On the substantiation of the technological scheme of the combine harvester with the stationary process of threshing bread mass

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Abstract. The article considers the following issue: that further improvement of the grain combine design with the classical threshing-separating device is possible due to the development of its technological scheme based on the principle of modular construction and stationary process of threshing grain mass. To achieve this goal, the problems were solved, by which laws were revealed and a mathematical description of the technological process of the combine harvester was given, as well as patterns characterizing the effect of straw on the process of threshing the grain mass were revealed. It is revealed that the coefficient of straw of grain mass is possible to reduce during combining, grain crops through the application of high-cut stems. Production check has established that the technological resource of this process of direct grain crops harvesting is limited due to the increase of the negative impact of both the ratio of grain and straw by weight and the height of the cut of the stems on the agrotechnical indicators (grain loss) of the combine.

1. Introduction

At present, along with direct and separate methods of harvesting grain crops, others are also used, for example, stripping on the vine [1, 2], inertial-stripping [3], stationary [4] and others [5]. When applying the method of threshing grain crops in a hospital, the formation of bread mass rolls is carried out with their subsequent drying and threshing. It should be noted that when using this method, the profit of grain producers is determined, in particular, by the degree of use of grain harvesting machines [6] and the volume of work performed [7], and the cost of operating grain harvesting equipment should be optimal [8]. The efficiency of use of harvesting machines is largely determined by their design features [9, 10].

The results of studies [9] indicate that further improvement of the designs of a combine harvester with a classic threshing and separating device is possible due to the development of its technological scheme based on the principle of modular construction and the stationary process of threshing grain mass.

The studies were carried out with the aim of substantiating the theoretical premises of the stationary process of threshing the grain mass in the threshing and separating device of a combine harvester.
To achieve this goal, the following tasks were envisaged: to uncover patterns and give a mathematical description of the technological process of the combine harvester; to reveal patterns characterizing the effect of strawiness on the process of threshing grain mass.

2. Materials and methods
The studies are based on the accepted principles of the general logical method, the methodology of system analysis and mathematical analysis.

3. Results and discussion
In the course of the research and evaluation of the effectiveness of the use of a combine harvester, they are guided by hourly productivity (ha / h), which is determined by the formula:

$$W_h = 0.36 \cdot B_j \cdot V_k \cdot \tau_t,$$

where $B_j$ – grasp width of a harvester, m; $V_k$ – working speed of a combine; $\tau_t$ – coefficient characterizing the loss of time for technological and technical reasons.

The width of the harvester header (header) from the expression (1) is determined from the ratio:

$$B_j = \frac{q}{V_k \cdot Y_g \cdot (1 + \delta_c)},$$

where $q$ – threshing throughput, kg/s; $Y_g$ – grain yield by grain, kg/m$^2$; $\delta_c$ – coefficient characterizing the strawiness of the grain mass.

During the harvesting of grain crops, regardless of the method, in addition to productive plants, there are accompanying, as well as unproductive (weed) plants, and there are fluctuations in the supply of bread mass to the threshing machine of the combine. Based on these provisions, then the throughput of the classic threshing machine of the combine is equal to:

$$q = 0.6 \cdot q_p \left(1 + \frac{1-\varepsilon}{\delta_c + \varepsilon}\right) \cdot \chi,$$

where $q_p$ – passport throughput of the combine thresher, kg/s; $\varepsilon$ – coefficient which characterizes bread mass; $\chi$ – coefficient taking into account the effect of fluctuations in the supply of bread mass on the throughput of the thresher.

Based on expressions (2) and (3), we can write the equality:

$$B_j \cdot V_k \cdot Y_g (1 + \delta_c) = 0.6 \cdot q_p \left(1 + \frac{1-\varepsilon}{\delta_c + \varepsilon}\right) \cdot \chi.$$

After all the transformations we get:

$$V_k = \frac{0.6 \cdot q_p \left(1 + \frac{1-\varepsilon}{\delta_c + \varepsilon}\right) \cdot \chi}{B_j \cdot Y_g (1 + \delta_c)}.$$

Expression (5) allows us to consider the change in the working speed of the combine depending on the technological properties of grain crops, such as the ratio of grain to straw by weight through the coefficient of strawiness and weediness, that is, $V_k = f(\delta_c, \varepsilon)$, which is shown in Figure 1.

From Figure 1 it can be seen that the weediness and strawiness of the bread mass negatively affect the resulting criterion – the working speed of the combine, and therefore, its hourly productivity. The nature of the change in the dependences (Figure 1) indicates that the increase in the working speed of the combine $V_k$ is affected more intensively by the factor of strawiness of the bread mass. The value of the straw coefficient $\delta_c$ is determined by the ratio $m_c / (m_z + m_c)$, that is, the ratio of grain $m_z$ and straw $m_c$ by weight.

During the harvesting of crops by the combine harvester, the grain mass of the ear $m_z$ can be considered as a constant, that is, $m_z = const$. Then the ratio of grain and straw by weight as a technological property of grain crops, expressed through the straw coefficient $\delta_c$, is determined primarily by the length of the plants.
Figure 1. Change in the working speed of the combine $V_k$ depending on the strawiness $\delta_c$ and weediness of the bread mass $\varepsilon$.

In [11], it is noted that the value of the coefficient of strawiness of the bread mass $\delta_c$ can be reduced during the harvesting of crops through the use of a high cut of stems. It was found that with an increase in the height of the cut of the stems (wheat) from 0.10 to 0.20 m, the value of the coefficient of strawiness of the bread mass decreases from 0.726 to 0.578. At the same time, direct combine harvesting of cereals (Chelyabinsk 2 wheat and Omskaya 36, respectively, a rate of 0.82 and 0.96, respectively) by Vektor-410 combines (6.0 m reaper) and John Deere 9500 series harvesters (7.2 m reaper) showed the possibility of increasing the operating speed of cars to 2.5 m/s (9.0 km/h). It was established that with an increase in the working speed by the combine from 1.4 m/s to 2.5 m/s and the formation of a stubble height from 0.15 m to 0.30 m, the intensity of the increase in grain losses by the ears behind the header in the range 73.9–75.0% (Figure 2). Despite this fact, the absolute value of grain losses by the ears behind the header is 0.45% (agrotechnical tolerance 1.0% [11]).

Figure 2. Grain losses by an ear behind the header of the combine Vektor-410 (a) and John Deere of the 9500 series (b) depending on the stubble height and the operating speed of the machine $V_k$.

Field tests show that the working speed of the combine with direct combine harvesting of grain crops more significantly affects the formation of grain losses by the ears behind the header than the cutting height.

From the above it follows that a decrease in the strawiness of the grain mass due to the control of the cutting height during direct combine harvesting of grain crops has a positive effect on the efficiency of using combine harvesters. However, a production check shows that the technological resource of this direct grain harvesting process is limited due to an increase in the negative effect of both the grain to straw ratio by weight and the stalk cut height on agrotechnical indicators (grain loss) of the combine.
harvester. This begs the question: what to do next? How to minimize the effect of the ratio of grain to straw by weight on the technological efficiency of using the threshing of a combine harvester with a classic threshing and separating device?

Science and practice [9, 12] show that it is possible to minimize the influence of the ratio of grain to straw by weight on the technological efficiency of the threshing apparatus of the classic threshing and separating device of the combine harvester by applying the method of towing crops, since in this case the value of the coefficient of strawiness of the bread mass changes significantly. Since in this case, the cereal mass contains up to 80.0% of free grain and 20.0% of the plant part [9, 11, 12] and is characterized as a grain-straw mass. The plant part consists of spike residues and the prickly part of the stem, which varies in length due to the peculiarity of the process of separating the ear from the stem by the towing method, the physicomechanical properties of the plant, and the diameter of the stem.

Experimental studies have shown that the diameter of the stem on the spike part (Omskaya 36 wheat) is significantly different from the diameter at the base and in the middle of the stem. When changing the height of the stem from 0.10 m to 0.55 m, the difference is: base – 2.81 mm (100.0%); the middle part is 2.24 mm (79.7%) and the side part is 1.35 mm (48.0%). As a result of processing the experimental data by the least squares method (least squares) using the MathCAD14 program, the following dependence was obtained:

\[ d_{st} = -1.2l_{st}^2 - 1.8l_{st} + 2.5 , \]  

where \( d_{st} \) – stem diameter (wheat), mm; \( l_{st} \) – stem height (base, middle, prickly part), m.

Based on this fact, we conducted additional experimental studies to determine the value of the coefficient of strawiness of the bread mass \( \delta_c \) depending on the length of the prickly part of the stem, which is shown in Table 1.

**Table 1.** Change in the coefficient of strawiness of the grain-straw mass.

| Experience number * | Stem length, m | The coefficient of strawiness of the bread mass ** | The length of the prickly part of the stem \( l_{pst} \), m | \( \bar{X} \) | \( \bar{X} \) | \( \bar{X} \) | \( \bar{X} \) |
|---------------------|---------------|------------------------------------------------|-----------------------------------------------|-------|-------|-------|-------|
| 1                   | 0.8           | 0.66                                           | 0.36                                          | 0.21  | 0.17  | 0.03  |       |
| 2                   | 0.7           | 0.64                                           | 0.28                                          | 0.23  | 0.20  | 0.04  |       |
| 3                   | 0.6           | 0.67                                           | 0.41                                          | 0.30  | 0.28  | 0.06  |       |
| 4                   | 0.5           | 0.69                                           | 0.57                                          | 0.45  | 0.34  | 0.05  |       |

*note: culture: Chelyabinsk wheat 2; grain moisture – 15.9%; place of testing - Akbashevsky Limited Liability Company; ** Values obtained from the point of normal stalk cut (cut height 0.12 m).

As a result of processing the data presented in the table by the least squares method (least squares) using the MathCAD 14 program, the following dependence was obtained:

\[ \delta_c = a \cdot l_{st}^2 + b \cdot l_{st} + c , \]  

where \( a \) and \( b \) – odds (constant member), \( a = 0.75 \text{ m}^{-1} \) and \( b = -1.065 \text{ m}^{-1} \); \( c \) – coefficient (free member), \( c = 1.028 \).

At \( l_{pst} = 0 \text{ m} \), the value of the coefficient of strawiness of the grain mass \( \delta_c \) varies by the formula:

\[ \delta_c = d \cdot l_{st}^2 + e , \]  

where \( l_{st} \) – stem height, \( l_{st} \epsilon(0.50 - 0.80) \text{ m} \); \( d \) and \( e \) – coefficients (constant and free member), \( d = -0.08 \text{ m}^{-1} \) and \( e = 0.097 \).

In addition, the dependences of changes in the coefficient of strawiness of the bread mass \( \delta_c \) on the length of the prickly part of the stem were obtained:

\[ \delta_c = 0.947 \cdot l_{pst} + 0.034; \text{ at } l_a = 0.8 \text{ m} ; \]

\[ \delta_c = 0.75 \cdot l_{pst} + 0.075; \text{ at } l_a = 0.7 \text{ m} ; \]

\[ \delta_c = -2.75 \cdot l_{pst}^2 + 1.895 \cdot l_{pst} + 0.075; \text{ at } l_a = 0.6 \text{ m} ; \]

\[ \delta_c = -4.25 \cdot l_{pst}^2 + 2.945 \cdot l_{pst} + 0.06; \text{ at } l_a = 0.5 \text{ m} ; \]
where $l_{ps t}$ – stalk length, $l_{ps t} \in (0–0.3)$ m.

During the work of the combing header of the combine harvester, a grain-straw mass is formed, which is characterized by a random ratio of the fractions of the straws of the stem of the stalk part. Based on this fact, then the coefficient of strawiness of grain-straw mass $\delta_c$ should be considered as not a point, but a weighted average value. Having accepted the assumption that all fractions in the structure of the grain-straw mass are equally probable, then the coefficient $\delta_c$ can be written:

$$P(\delta_c) = \frac{P_o(\delta_c) + P_{0.10}(\delta_c) + P_{0.20}(\delta_c) + P_{0.30}(\delta_c)}{\sum_{i=0}^{30}\frac{P_i}{l_{ps t}}}.$$  \hspace{1cm} (9)

where $P(\delta_c)$ – the probability of a weighted average coefficient of strawiness of grain-straw mass; $P_o$ – the probability of an event that the length (m) of the prickly part of the stem $l_{ps t}$ equals to zero; $P_{0.10}$, $P_{0.20}$, $P_{0.30}$ – the probability of the event, respectively, that the length of the prickly part of the stem is: $l_{ps t} = 0.10$ m; $l_{ps t} = 0.20$ m; $l_{ps t} = 0.30$ m.

Based on the expression (9), the coefficient of strawiness of the grain-straw part of the mass can be determined from the ratio:

$$\delta_c = \frac{m_0 + m_{0.1} + m_{0.2} + m_{0.3}}{m_x + (m_0 + m_{0.1} + m_{0.2} + m_{0.3})}.$$ \hspace{1cm} (10)

where $m_x$ – grain weight, g; $m_0$ – mass of the fine fraction of the plant part, g; $m_{0.1}$ – length fraction of the plant part $l_{ps t} = 0.10$ m; $m_{0.2}$ – length fraction of the plant part $l_{ps t} = 0.20$ m; $m_{0.3}$ – mass fraction of the plant part of the length $l_{ps t} = 0.30$ m.

4. Conclusion

It has been established that it is possible to increase the throughput of the thresher of a combine harvester with a classic threshing and separating device, and, consequently, hourly productivity by reducing the negative impact of such technological properties of grain crops as the ratio of grain to straw by weight. This can be done through the development of a combine header in the form of a technological module – a wide sweeping header. The technological process, which is characterized by the fact that the grain mass is converted into a new state – grain-straw mass by reducing the proportion of the plant part. This technological object of influence is characterized by a chaotic spatial arrangement of the remains of the plant part and, above all, the prick part of the stem. The chaotic nature of the structure of the plant part of the straw-straw mass puts forward new requirements for feeding it to the threshing machine of a combine harvester with a classic threshing and separating device.

References

[1] Aldoshin N V, Lylin N A and Mosyakov M A 2017 Harvesting legumes by combing Far Eastern Agrarian Bulletin 1(41) 67–74
[2] Buryanov M A, Buryanov A I, Chervyakov I V and Goryachev Yu O 2017 Development and improvement of methods for substantiating the technology of combine harvesting of cereal crops with towing Bulletin of the agrarian science of the Don 2(38) 59–72
[3] Byshov N V, Ryadnov A I and Fedorova O A 2018 Machine for harvesting grain crops Proc. of the Lower Volga Agro-University Complex: Science and Higher Professional Education 1(49) 220–227
[4] Zapevalov M V, Sergeev N S and Petrova G V 2015 Strategy for post-harvest deep processing of grain crops Bulletin of the Orenburg State Agrarian University 2(52) 95–97
[5] Tseplyaev A N, Dugin Yu A and Tronev S V 2019 Improvement of the design of the threshing machine for threshing leguminous crops J. of Advanced Research in Dynamical and Control Systems 11(8) 2685–2690
[6] Masek J, Novak P and Jasinskas A 2017 Evaluation of combine harvester operation costs in different working conditions Engineering for Rural Development 16 1180–1185
[7] Mimra M and Kavka M 2017 Risk analysis regarding a minimum annual utilization of combine harvesters in agricultural companies Agronomy Research 15(4) 1700–1707
[8] Vasylieva N and Pugach A 2017 Economic assessment of technical maintenance in grain production of Ukrainian agriculture *Bulgarian J. of Agricultural Science* 23(2) 198–203

[9] Ryadnov A I, Lovchikov A P, Shagin O S and Shakhov V A 2019 To the development of a stationary process of threshing grain mass with a combine with a classic threshing and separating device *Proc. of the Lower Volga Agro-University Complex: Science and Higher Professional Education* 2(54) 314–322

[10] Fedorova O A 2017 Factors affecting the performance of combine harvesters *Proc. of the Lower Volga Agro-University Complex: Science and Higher Professional Education* 4(48) 239–245

[11] Lovchikov A P, Lovchikov V P, Iksanov Sh S and Shagin O S 2017 Results of the production inspection of direct combine with a high cut of grain crops *Bulletin of Omsk State Agrarian University* 1(63) 75–77

[12] Buryanov A I, Zaitsev S G and Cheryakov I V 2018 Method and means of harvesting crops with tow with separation of a heap at the hospital *Polymathematical network electronic scientific journal of the Kuban State Agrarian University* 140 1–16