The following types of macrotrauma were observed: part of the endosperm was repelled, part of the membrane was removed. As a rule, the endosperm is beaten off and the casing is removed if there is an uneven supply of dry short-stem masses. The damage coefficient with the traditional harvesting technology was 0.9 (Figure 7 a), and with an experimental combine harvester it was 0.5 (Figure 7 b). The following types of microtraumas were also recorded: single, minor damage to the embryo, damage to the endosperm or membrane in the endosperm [18-19].

4. Conclusion

Based on the studies, the structural parameters are determined: the amount of discreteness of the corrugation in the device n = 4.0 units; angle of attack of V-shaped corrugations α = 40 degrees; the gap between the conveyor and the working surface of the device δ = 20.8 mm., at which the degree of uniform distribution of the bread mass of dry short-stemmed Y_1 = 84.1%, deformed ears Y_2 = 6.4%; free grain Y_3 = 3.3% design parameters: the amount of discreteness of the corrugation in the device n = 4.0 units; angle of attack of V-shaped corrugations α = 40 degrees; the gap between the conveyor and the working surface of the device δ = 20.8 mm., at which the degree of uniform distribution of the bread mass of dry short-stemmed Y_1 = 84.1%, deformed ears Y_2 = 6.4%; free grain Y_3 = 3.3%.
The damage coefficient in the traditional harvesting technology, which was 0.9 for both the internal epidermis and the germ of the grain, and 0.5 for the experimental combine.
Based on the research results, an inclined chamber with a device for normalizing the grain mass before threshing was developed and manufactured at the SBK of the “AgromashHolding” JSC plant (Kostanay city). The operational and technological indicators of the operation of the combine with a modernized inclined chamber are determined; in comparison with the serial inclined chamber, the number of grain crushing decreased from 5.5% to 1.0%; output per hour of net work increased by 22%, output per hour of shift time - by 16%. The annual economic effect of using one device in an inclined chamber to harvest dry short-stalked bread due to an increase in combine harvester productivity and an increase in grain quality is 664520 tenge [20-29].

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