Combine harvester improvement for selection and collection of high-quality soybeans

I M Prisyazhnaya, S P Prisyazhnaya, V T Sinegovskaya and M O Sinegovskiy

Federal State Budget Scientific Institution Federal Research Center «All-Russian Scientific Research Institute of Soybean», 19, Ignatievskoe sh., Blagoveshchensk, 675027, Amur Region, Russia

E-mail: info@vniisoi.ru

Abstract. To obtain biologically valuable and high-quality soybeans it is necessary to improve the design of the two-phase threshing combine harvester which will have a gentle mode for threshing the most mature soybeans in the first threshing drum, make their high-quality cleaning directly in the combine harvester and collect them in a separate hopper. The first seed fraction of biologically valuable and high-quality soybeans is obtained by separating the threshed heap in the first threshing drum. It’s cleaned and collected in a separate hopper. The return is processed in the second threshing drum, and the second fraction of seeds is cleaned and collected in the second hopper of the combine. The straw that comes off the straw walker and enters the auger is divided into two parts, and when it leaves the auger on both sides, it is crushed and thrown out of the sides of the combine. At the same time, during the combine harvesting of soybeans, the chaff coming of the sieve boot and being the high-protein feed consisting of 90% of the bean flaps is collected in the chaff collector. By collecting the most valuable components of the soybean crop, i.e beans and chaff, and embedding the crushed plant stems on the small depth by disking or cultivation, the task of creating conditions for the growth and development of plants in the crop rotation with full mechanized technology of soybean harvesting is solved.

1. Introduction

The Amur region, where the Federal Scientific Center «All-Russian Scientific Research Institute of Soybean» is located, has a great potential for the production and propagation of varietal soybean seeds with high stability, productivity and product quality [1]. Scientists and employees of the state institution have created a regulatory legal framework for the development of soybean seed selection, production and reproduction [2].

Along with certain achievements, there are also some problems. The analysis of the machine and tractor fleet showed that specialized equipment for soybeans harvesting is not produced, and the combines used for their harvesting have a high degree of mechanical damage. The crushing of hopper soybeans by combines of various brands [3] ranges from 6.9 to 15.1%. Modern new combines of Russian and foreign production are mainly single-drum ones by design and collect the threshed soybeans in one hopper, while not separating biologically different quality seeds [4]. Soybeans in terms of the physical and mechanical properties and their biological characteristics differ significantly from the crops of the grain group [5], which should be taken into account when improving grain harvesters. The dimensions of soybeans in width and thickness are twice as large as grain crops; when threshed, they are significantly crushed and destroyed; soybeans are characterized by biological diversity of seeds, due to different
flowering periods, bean formation and maturation on the plant. Soybeans beginning to grow early have the increased growth energy, germination, productivity, and absolute mass [6]. Single-drum combines, with a hard mode of threshing and increased dynamic impact on plants and beans, crush this high-quality grain, mix it with the rest of the threshed grain and collect it in a single hopper [7, 8]. The harvesters are equipped with crushers and the technology of harvesting soybeans is based on crushing and spreading of straw and throwing out of the chaff.

Soy chaff, consisting of 90 % of the leaves of soybeans with a high content of digestible protein, fat and carotene, is an important factor in increasing the productivity of livestock; to provide public and private livestock feed, devices are needed for its collection and transportation to livestock complexes.

It is possible to increase the efficiency of soybean harvesting on the basis of technology of development of devices which will allow for the combine to obtain high-quality seeds, use them for sowing without conditioning, have additional harvesting of protein from the chaff for feeding animals, crush and spread the straw to create conditions for the growth and development of plants (figure 1).

**Figure 1.** Classification of developed soybean harvesting technologies.

The main task of the experimental combine is to fully harvest the entire crop per unit area of the field, to obtain biologically valuable and high-quality seeds of the first fraction, to use them for sowing without additional processing. The economic component is the criterion for evaluating this technological system; it consists in identifying the quality of seeds, the amount of increase in their yield on average for the two fractions obtained, in the additional collection of protein from the feed chaff and the creation of conditions for the growth and development of plants, embedding of crushed stems in the upper layers of the soil and replenishing the humus balance to its optimal state for the crop.

2. Experimental methods

The quality of the work of the improved harvesting machine was identified when soybeans of the October 70 variety on the territory of the Federal State Unitary Enterprise «Sadovoye» of the Amur region were harvested. By the time of harvesting beginning, the contamination of soybean crops was characterized as low. The weight of weeds from the total weight of plants on the root was 5.1%, the moisture content of seeds and straw impurities was 9.4 and 15.7 %. The density of soybean stalks was 52.6 units per 1 m². The grain yield on the root during the research was 21.9 c / ha. When conducting research on the improved combine, the speed of rotation of the drums was 330 min⁻¹ for the first drum, and 560 min⁻¹ for the second one. The ratio of the circumferential speed of the beaters of the first drum to the second one was consistently changed: \( \frac{V_2}{V_1} = 12.5 / 18.3; 11.0 / 16.8; 9.6 / 15.4; 8.1 / 13.9 \) and 6.9/13.9 m/s. In this case, the threshing gaps were set to 24/12 mm at the front and back for the first drum and...
18/9 for the second drum, respectively. The air flow velocity in the fan discharge duct was 10.45 m/s. The cleaning operation mode was regulated by setting the fan shaft speed equal to 1400 min⁻¹. The opening of the lip of the upper sieve was 14 mm, of the lower sieve was 9 mm, the extension arm was 17 mm, and the angle of inclination of the extension arm was 15° due to the intensive supply of air flow into the cascade between the transition grate and the upper lip sieve.

The quality of the combine thresher performance was identified by the quality of the hopper grain of the first seed fraction obtained from the first drum and of the second fraction from the other parts of the thresher and returns in straw.

The studies were carried out on a harvesting machine; its design and technological scheme is presented in figure 2 and it includes: an inclined chamber 1, two rasp-bar threshing drums 2 with concaves 3, two spacers 4, an inclined transition grate 5, separating the separation zones of the threshed grain by the first and second threshing drums 2; a roll with a transition grate and a finger rake 6, which ensures the separation of grain from the chaff and sending the grain together with the chaff to the first half of the scalping shoe 7 with a lip sieve and an extension arm from which the cleaned grains fall on the lower screen shoe 8 with a lip sieve; the first grain board 9 which ensures the movement of the cleaned grain into the trough-shaped casing of the horizontal auger 11 with a brush frame of the outer edge of the screw; the fan 10; an inclined belt conveyor with a brush frame around the edges of the belt 12; a separate hopper for collecting biologically valuable seeds 13; a second grain board 14; a horizontal auger 15 in a trough-shaped casing with an elevator; a hopper of return 16, with an independent mechanism for turning on the discharge augers of two hoppers of separated seeds, a straw walker 17, a tailings auger 18 with an elevator; brackets and wooden supports of the roll and an inclined transition grate 19. The straw coming off the straw walker enters a trough-shaped auger with the left and right winding of the screw spiral 21 for removing the crushed straw to the left and right of the sides of the combine. The harvester-stacker chaff collector contains a storage chamber 22 with two hinged sidewalls that pass into the bottom, with the removal of which it is discharged. The upper part of the harvester-stacker is closed by a grid 23.

The cut plants are fed through the inclined chamber 1 and enter the first threshing drum 2, where they are threshed. The grain pile, sifted through the concave 3, enters a roll with a transition grate and a finger rake 6, where it is redistributed into grain and chaff. Then it moves along the roll to the initial part of the first half of the scalping shoe 7 with a lip sieve and an extension arm, where, together with the air flow coming from the fan 10, it is cleaned on the first half of the scalping shoe 7 and lower screen
shoe 8 with lip sieves. The separated grain on the first half of the lower screen shoe 8 falls on the first grain board 9 installed obliquely on the combine. Rolling down, the grain is collected in a trough-shaped casing of a horizontal auger 11 with a brush frame of the outer edge of the screw and moves to an inclined belt conveyor 12 with a brush frame of the edges of the tape, from where it enters the first seed hopper 13.

The mass remaining after threshing by the first threshing drum is moved by the spacer 4 to the second threshing drum 2 where it has finish threshing. The soybean grain threshed on the second drum is separated from the chaff through the concave 3 and moved by an additional transition board 5 to the second half of the scalping shoe 7 and lower 8 screen shoe of the combine. There, the mass of seeds is cleaned, blown by the air flow from the fan 10 and enters the obliquely installed second grain board 14, along which it moves and is collected in the trough-shaped casing of the horizontal auger 15 with an elevator, with the help of which the second seed hopper 16 is filled. Straw after the second threshing drum of the combine with a spacer 4 is thrown onto the straw walker 17; not threshed spikes or beans coming off the extension arm of the scalping shoe are collected in the spike auger 18 and the auger with the elevator 15 send them to finish threshing. The soy straw coming off the straw walker enters the trough-shaped distribution casing of the auger 20 with the left and right winding of the spiral of the harvester-stacker.

3. Results and discussion
It is established that soybean seeds are threshed and separated most intensively in the front threshing and separating part of the two-phase threshing combine. In the zone of the first threshing drum, when they are sent to the threshing machine of 1.6 to 4.9 kg/s, the separation is from 88.5 to 70.8% of the seeds, while the separation of straw impurities increases by 2-3%.

The device for separate collection of seeds with two-line cleaning threshes due to the beaters and sifts through the concave of the first threshing drum up to 70% of the entire threshed mass. With the further movement of the layer of the threshed mass through the second threshing drum, the rest of the threshed seeds is threshed and separated through the concave. The increase of the length of the lip sieves to 70 mm reduces the content of weed impurities in the cleaned grain.

Studies of the combine harvester, collecting high-quality seeds in a separate hopper, have shown that up to 60% of biologically valuable and high-quality seeds are allocated to the first fraction. The purity of the seeds of this fraction is 98.2%, which is 1.0-1.2% higher than the purity of the hopper grain (table 1).

The content of crushed seeds of the first fraction is 1.94%, of the second 7.3%, and in the hopper grain of the standard combine, the crushing was 8.3%. The micro-damage of the first fraction was 3.62, of the second 8.1 and of the hopper grain it was 7.95%.

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

The total loss of grain in straw was 0.34% and was 1.4 times lower than the total loss for the standard combine.

Table 1. Obtaining high-quality soybean seeds during harvesting.

| Indicators                  | First seed fraction | Second seed fraction | Grain of standard cleaning in the standard combine |
|-----------------------------|---------------------|----------------------|---------------------------------------------------|
| Seeds separation, %         | 60                  | 40                   | 100                                               |
| Seeds purity, %             | 98.2                | 96.3                 | 97.0                                              |
| Crushing, %                 | 1.94                | 7.3                  | 8.3                                               |
| Micro-damage, %             | 3.62                | 8.1                  | 7.95                                              |
| The content of unripe seeds | 1.43                | 5.4                  | 5.0                                               |
The weight of 1000 seeds, g  
156.3  151.6  154.2
Moisture content, %  
9.4  10.3  9.8
Laboratory / field germination, %  
96.0 / 91.5  86.3 / 77.8  86.5
Average yield, t / ha  
1.89  1.55  1.59

The main indicators by which the class is established are the germination and purity of seeds. Evaluating soybean seeds of the first fraction, it should be noted that by all sowing quality indicators, they can be attributed to the second class of the state standard. The content of seeds of the main crop in the first fraction is 96.6%, and according to GOST (All-Union State Standard) it is not less than 95%. Laboratory and field germination rates are 96 and 91.5%, and these indicators correspond to GOST seeds of the first class. The selected seeds contain crushing, which is 4.25 times less than the content of crushed hopper grain obtained when harvesting soybeans by combine harvesters without the proposed device. The use of the first seed fraction on sowing without additional cleaning, which corresponds to the indicators of the seeds of the first and second sowing classes, allows saving the whole grain from damage during cleaning by the sowing machine. This technology of obtaining high-quality seeds reduces the material costs for cleaning and preparing seeds, increases the value of the soybean crop by 3.0 c / ha and provides high profits to farms.

According to the data of the soybean harvest for about 10 years, the biological yield of straw and chaff to soybean grain was 68.5, and of chaff 49%.

To experimentally determine the optimal volume of harvester-stacker for chaff collection, depending on the soybean yield, the speed of the combine and the width of the header, a multivariate experiment was conducted and a regression equation was compiled:

\[ Y = -1.7067 + 0.5Y + 4.68V + 1.7174B + 0.8VB - 2.761V^2 \]

In order to analyze the paired influence of factors on the optimization criterion (the chaff getting into the harvester-stacker), the response surfaces are constructed from two factors: the speed of the combine and the width of the header. At a constant level of yield there is \( Y = 1.75 \) t / ha, with varying speed of the combine and yield and a constant width of the header there is \( B = 7 \) m, with varying yield and width of the header and at a constant speed of the combine there is \( V = 1.7 \) m/s (figure 3 a, b, c).

[Figure 3. The response surface \( Y = f(B, V) \) at zero level \( Y \). a) \( Y = -0.8317 + 4.68V + 1.7174B + 0.8VB - 2.761V^2 \), b) \( Y = 10.31 + 10.28V + 0.5Y - 2.761V^2 \), c) \( Y = 0.5Y + 3.077B - 1.7307 \).]
On the basis of the conducted studies, 4.5 m$^3$ is the volume of the harvester-stacker, taking into account its optimal parameters of length and width, chaff moisture of 30% and an average length of the rut of fields of 600 m.

4. Conclusion

Effective separation of soybean seeds by quality into the first (seed) and second fractions occurs when a scalping shoe is used with elongated (70 instead of 22 mm) lip sieve blades and overlapped with a roll extension of 300 mm; a long grate board of 500 mm is used for the first production.

The analysis of the biological soybean crop showed that the yield of straw and chaff from 1 m$^2$ of the accounting area to soybean grain is on average 68.5% : 47.8%: 100%. The trough-shaped auger of the harvester-stacker with a diameter of 400 mm, a pitch of 420 mm and an angular speed of 20.93 rad / s provide the removal of up to 3 kg/s of straw to the left and right along the course of the combine, and with a soybean yield of 3.0 t/ha, the optimal volume of the harvester-stacker for collecting the chaff is 4.5 m$^3$.

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