Comparison of Different Methods for Preliminary Separation of Free Grain When Hatcheling Standing Plants

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Abstract. The article presents the results of laboratory studies, confirming the possibility of preliminary separation of free grain from the hatchelled grain heap before it enters the combine harvester threshing chamber. It has been established that the most promising methods for performing this technological process are a mesh conveyor mounted in front of the thresher and an inclined chamber equipped with a grating bottom with oblong holes. The experimental results indicate that the maximum passage of free grain through the openings of the mesh conveyor 2000 mm long is 94.66%, and for an inclined chamber with a grating bottom 950 mm long – 68.7%. To ensure the passage of 99% free grain, the length of the mesh conveyor separating surface should be at least 2.69 m, and the length of the inclined chamber should be 1.17 m. The practical implementation of the first separation method requires shifting thethreshing drum back and drastically shortening the straw walker. The second method of separation is more acceptable, since it does not require a substantial rearrangement of the serial harvester.

1. Introduction
Hatchelling of standing plants is one of the most promising areas for improving the technological process of harvesting grain and leguminous crops [1-3]. This is due to the fact that with this technology the flow of grain into the combine is reduced by 1.5-2 times, which leads to savings of up to 70% of the energy that a modern harvester spends on the deformation of straw in the thresher. As a result, the performance of the harvester increases by 1.7-2 times, fuel consumption decreases by 20-25% [4, 5]. The cost of grain is reduced by 25-30% [6]. However, the reserves for improving this cleaning method are not exhausted. The fact is that the grain mass obtained as a result of towing contains up to 80% of free grain [7-10]. Its entry into the threshing chamber complicates the process of further threshing the remaining spike part of the crop, and also reduces the throughput of the device. In addition, there is an increased free grain crushing (about 5%) by the working units of the grind [11].

From the point of view of optimization of the technological process, it would be advisable to allocate free grain before it enters the thresher. As a result, not only its throughput, but also the productivity of the combine as a whole should increase.

2. Relevance
For this purpose, we synthesized several variants of mechanisms that allow preliminary separation of free grain from hatchelled grain heaps with the subsequent supply to the threshing device of only under-
thinned ears and straws of different lengths. The first option assumes that a movable mesh conveyor will be mounted in front of the threshing machine, which performs vertical vibrations due to the eccentricity of the drums. Free grain and fine impurities commensurate with it should wake up directly on the transport board, and only under-thinned ears and part of the straw should enter the threshing device [12-14].

The second option is to equip the inclined chamber of the combine harvester with a special grating bottom, through the elongated openings of which the grain and small impurities (floor and partially chopped straw) should wake down, where two screws are mounted, which feed it directly for cleaning bypassing the threshing chamber [15-18].

The results of the calculations indicate that, for example, for the "Vector" harvester, the additional power consumed by the drum during its excessive interaction with free grain is about 10 kW. In this regard, minimizing this negative process, in particular, through preliminary separation of free grain, is an urgent scientific and practical task.

3. Formulating the problem
To evaluate the possibility of preliminary separation of free grain from hatchelled heap through the development of special experimental plants and determine their optimal parameters.

4. Theoretical part
The main purpose of the theoretical part of the study was to simulate the process of separating free grains from a hatchelled heap using the grating bottom of the inclined chamber of the harvester and a moving mesh surface mounted in front of the threshing drum.

In the version with an inclined chamber, the research hypothesis considered processes occurring in the elementary volume of a heap formed by each scraper of a floating conveyor. The separation is as follows. When the heap reaches the edge, the grain openings roll down in layers along the separation line between the inclined layers, oriented at an angle of internal friction of the material to the horizon $\alpha$ and pass through the oblong holes of the grating bottom of the inclined chamber (figure 1). At the same time, part of the grain of the moving layer slides along the interface without turning, and part is rolled, accelerating as it moves. If the length of the rolling layer exceeds the path traveled by the grain that was in the initial state in the upper part of the elementary volume during the movement of the scraper above the longitudinal hole of the grating bottom, then its passage is impossible. In this regard, it can occur at one of the following holes located on the path of the scraper and the elementary volume of the heap moved by it.

![Figure 1](image)

**Figure 1.** Phases of the process of passing the heap through the hole of the grating surface: 1 – a scraper; 2 – a grating bottom; 3 – a longitudinal hole; 4 – elementary volume of a heap; 5 – a hatchelled heap; 6, 8, 10 – the second and subsequent layers of the heap; 7 – separation surface; 9 – the initial position of the hatchelled heap.
From a formal point of view, the time during which an elementary heap of grain passes through an opening can be found as follows

\[ t_{sep} = \frac{L_{heap}}{v_{sep}}, \]  

(1)

where \( L_{heap} \) – the maximum distance traveled by grain along the separation line between the layers of the heap during the time \( t_{hole} \); \( m \); \( t_{hole} \) – the time required for the scraper to pass over one hole, \( s \); \( v_{sep} \) – heap separation rate through the hole, \( m/s \).

When calculating we took into account different nature of movement characteristic of grains with different cross-sectional shapes: a round rolling cylinder, a rolling cylinder with a cross-section in the form of an incomplete circle, and a sliding cylinder of the same shape. With the length of the hole of the grating surface \( l_{hole}=0.16 \, m \) and the speed of the floating conveyor scraper \( v_{scr}=3 \, m/s \), the time spent by the free grain above the hole is about \( t_{hole}=0.053 \, s \). Therefore, the average separation speed is equal to \( v_{av,sep}=0.146 \, m/s \).

However, the separation intensity depends not only on the speed of the conveyor and the size of the holes, but on the fractional composition of the heap as well, since the presence of flooring, straws and under-ground ears impedes the process of rolling the grains, creating interference on their way. In this regard, the real nature of the process can be represented as follows

\[ v_{act,sep} = v_{av,sep} \cdot \eta_1 \cdot \eta_2, \]  

(2)

where \( v_{av,sep} \) – the average speed of grain heap separation through the holes of the grating surface, \( m/s \); \( \eta_1 \) – deceleration coefficient taking into account the amount of free grain in the hatchelled pile; \( \eta_2 \) – deceleration coefficient taking into account the amount of free grain remaining on the jumpers.

Since the hatchelled grain heap contains up to 80% of free grain [4, 7], we believe that the deceleration coefficient is directly proportional to this amount, that is, \( \eta_1=0.8 \).

The deceleration coefficient \( \eta_2 \), is determined by the amount of free grain remaining on the jumpers between the holes. In view of ensuring the strength of the sieve sheet, \( \eta_2=0.9 \). Thus, according to the theoretical hypothesis, \( v_{act,sep}=0.105 \, m/s \), and in order to ensure the passage of all free grain contained in the combed grain heap, at least five consecutive rows of elongated holes 160 \( mm \) long must be made in the inclined chamber bottom.

As for the passage of grain through the openings of the sieve sheet, the nature of the separation process should be closer to the operation of the keyboard straw walker and described by an exponential dependence. In this case, the optimization of parameters should be carried out through a multivariate experiment.

Despite the fact that the moving sieve sheet is used in the design of grain cleaning machines [19], it was necessary to verify the operability of the proposed design when separating a hatchelled grain heap of a specific composition, which was the subject of the corresponding experiment. To this end, we developed an experimental installation that simulated the operation of the proposed mesh conveyor. The passage and exit of the heap from the sieves were recorded in five zones. For this, four containers were installed under the sieve sheet (along its entire length), and the fifth container was installed at the exit of the heap from the conveyor. Thus, the total mass of the heap in the first four containers represented the volume of passage through the sieve sheet openings, and the descent from it accumulated in the fifth tank. As a result of this, it becomes possible to determine the pattern of distribution of the heap passage through the holes of the sieve sheet along its length.

In the experiment, a heap of controlled composition was used. Its parameters had been determined earlier when testing a hatchelling device when harvesting winter wheat of the "Moskovskaya 56" grade [20]. For about one second, a sample of a heap (based on grain of the "Moskovskaya 56" grade) with a mass of about one kilogram was fed into the receiving part of the mesh conveyor. With a width of the experimental setup of 150 \( mm \), the feed (in terms of the full width of the inclined chamber and combine thresher) corresponded to 10 \( kg/s \). The experiment was carried out at a mesh conveyor speed of 3 \( m/s \), which corresponds to the kinematic parameters of the floating conveyors of most combine harvesters. The length of the mesh conveyor was 2 \( m \), and the sieve sheet cells had dimensions of 17 \( \times \) 15 \( mm \). The
grain passing through the holes of the sieve sheet was weighed. Each experiment was carried out with tenfold repetition.

Similarly, we conducted studies on an experimental installation simulating the operation of an inclined chamber with a grating bottom, which was made on the basis of the spike elevator of the KZS-10K "Polesye GS-10" combine harvester. The bottom wall of the elevator casing was removed, and replaceable sieves of 950×150 mm in size were installed instead of it, the dimensions of the holes 160×8 mm corresponded to the results of theoretical modeling of the process [21, 22]. At the same time, the length of each interchangeable sieve corresponded to the length of the free part of the bottom of the inclined chamber of the KZS-10K "Polesie GS-10" combine harvester, through which the organization of the heap separation process is possible. The experiment was carried out at a conveyor speed of 3 m/s and an elevator inclination angle of 45°, which corresponds to the parameters of most serial combines.

5. Results of experimental studies

The experimental data was processed in Excel and STATISTICA. According to their results, it was found that the free grain passage for an experimental installation simulating the operation of the mesh conveyor is about 94.66%.

To identify the nature of the free grain separation process, a graph for the decrease of free grain along the length of the separation surface (figure 2, a), with its quantity recorded in four control plots was constructed. At the same time, the start of the experiment at the time of its entry into the installation was taken as a 100% amount of free grain. The calculation of the free grain amount entering the second control section (53.15%) is determined by the difference between the previous value (100%) and the amount of free grain passing through the holes in the first control section (46.85%). Similarly, the remaining values were obtained (22.71; 9.89 and 5.34%, respectively).

![Figure 2](image-url)

**Figure 2.** Decrease of free grain from the hatchelled grain heap along the length of the separation surface: a) for the mesh conveyor; b) for the grating bottom of an inclined chamber.

Assessment of the decrease in free grain from the hatchelled grain heap along the length of the separation surface (figure 2, a) indicates the presence of a reserve to increase the separation degree. The
regression equation, which most fully reflects the nature of the dependencies, has an exponential form ($R^2=0.989$)

$$C_g = 86.609 \cdot e^{-1.66L}, \quad (3)$$

where $C_g$ – the current grain balance in the heap, as a percentage of its initial mass, available at the beginning of the separation process (free grain falling); $L$ – the length of the separating surface, m.

By setting the value $C_g=1\%$ (according agrotechnical requirements crushing seed material should not exceed 1\%), we determined the required length of the separation surfaces from the following equation

$$I = 86.609 \cdot e^{-1.66L}, \quad (4)$$

Having solved equality (4) using the "MathCAD" program, we determine the length of the mesh conveyor, which ensures the passage of 99\% of free grain, equal to $L=2.687$ m.

Similarly, the experimental data for the grating bottom of the inclined chamber of the combine harvester were processed (figure 2, b). According to the obtained results, it was found that the passage of free grain in this case is 68.7\%. With a high degree of probability ($R^2=0.982$), the trend line is straightforward and is characterized by the following equation

$$C_g = -80.424 \cdot L + 95.045. \quad (5)$$

The extrapolation of the trend line (Fig. 2, b) shows that to ensure the passage of 99\% of free grain, it is necessary that the separation surface be about 1.169 m. Such a technical solution can be implemented, for example, in the inclined chamber of the KZS-10K "Polesye GS-10" combine harvester, having a length of the order of 1.3 m [23]. In this case, the grain heap (free grain and small impurities), passed through the holes of the grating bottom, is advisable to be send to the transport board either by means of a screw or by means of a scraper conveyor.

6. Conclusions

1. Using the proposed technical solutions will reliably exclude the likelihood of free grain entering the threshing chamber and passing the remaining spike of the crop through the holes of the grate. To ensure maximum separation of free grain from the hatchelled grain heap, the length of the mesh conveyor should be at least 2.69 m. The practical implementation of such a technical solution requires the threshing drum to be moved back and the straw walker shortened (as unnecessary) without disrupting its technological process.

2. The most acceptable way to isolate free grain from a hatchelled grain heap that does not require a significant re-arrangement is to use the grating bottom of an inclined chamber for this purpose. To ensure the highest degree of grain separation, the length of its grating surface should be at least 1.17 m.

3. The high degree of convergence of theoretical predictions and experimental results indicates the acceptability of theoretical hypotheses that adequately describe the separation processes of a hatchelled grain heap in two different ways. This applies both to the linear dependence characteristic of an inclined chamber, and the exponential dependence obtained in the study of the mesh conveyor.

7. References

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