Harvester and transporting device development for high-quality soybean seeds obtaining

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Abstract. Soybean in the Amur Region occupies up to 30% of its area in Russia. With a high content of protein and oil, it is an energy-efficient crop, and its processed products are widely used in the food industry and animal husbandry. An increase in soybean production is planned by improving the structure of sown areas, introducing new varieties, and intensifying crop production. It is possible to increase its productivity through the use of high-quality and most productive seeds that can be isolated, separately collected in a combine harvester during harvesting and used without seeds after harvesting. For this, it is necessary to use combines of two-phase threshing, with the separation of threshed mass by the first threshing drum, cleaning and collecting this mass in an additional hopper. To avoid pinching and damage during transportation, it is necessary to use screws with a brush frame for the working edge of the screw and brush conveyor belts. The selected soybean seeds of the first fraction for all sowing quality indicators correspond to the second class of the state standard, and their laboratory and field germination, 96 and 91.5%, corresponds to the seeds of the first class. The use of the first seed fraction during sowing, without additional purification, reduces material costs, increases soybean yield by 3.0 kg / ha and increases profit.

1. Introduction
An increase in soybean yield is possible due to the use of high-quality and most productive seeds, which can be isolated and separately collected in a two-phase threshing combine harvester, providing a more complete preservation of the grown crop from mechanical damage, a high content of which (up to 10-14%) leads to a decrease in field germination and productivity [1].

Combine harvesters of various grades are used to harvest soybeans, which collect milled grain into one hopper and do not separate it according to the soybean biological diversity. The working parts of the harvester are divided into two groups according to the power activity of the impact and the amount of damage. The working parts that carry out the selection of grain from the straw heap and damaging 59% of the grain [2]. The working bodies that separate the grain, collect it and move it into the bunker of the combine damage the remaining 41%. That is, in terms of the number of damaged grain, the group of nodes of the combine of the threshing separating device is in the first place, and therefore, their structural and technological revaluation is a paramount task.

Combine harvesters of domestic and imported brands are used for harvesting soybeans. In order to renew the combine fleet obsolete by 26% (as of 01.01.2020), farms are acquiring new, more productive
combines of various manufacturers and models for harvesting an increasing volume of grain, soy and corn crops, of which 20% are imported combines (table 1).

A comprehensive assessment of the harvesting units operation, conducted by the Far Eastern Research Institute of Mechanization and Electrification of Agriculture (DalNIIIMESKh) of the Russian Agricultural Academy in 2009, showed that, despite a number of advantages, the use of imported combines for soybean harvesting is not economically feasible. Considering the cost of these combines, agricultural and operational indicators, the cost of harvesting when using them is 1900–1100 rubles/ha higher, and the conditional profitability is 1.54–2.56 times lower than that of Russian-made combines.

Table 1. The state of the Amur region combine park.

| Harvester brand           | Quantity on 01.01. 2020 | Service life over 10 years |
|---------------------------|--------------------------|----------------------------|
| "Acros", "Don"            | 110                      | -                          |
| Sk-5, “Niva”, “Vector”    | 600                      | 60                         |
| “Amur-Polesye”            | 785                      | -                          |
| “Yenisei-950”             | 459                      | 459                        |
| Imported (“John Deere”, “Case”, “Claas”, “Track” and others) | 486                      | 62                         |
| **Total**                 | **2440**                 | **581**                    |

An analysis of the agrotechnical assessment of combines for soybean harvesting showed that the purity of bunker grain in all tested machines is at a sufficiently high level of 99.1–99.8% (according to requirements of at least 96%). At the same time, the largest crushing (12.5%–15.1%) was noted for import combines and a slightly lower crushing (8.9%–10.5%) for Russian-made combines. This situation is due to the fact that the lower frequency range of threshing drums rotation for foreign combines is very high and amounts to (450–480 min-1). And for the Amur varieties of the All-Russian Research Institute of Soybean, the rotation speed should not be higher (220–240 min-1) and for combines of the latest releases it should be reduced to 250 min-1 due to the installation of a reduction gear (RSM-081.27) [3, 4, 5].

The developed separate collection device emits up to 60% of separated, high-quality and first-class seeds, which are obtained after threshing with the first threshing drum, cleaned and collected from the first half of the sieve mill. Therefore, it is necessary to justify technology and new technical solutions to reduce mechanical damage when transporting these soybean seeds to a separate hopper of the combine [6, 7].

The aim of the work is to develop a combine harvester and transporting devices that have less power impact on soybean grain when it is milled, harvested and moved to a separate seed hopper for subsequent use on sowing without post-harvest processing.

The main cause of mechanical damage to grain in screw and scraper conveyors is the presence of a gap between the inner surface of the casing (trough) and the outer edge of the screw (scraper), which contributes to the jamming of grain with different sizes of its length, width and thickness. For soybeans, the most dangerous loads are those caused by forced abrasion or rolling with pinching during drawing, as is observed in screw and scraper conveyors. In the process of pinching, and subsequent friction during drawing, the shell deforms, ruptures or cleaves, which reduces its strength and leads to the destruction of soybean grain or to delamination into halves.

For a complete elimination of pinching and reduce mechanical damage to soybeans during transportation by the screw it is necessary to increase the gap between the edge of the screw and casing up to 15-20 mm. To cover the gap in the screw, it is effective to use a brush elastic frame of the screw edge. This technical solution can almost completely eliminate, under certain conditions, the destruction
of the grain, reverse the scree with inclined movement. The thickness of the threads of the frame, their length and the number of the beam must be sufficient to withstand the load from the floating material and will not deviate to a critical position which will be a tightening of grain or impurities under the frame. Even in the case of getting grain under the frame it will not be destroyed, as the pressure of the frame on a trapped grain will be many times below the critical failure load. Brush frame of the belt conveyor prevents the shedding of the grain from the edges of the tape when it is moved. To withstand axial load from the transported grain and to prevent bending of the frame greater than the critical value, you must have the stiffness of the beam more axial pressure of the transported material. The axial pressure exerted by the transported grain to the brush element, generates bulk servings of grain at the height of the frame and the length of the pitch screw conveyor. In the brush-belt conveyor, the axial load on the brush element is created depending on the height of the frame and the linear mass of the seeds being moved. The thickness of the frame equal to the critical, is the minimum acceptable and depends primarily on the free length and the diameter of the filaments constituting the frame, as well as on physical-mechanical properties of the transported seeds, the elastic qualities of the material of the frame and structurally-kinematic parameter view and belt conveyors.

Figure 1. Horizontal metal auger with a frame.

2. Experimental methods
To conduct the research on the operation of various transporting devices, a universal laboratory unit was developed and manufactured. Its design made it possible to install conveyors of various lengths (from 1.5 m to 3.5 m) and diameters (160 mm – 240 mm) for testing, to change the angle of inclination from 0 to 50° and the rotational speed from 0 to 13 s-1.

The experimental setup made it possible to study interchangeable conveying devices (according to patents No. 20152528, 2038998, 2291094, 2596045): horizontal metal augers with and without framing, a polyethylene, scraper and belt conveyor with a tape frame. The height and thickness of the screw conveyor frame was 20 mm and 10 mm with a diameter of kapron filaments equal to 0.4 mm (OST 6.06.10–76; E = (2.5-2.7) * 103 N / mm²). The rotational speed of the screws was set on a calibrated scale URS – 10 and was controlled by a tachometer ТЧ10 – P of the first accuracy class. Laboratory results are summarized in table 2.
Table 2. Damage to soybean grain by transporting devices.

| Conveyor                                           | Splitting up, % | Micro damage, % |
|----------------------------------------------------|-----------------|-----------------|
| Horizontal steel auger, D=S=160 мм                 | 1.6             | 4.0             |
| Horizontal steel screw with a frame, D = S = 168 mm, frame height h = 20 mm | 0.4             | 0.5             |
| Horizontal polyethylene screw with a frame, D = S = 168 mm, frame height h = 20 mm | 0.35            | 0.4             |
| Scraper conveyor with base scrapers B = 300 mm     | 1.5             | 2.0             |
| Scraper conveyor with volumetric scrapers (patent No. 2038995) | 1.0             | 1.5             |
| Belt-screw conveyor with a frame, ΙΙ = 300 mm; frame height h = 100 mm | 0.4             | 0.6             |

The re-equipment of the combine for double flow grain cleaner (figure 2) included the installation of an additional screen 1, a grain elevator and a screw with a brush frame for the screw edges, as well as an additional seed hopper with samplers of the first seed fraction 2, the horizontal trough-shaped screw of the first elevator was replaced with a metal screw with a brush frame for the screw edges. To collect the second seed fraction, a hopper 3 with a sampler 5 was installed and for feeding the seeds, minced by the second drum and cleaned on the second half of the sieve mill the elevator 4 with a quick screw 6. The straw and floor were collected in the samplers 8 and 9 after passing the test section after the transfer movable frame cutter 7.

Figure 2. Test harvester scheme.

The operating modes of the thresher and cleaner were as follows: the peripheral speed of the scourges of the first drum V1 = 9.5, the second V2 = 16.11 m / s, threshing gaps at the inlet and outlet 24/12 and 18/9 mm, respectively, the solution of the blinds of the upper sieve 12 ~14 mm, bottom 9–11 mm, extension cord 16–18 mm, angle of inclination of extension cord 150. The side flaps of the fan are 100% open. The feed for cleaning was changed by the translational speed of the combine from 0.61 to 2.44 m / s.

3. Results and discussion
Laboratory studies have shown a significant advantage in maintaining the quality of soybean seeds when moving them to a separate seed hopper of the combine. Assessing the operation of framed transporting devices, it should be noted that these devices work when moving seeds without pinching and with
minimal damage, which is 3.5–6 times less than the damage compared to basic conveyors and they are structurally acceptable for working in a combine.

Combine studies, with the developed device for collecting high-quality seeds in a separate hopper, showed that up to 60% of biologically complete seeds are allocated to the first fraction. The seed purity of this fraction is 98.2%, which is 1.0-1.2% higher than the purity of the bunker grain (table 3).

The content of crushed seeds of the first fraction is 1.94%, the second is 7.3%, and in the bunker grain crushing was 8.3%. Microdamage to the first fraction was 3.62%, the second to 8.1%, and bunker grain 7.95%.

The content of unripened seeds in the first fraction was 0.43%, in the second 3.0% and in bunker grain 1.5%. The weight of 1000 seeds of the first fraction was 173.6 g., the second 160.8 g. and bunker grain 168.5 g.

The total grain loss was 0.34% and was 1.4 times lower than the total loss for the reference combine.

**Table 3.** Getting high-quality soybean seeds directly during harvesting.

| Indicators                      | First seed fraction | Second seed fraction | Grain cleaning |
|---------------------------------|---------------------|----------------------|---------------|
| Seed isolation, %               | 60                  | 40                   | 100           |
| Grain purity, %                 | 98.2                | 96.3                 | 97.0          |
| Splitting up, %                 | 1.94                | 7.3                  | 8.3           |
| Microdamage, %                  | 3.62                | 8.1                  | 7.95          |
| The content of unripe seeds, %  | 1.43                | 5.4                  | 5.0           |
| The mass of 1000 seeds, g       | 156.3               | 151.6                | 154.2         |
| Humidity%                       | 9.4                 | 10.3                 | 9.8           |
| Laboratory / field germination, % | 96.0/91.5         | 86.3/77.8            | 86.5          |
| Average productivity, t / ha    | 1.89                | 1.55                 | 1.59          |

The main indicators by which the class is established are germination and seed purity. Assessing the soybean seeds of the first fraction, it should be noted that for all sowing quality indicators they can be attributed to the second class of the state standard. The seed content of the main culture in the first fraction is 96.6%, according to GOST at least 95%. Laboratory and field germination are 96% and 91.5%, and these indicators correspond to the first-class seeds according to GOST. The selected seeds contain crushing, 4.25 times less than the content of crushed seeds obtained by harvesting soybeans with combine harvesters without the proposed device. The use of the first high-quality seed fraction at sowing without additional purification, which corresponds to the seeds of the first and second sowing classes in terms of indicators, allows you to save the whole grain from damage during cleaning by the sowing complex. This technology for producing high-quality seeds reduces material costs for cleaning and preparing seeds, increases the size of soybean yield by 3.0 kg / ha and ensures high profit for farms.

4. Conclusion

While harvesting soybeans with a two-phase threshing combine ripened beans are threshed out most intensively and are separated in the area of the first threshing drum. Deseeding, scraping and collecting this fraction (60%), you can get high-quality and biologically viable seeds with high absolute mass, having by 3.57% and 1.2% below content of the frost seeds and impurities and use for sowing without post-harvest processing.

Replacing the auger and elevator in the basic combine to transfer grain to the combine hopper, to the auger and belt conveyor with a brush frame for the screw edges and belt edges eliminates pinching and damage to the seeds of the first seed fraction.

The first fraction of seeds contains 4- and 2-times lower crushing and a minor injury and has 96% and 91.5% of laboratory and field germination, and 0.3 t/ha increases the value of the soybean crop.
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