A NEW TECHNICAL SOLUTION OF A HEADER FOR SUNFLOWER HARVESTING
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НОВЕ ТЕХНІЧНЕ РІШЕННЯ ЖАТКИ ДЛЯ ЗБИРАННЯ СОНЯШНИКУ

Nalobina O.O.[1)], Vasylchuk N.V.[2)], Bundza O.Z.[1)], Holotiuk M.V.[1)], Veselovska N.R.[3)], Zoshchuk N.V.[1)] [1]
[1)]National University of Water and Environmental Engineering, Rivne / Ukraine;
[2)]Lutsk National Technical University, Lutsk / Ukraine;
[3)]Vinnytsia National Agrarian University, Vinnytsia / Ukraine
Tel: +380960825360; E-mail: o.z.bundza@nuwm.edu.ua
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ABSTRACT

A number of the current research about the headers of the sunflower harvesting machine have been analysed and the main directions of their implementation are outlined. The design of the improved header is developed, which is designed to reduce the loss of seed and the height of the stubble on the field which remains after the completion of harvesting operations. The results of field research of developed and conducted construction are presented. Directions and fields of further research are outlined.

РЕЗЮМЕ

Проаналізовано ряд чинних досліджень жаток для збирання соняшнику та окреслено основні напрямки їхнього проведення. Представлено конструкцію удосконаленої жатки, яка розроблена з метою забезпечення зменшення втрат насіння та висоти товстостовбурової стерні на полі, яка залишається після виконання збиральних робіт. Викладено результати польових досліджень розробленої та виготовленої конструкції. Окреслено напрямки подальших досліджень.

INTRODUCTION

Sunflower is an annual plant, its name coming from the Greek ‘helios anthos’. It is called a flower of the sun; it is one of the most productive crops. Interest in this culture is increasing due to high cultural adaptability to diverse agro climatic conditions and high quality oil *(Martinez-Force E. et al., 2015)*.

The most powerful sunflower producers in the world today are Ukraine, Turkey, Bulgaria, Romania, Argentina, and Russia (Fig. 1).

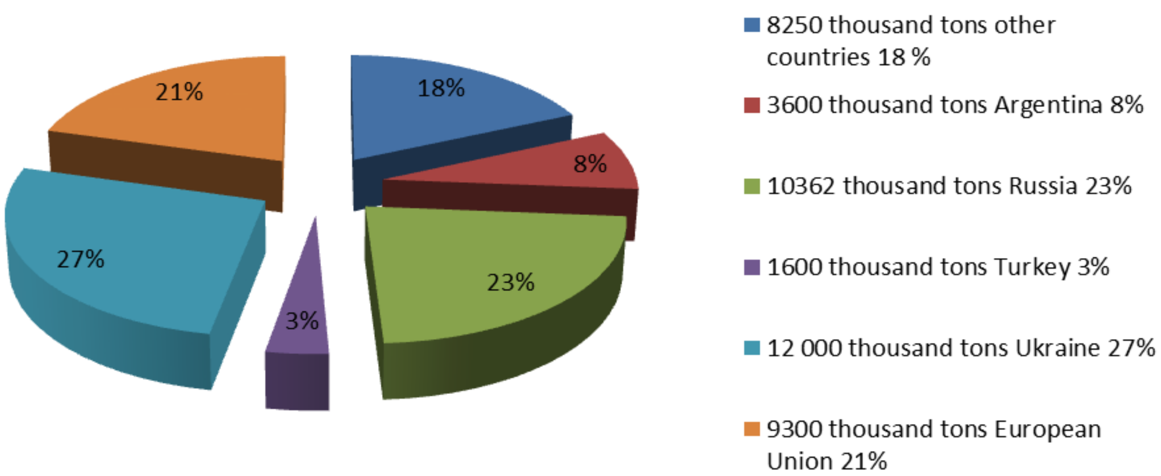

Fig. 1 - Diagram of sunflower seed production

[1)] *Nalobina O.O., Prof. Ph.D. Eng.; Holotiuk M.V., Ph.D. Eng.; Bundza O.Z., Ph.D. Eng.; Zoshchuk N.V., Ph.D. Eng.; Vasylchuk N.V.; Veselovska N.R., Prof. Ph.D. Eng.*

In Ukraine, in particular, over the past ten years the area under cultivation has grown by almost 60% (Fig. 2).

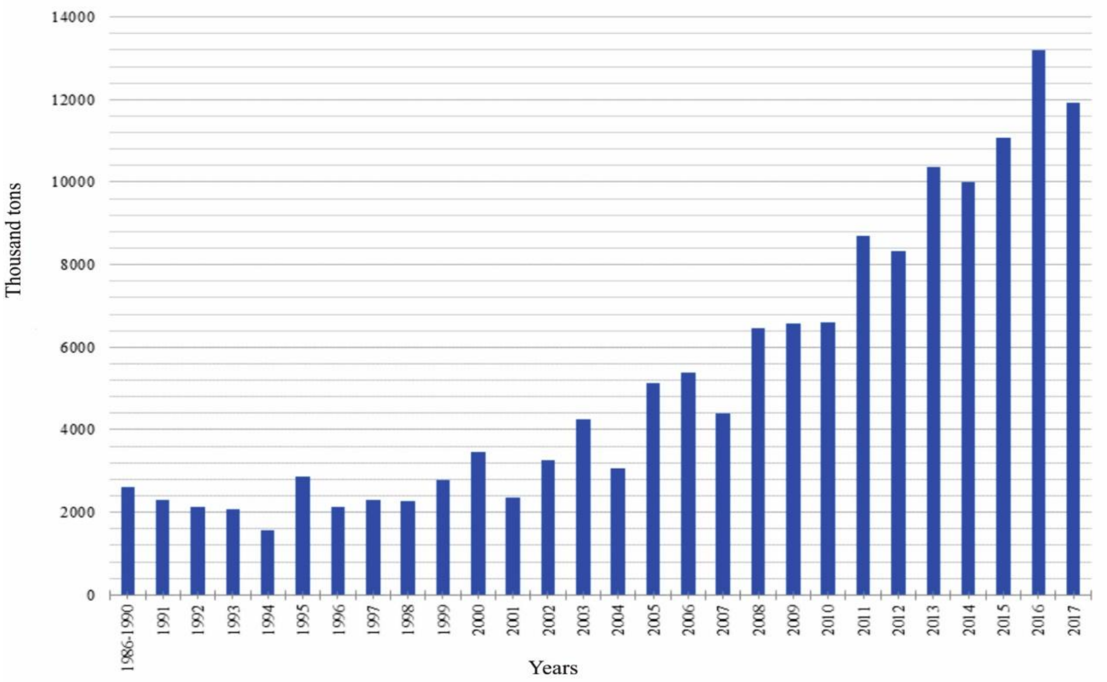

Fig. 2 - Dynamics of sunflower production in Ukraine

An important technological process for the cultivation of sunflower is harvesting. For the harvesting of sunflower grain harvesters with adaptations are used ('Sun Plant' PZN-9,4, PSP-1,5M, PS-4, PS-5, PS-6, PSP-10, PZS-8, KMS-8, CCD -12-45-01, etc.).

In order to ensure the high quality of the harvesting process, it is necessary to reduce the losses due to the peculiarities of the harvester structures, the falling of the calathidia with long stem remnants into the threshing apparatus that leads to the clogging of the deck, decreasing its passage section and, as a result, leads to seed traumatism *(Skorik Dragan, 1992)*.

In addition, after harvesting there are relatively strong sunflower stems on the field, which complicate the preparation of the field until the next growing season (Fig. 3).

Vegetable sunflower wastes after harvesting require shredding and digging them in the soil for the purpose of their rapid decomposition and prevention of disease development. Thus, after-harvesting involves the use of additional equipment. For this purpose, disc harrows, toothed rotors, cutters are used. Additional damage to the upper layer of the soil contributes to the development of water and wind erosion. After harvesting, additional energy and human resources are required.

To eliminate this disadvantage, the technology of No-till farming has become widely used - a system of zero tillage, which is now gaining popularity in Ukraine. The main principle of the system is the use of natural processes that occur in the soil. Application of this technology to farms growing sunflower is hampered by reasons of operational nature such as the life of tires and caterpillars of agricultural machines is significantly reduced due to the rigors of rigid high stubble *(Nalobina et al., 2018)*.

Popov (2012) is dedicated to the study of sunflower seeds harvesting process. Also *Startsev and Popov (2011); Startsev (2017); Kukhmazov and Fedorov (2013), Shaforostov et al., (2007); Hunt (2001); Chancellor and Cervilka (1975); Nyborg et al., (2018); Nalobina et al., (2016)* and others.

In the works by *Startsev and Popov (2011); Kukhmazov and Fedorov (2013)* the analysis of losses that appear during sunflower harvesting is described. In particular, the authors consider the influence of the working bodies' regime parameters on the loss of seeds. The analysis of all types of losses that appear during sunflower harvesting process is performed. Their classification by quantitative indicator is made.

A significant number of well-known researches are aimed at developing and improving working bodies for sunflower harvesting in order to reduce crop losses. In particular, in the work of *Shaforostov et al., (2007)* presents the results of studies by authors on the creation of a header for sunflower harvesting with screw conveyors for feeding the stems to the cutting unit. The authors developed screw feeding equipment with a variable step of winding. As a result of the field trials, it was established that the header, equipped with an auger with an adjusted step, provides a reliable process, better stem selection, eliminates dynamic effects, which provides high qualitative parameters of the process.

Popov (2012) proposed a constructive solution of the screw-reel for sunflower harvesting. The author presented the results of theoretical analysis of a screw-motor design and the derivation of the equation of its rotation.

Startsev (2017) developed the design of a screw-feeder based on the concept of taking into account the physico-mechanical properties and geometric features of crops to be harvested during the design of harvesting machines. The author proposes to improve the design of an auger due to the installation of the G-shaped cut-off devices. The equation of the dependence of the seed loss on the acceleration of the collision of the calathidium and the sunflower stem with the working parts of the rope was obtained. It was established that losses decreased by 15% with reducing the diameter of the rotor shaft from 0.5 m to 0.32 m.

The quality of sunflower collecting process implementation, which is estimated by the size of the losses of the uncut calathidia, cut-off calathidia, and seeds, affects not only the design of the headers working bodies, but also the kinematic parameters, in particular the speed of the combine harvester with header. It is the analysis of this influence that the work of *Hunt (2001)*; *Chancellor and Cervinka (1975); Nyborg et al., (2018)* is devoted to.

The importance of this parameter was demonstrated by *Hunt (2001).* The author finds that overall losses increase with increasing speed. The growth of losses is directly proportional to the speed and can reach 4% of the total yield at an increase in speed from 3.2 km / h. up to 5.6 km / h.

Chancellor and Cervinka (1975) also investigated the effect of combine speed on the progress of the sunflower harvesting process. The author has proved that the rational speed is 3-5 mph, with lower values recommended for dry seeds (humidity of which is within 13-15%).

The performed analysis of current research has revealed that it can be divided into two directions as:

- research aimed at improving the design of the header to improve the quality of the harvesting process by reducing the damage to the seeds and their losses and shredding the remains of sunflower plants remaining in the field;
- research aimed at optimizing the kinematic parameters, in particular the speed of the harvesting combine.

Taking into account the above, we will formulate the purpose of the work: development of an improved design of a header for the harvesting of sunflower, which provides a reduction in seed losses and a decrease in the height of the long-winding stubble in the field, which remains after the completion of the harvesting operations.

To achieve this goal, the following tasks need to be solved:

- to make the design of the advanced header in accordance with the stated purpose;
- to make and investigate the physical model of the advanced header to prove its ability to work in the field.

MATERIALS AND METHODS

The tasks were solved in several stages:

1. Development of the header design.
2. Making a physical model of the header.
3. Conducting field trials.

The development of an improved header design was carried out based on the principles of morphological analysis. To this end, a morphological table was formed *(Nalobina O., Markova O., Vasylchuk N., 2016)*, the exclusion of variants from which was conducted under the following conditions:

1. Provision of planting sunflower seeds of any height.
2. Securing the cut of sunflower calathidia as close as possible to their base.
3. Avoiding clogging of the moving units with the remains of stems.
4. Reducing seed loss.

The choice of variants of the header constructive execution was carried out by successive exclusion of combinations of two and three variants. Results of the performed morphological analysis and synthesis of the technical object are reflected in the materials of the patent for the utility model "Sunflower harvesting knife" *(Vasylchuk and Nalobina, 2017)*.

The basis of the proposed design is to create a sunflower header that will ensure the harvesting of a culture of any height, shredding the stems and reduce the clogging of the stubble unit moving knots *(Nalobina et al., 2018).*

In fig. 3, a schematic diagram of the sunflower harvesting kit design is provided.

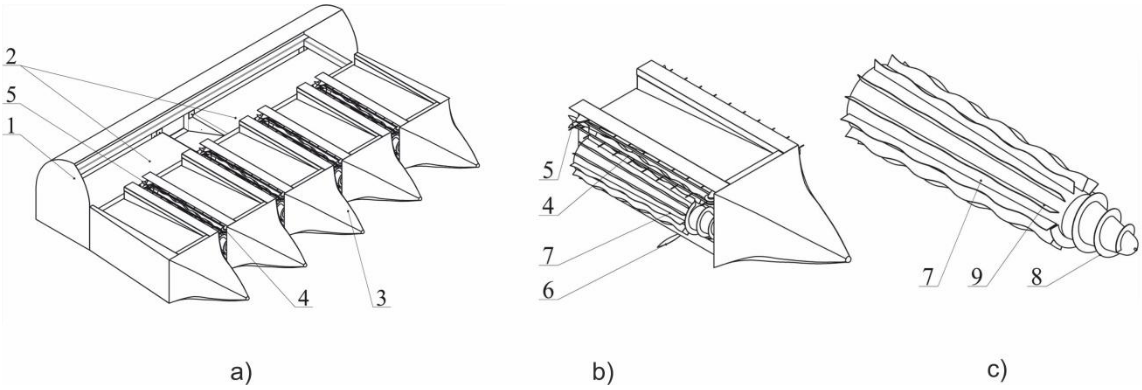

Fig. 3 - Scheme of the header for sunflower harvesting
a – general view of the header; b – lift; c – the rotor

The header consists of a frame *1,* on which two belt conveyors *2* and lifters *3* are placed. Behind the lifters *3,* passes with grips *4,* are located cutters *5,* for cutting the calathidia, cutting knives and shredding of stems, *6* and a tapered rotor *7*, at the beginning of which there are screw turns *8*, and then the surface of the rotor has sinusoidal ridges *9*.

The sunflower harvesting kit works as follows: while the combine is used, the stems of the sunflowers are rejected by the lifters *3* and fall into the area of the passes with the ridges *4,* that move the stems to the rotary knives *6* which cut the stems and to the knives *5* which cut the calathidia. At the same time, screw turns *8* and holds *9* on the rotor *7,* capture the stems and move them down to rotating knives *6*, where they are chopped into pieces. Due to the fact that the rotor 7 is conical, the capture of the lower stems does not occur immediately, while the higher stems fall under the action of seizures from the very beginning. This allows aligning the height of the stems with calathidia. After the calathidia are cut with knives *5*, they hit the belt conveyors *2*, which move them to the main part of the combine.

The proposed design of the header is intended for the harvesting of sunflower of any height, ensuring the cutting of calathidia as close as possible to their base, which will reduce the clogging of the header. It will additionally improve grinding of stems, which in turn eliminates the need for mulch application.

On the basis of the developed construction a physical model of the header was made. The header was aggregated with the CLAAS Lexion 570 combine. The equipment was installed on the Massey Ferguson 1006 sunflower header (Fig. 4).

Fig. 4 - Improved header

Before the research, measurements of the main indicators of sunflower plants (table 1) were made.

Table 1

Characteristics of sunflower stems on the field

Parameter	Years of research	
	2017	2018
Length of the stem, m	1.61±0.29	1.74±0.26
Plant height, m	1.47 ±0.34	1.69±0.38
Height of calathidia location, m	1.25 ±0.26	1.38±0.22

The harvesting was carried out with the upgraded header and the Massey Ferguson 1006 header. The list of parameters that were key subjects to change during the research is shown in table. 2.

Table 2

Name of regulated parameters

Name and units of measurement	Value
Speed of the combine, km / h	1.0 – 5.0
Duration of harvesting, days	2.0 – 16.0
Elevation position of elevators above the soil surface, m	0.5 – 0.75

The parameters were chosen based on a primary estimation of the regression relation between the following indicators:

- loss of seeds (Δ_H) – duration of carrying out the harvesting process (t);
- loss of seeds (Δ_H) – speed of combine (V_p) ;
- loss of seeds (Δ_H) – height of elevators over the surface of the soil (h).

The dependencies describing the regression relationship and the corresponding correlation indices are given in table 3.

Table 3

Results of parameters regression evaluation

Regression equation	Randomization factor
$\Delta_H(t)=0.025t^2-0.2509t+2.33$	$R^2=0.916$
$\Delta_H(V_p)=0.144\ V_p^{\ 2}-0.3232\ V_p+0.489$	$R^2=0.9849$
$\Delta_H(V_p)=41.005h-40.543h+12.253$	$R^2=0.9849$

A high randomization coefficient that is close to 1, indicates the reliability of the equations obtained.

Field tests were conducted to evaluate the work of the header proposed design and the definition of rational kinematic and structural parameters. Indicators were used to evaluate the work of the harvesters: seed loss, %; the length of the stem segment which comes with a calathidium for threshing.

On the basis of the experimental data obtained using the Mathcad program, regression equations were obtained that describe the effect of combine speed, duration of harvesting operations and height of lifters installation on the amount of seed loss:

For main header:

$$\Delta_H(t)=1.0253V_p+0.4651t+0.7052h-0.1089V_p\cdot t-0.5162V_p\cdot h-0.3092 \tag{1}$$

where h - height of installer, m.

For the proposed construction of the header:

$$\Delta_H(t)=0.81891V_p+0.4229t+0.53h-0.064V_p\cdot t-0.23V_p\cdot h-0.2071 \tag{2}$$

Surface of response is presented in fig. 5 and fig. 6.

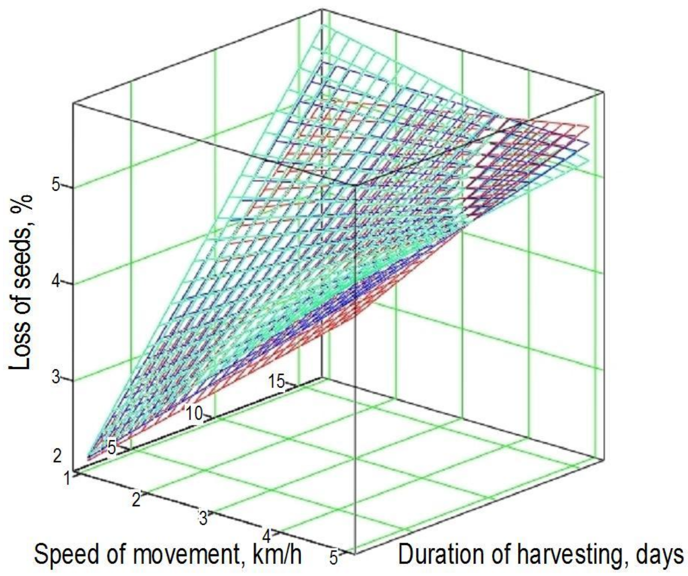

Fig. 5 - Basic header (Massey Ferguson 1006)

1 – h=0.55 m; 2 – h=0.65 m; 3 – h=0.75 m

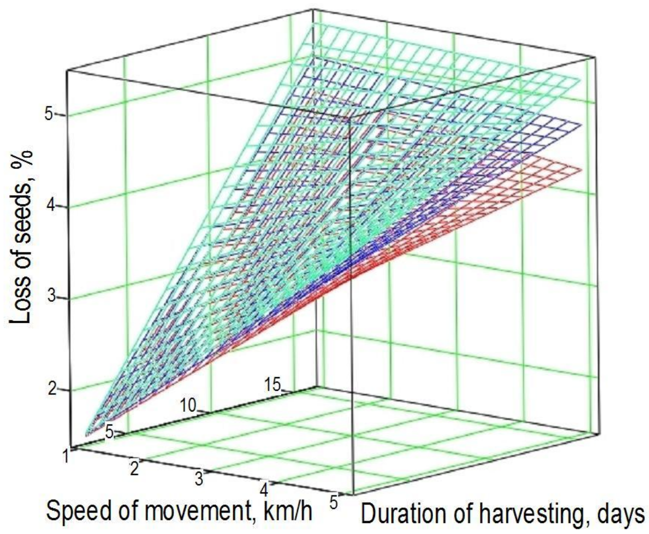

Fig. 6 - Header of the proposed construction

1 – h=0.55 m; 2 – h=0.65 m; 3 – h=0.75 m

The most important factor that functionally characterizes the loss of seeds (figs. 5, 6) is the speed of the harvester. Taking into account the performed calculations (equations (1) and (2)) it is established that the lowest seed losses are provided under the following conditions:

- movement speed $V_p=1.0…2.5$ km/h.;
- height of lifters $h = 0.5…0.7$ m;

Terms of harvesting $t \le 5$ days.

On average, the use of an improved header allowed to reduce seed losses, by 1.4 times.

As mentioned above, to measure the work of the header it is needed to consider the length indicator of the stem segment, which comes with a basket for threshing.

The purpose of determining this indicator is to establish the rational parameters of the rotor 7 (fig. 1) length and angle of inclination to the surface of the soil.

The rotor was made with the length of 0.2 m and 0.4 m. The rotor was installed in two variants as 1 - the rotor axis was located parallel to the surface of the soil; 2- axis of the rotor inclined along the direction of the combine's movement to an angle of 10 degrees (fig. 7). The speed of rotation was constant and it was 300 min^{-1}.

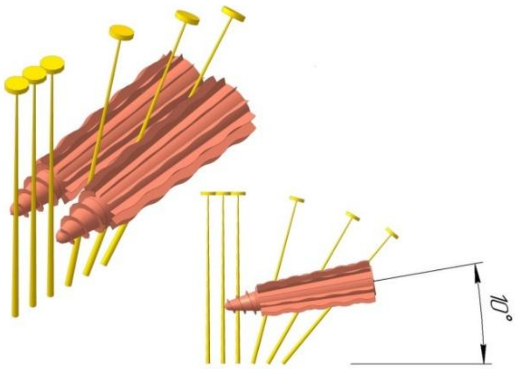

Fig. 7 - Scheme for capturing and transporting stems by rotor

The results of the research are shown in fig. 8.

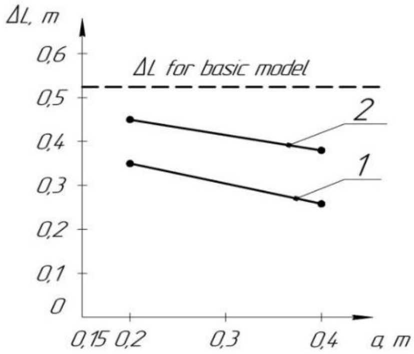

Fig. 8 - Dependence of the length of the stem ΔL with basket reaching a threshing wheel on the length of the rotor a and the angle of its inclination to the surface of the soil
1 – the axis of the rotor inclined at an angle of 10 degrees; 2 – axis rotor

Comparison of the obtained results showed that in order to minimize the length of the stem of the calathidium entering the threshing mechanism, it is expedient to use a 0.4 meter long rotor and set it at an angle of 10 degrees to the soil surface. The analysis of the cut off plants that entered the range of the reel saw that the application of the proposed design allowed reducing the length of the stem with the calathidium, on average, by 31.6% compared to the control plants (stems with baskets that reached the reel area from the channels of the basic design header).

RESULTS

Taking into consideration the increase in sunflower seeds harvesting in Ukraine and the need to address the application problems associated with ensuring the high quality of the harvesting process, it can be argued that scientific and experimental research aimed at finding technical solutions that will contribute to reducing losses of seeds, eliminating the problem of frequent hammering; reducing the height of the stubble. The proposed construction of a header for sunflower harvesting is promising in terms of solving the above mentioned problems. It has been established that during sunflower harvesting, a harvester must move along the field at the speed *Vp = 1.0-2.5 km / h;* lifters are installed at the height of *h = 0.5-0.70 m*; the terms of the harvesting work are *t ≤ 5* days.

The rotor, equipped with an improved header, is *0.4 m* long and is installed with an inclination of its axis to the soil surface at an angle of 10 degrees. The fulfilment of these conditions allowed to reduce the loss of seeds on average by *1.4* times and reduce the length of the stem with a calathidium on average by *31.6%* compared with the control plants (stems with calathidia entering the reel area from the channels of the basic design header).

CONCLUSIONS

Taking into account the increase in sunflower seeds sown in Ukraine and the need to address the application problems associated with ensuring the high quality of its harvesting process. It can be argued that scientific and experimental research aimed at searching technical solutions will contribute to reduce losses, eliminate the problem of frequent hammering, and reduce the height of the stubble.

The proposed construction of a header for sunflower harvesting is promising in terms of solving the above mentioned problems. As the results of field trials of the proposed design have been revealed, further research should be directed to:

- determination of the influence of proposed header design parameters on sunflower seeds loss;
- elimination of the revealed defect of the design which is in drive mechanism of the rotors (rotor drive, which is located in the front of the combine, contains an open cone gear).

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