Bulgarian Journal of Agricultural Science, 30 (No 3) 2024, 539–546

Pulling device for harvesting of Oleaginous Flax

Volodymyr Didukh[1], Svitlana Yaheliuk[2*], Volodymyr Bodak[1], Maksym Bodak[1] and Olexandr Yaheliuk[1]

[1] *Lutsk National Technical University, Department of Agricultural Engineering, 43018, Lutsk, Volyn region, Ukraine*
[2] *Lutsk National Technical University, Department of Commodity Research and Expertise Customs, 43018, Lutsk, Volyn region, Ukraine*
[*]*Corresponding author:* cler2010@gmail.com

Abstract

Didukh, V., Yaheliuk, S., Bodak, V., Bodak, M. & Yaheliuk, O. (2024). Pulling device for harvesting of Oleaginous Flax. *Bulg. J. Agric. Sci., 30*(3), 539–546

Oleaginous Flax is harvested using direct combining to obtain seeds. During this process – Stem-Fiber Mass (SFM) is disposed of by incineration or shredding. Both cases are harmful to the environment. With a sufficient amount of moisture and heat, a short non-oriented fiber is formed in a stem. The fiber creates a problem in the operation of the cutting device of the harvester. Especially, when harvesting *Oleaginous Flax* in the phase of full ripeness, when the fiber has strengthened and the woody part has turned into a shives. Thus, it is possible to save the grown crop by pulling the stems. Well-known technical means of pulling flax stems have a small width of grip, which affects their productivity. The solution to the problem lies in the creation of the harvesting working bodies, taking into account the width of the harvester. Such a device, when installed on the harvesting part of the combine, should not disturb its structure. As a section of the working body, a pair of rollers of the appropriate geometric shape, rotating towards each other, is offered. The technological process of stem pulling involves capturing a certain number of stems with rotating surfaces and clamping them in the space between the surfaces. Superimposition of surface rotation speeds and forward speed of the grain harvester helps pull the stems out of the soil. This approach makes it possible to preserve the grown crop of Oleaginous Flax and create prerequisites for the use of the SFM.

Keywords: Oleaginous Flax; harvester; pulling device; rollers; stem
Abbreviations: SFM – Stem-Fiber Mass

Introduction

There is a shortage of flax products from seeds and natural fibers on the world market. The raw material for the production of goods of various applications is flax – *Textile Flax* and *Oleaginous Flax*. Organic raw materials deserve special attention. Then the number of industries that need it increases sharply. The main productive component of *Oleaginous Flax* is oil. It is widely used in medicine, soap making, perfumery, food, paint, and automobile and aviation industries. No less important raw material of *Oleaginous Flax* is SFM, which contains up to 25% fiber (Ouagne et al., 2017). Short non-oriented fiber is used in the textile industry, in the production of paper and composite materials. The energy potential of *Oleaginous Flax* stems is equal to the energy potential of hard tree species and is 18 MJ/kg. Their use as fuel materials has been proven (Yaheliuk et al., 2020). There is research on the creation of new organic fertilizers with the inclusion of fiber (Tretjakova et al., 2018). But, currently, insufficient attention is paid to the use of *Oleaginous Flax* pulp (Dudarev & Say, 2020). Today, Oleaginous Flax occupies more than 3.5 million hectares of cultivated land in the world. The main countries that grow Oleaginous Flax are the USA (1 360 000 ha), Canada (812 000 ha), India (930 000 ha). Accordingly, the world leaders of seed production form the price (FAOSTAT, n.d., 2021) Under such conditions, Ukraine cannot compete in the cultivation of *Oleaginous Flax.* Despite the fact that *Oleaginous Flax* is considered a niche crop for agro-industrial production, the cultivation area has gradually decreased to 10 000 hectares **(**Rudik, 2020). Global warming has changed the temperature conditions for growing crops. They contribute to the formation of high-quality fiber in the stems. Despite the fact that linseed is considered a drought-resistant crop, it requires a significant amount of water. Therefore, in the North of the country, it is possible to obtain a seed yield of 12 to 25 t/ha and SFM of up to 45 t/ha and, the preservation and use of the entire harvest, can significantly increase the efficiency of growing *Oleaginous Flax* (Didukh et al., 2022).

Oleaginous Flax can be collected both in a direct and two-phase way. The choice of harvesting method depends on the ripeness of the crop and the weediness of the field. Direct harvesting of linseed is carried out on weed-free crops. As a rule, desiccation is carried out 3-4 days before harvesting. Then, in addition to accelerating the maturation of the main crop, weeds are dried. Direct harvesting is carried out at a seed moisture content of no higher than 15-16%. How climatic conditions affect the harvesting of grain crops was studied (Alsharifi et al., 2017). The improvement of grain harvesters was considered (Hamzah et al., 2020). However, the conditions for using a combine harvester for harvesting *Oleaginous Flax* are significantly different from harvesting other agricultural crops. Special attention is paid to the cutting apparatus when preparing for harvesting. It should not have worn out segments and counter-cutting plates on the fingers. Carefully adjust the stroke of the knife and set the appropriate clearances. Reinforced segments must be used. In the case of a two-phase method, mowing in the windrows is carried out at a seed moisture content of 25-35%, when 50-70% of the pods have already turned brown. There is mowing height – 12-14 cm. At this cutting height, the stubble easily supports the weight of the swath; the swath dries quickly and evenly. After drying (after 5-7 days) and reducing the moisture content of the seeds to 12%, the swaths are threshed (Didukh et al., 2022).

When using the combing harvesting technology, the seeds are released at the root without cutting the stems (Wendel, 2004). At the same time, straw does not enter the threshing machine, does not succumb to beating and does not create difficulties when separating seeds on a straw shaker. The stem remains undamaged in the field and can be removed if necessary not only by mowing in a swath, but also by harvesting with the help of flax harvesters. This principle did not spread during the harvesting of *Oleaginous Flax* in climatic conditions with increased environmental humidity.

To collect *Textile Flax*, a pulling method is used, according to which the stams are placed on the field with a tape for conversion into trust (retted straw), which determines the productivity of the traction machines. Well-known pulling machine are made by Dehondt, Depoortere, Fontanecany, Van de Bild companies. To increase productivity, such machines provide simultaneous stacking of two tapes in parallel. Pulling devices are intended for pulling out the stems of *Textile Flax* from the soil. Depending on the design of the working elements of the devices, they are divided into tape roller and tape drum (tape disc) machines. The working bodies of the pulling devices are made in the form of rollers, clamping belts. The most complete classification of measuring devices is presented in the monograph (Dudarev, 2015). Among the specified working bodies, the rollers are not fully researched. At the same time, their design makes it possible to create a device as a wide-grip harvesting device for installation on the harvesting part of a grain harvester.

The research was carried out with the aim of establishing rational parameters of a pair of rollers as the main working element to ensure pulling of *Oleaginous Flax* by stems, especially in the phase of full ripeness, by creating conditions for clamping a group of stems in the inter-roller space. The results of the research are aimed at the development of a wide-grip device for a grain harvester and the improvement of existing technologies for harvesting *Oleaginous Flax*.

Materials and Methods

Field studies with different varieties were used to identify the prospects for the implementation of the method of harvesting *Oleaginous Flax*, which under production conditions produce 20-25 t/ha of seeds and up to 45 t/ha of stems. The most common for growing seeds in the conditions of North – Western Polissia was the Liryna variety of the German breeding company DSV.

In the process of conducting research, the following varieties were also used: Iceberg, Orpheus, Pivdenna Nich, Sonechny (Onyuh et al., 2016). The formation of fiber in the stems of *Oleaginous Flax* depends on the variety, the method of sowing, the predecessor cultures and the natural and climatic conditions of the region during the current growing season. In addition, when conducting experiments, the condition of the soil was taken into account (Table 1).

In the studies, changes in the stem growth of *Oleaginous Flax* depending on the meteorological conditions of the growing season were noted; stem height measurements were carried out in different phases of plant development. After maturing, the fiber content and quality of the trusts

Table 1. Indicators of the soil condition before laying experiments

Soil conditions	Soil type	pH	Nutrient content			
			Hummus, %	Nitrogen, mg/100g soil	Phosphorus mg/100g of soil	Potassiu, mg/100 g of soil
1	Turf-medium – podzolic clayey-sandy	5.80	1.4	7.42	15.45	9.40
2	Black soil is gilded	6.67	1.7	9.50	34.83	14.30

a b c d

Fig. 1. Experiments to determine the force of pulling stems in field conditions:
a) installation scheme: 1 – frame, 2 – support surface, 3 – clamp, 4 – dynamometer; b) application of force at an angle of 45° with the support surface; c) applying effort under 30°; d) application of force under 90° without a support surface

were determined by plotting stack diagrams. As the results showed, all varieties have a high fiber content, which affects the choice of technology and technical means for harvesting oilseed flax. The presence of fiber in the petioles of the stems was noted, which complicates the cutting process if they are overripe.

Therefore, one of the ways to increase the efficiency of harvesting *Oleaginous Flax* in the phase of full ripeness, when short non-oriented fibers are formed in the stems, there is a need to extract them from the soil. Since the force holding the stem in the soil depends on its composition and humidity, it is variable and required experimental verification. At the same time, the ripeness phase of *Oleaginous Flax* is also important, as it affects the root system. In the phase of full ripeness, the root system loses its connection with the soil, and its moisture becomes the defining indicator of the selection effort.

The method of conducting the experiment involves fixing one stem, five and ten stems of *Oleaginous Flax* at three different heights, but no higher than 500 mm from the field surface (Figure 1).

Experiments were also conducted with cylindrical support surfaces, which are necessary for fixing the stem in a certain position when removing it from the soil.

In the process of conducting research, it was found that the main factors determining the effort of stem pulling are the environment in which the stem grows: soil moisture and its mechanical composition and the shape of the rhizome (Table 2).

Simulation of the process of pulling stems in laboratory conditions was carried out in a soil channel (Figure 2a). The working elements of the installation are a pair of rollers (Figure 2b), which rotate towards each other due to crown engagement. The absence of a gap between the rollers in the zone of crown engagement is achieved by the fastening parts of the supports, which ensure their connection to the platform. The speed of rotation of the drive sprocket is provided by an electric motor with the ability to change revolutions.

This installation makes it possible to study the pulling of *Oleaginous Flax* stems depending on the following factors:

– soil resistance (harvesting force), which depends on the simultaneous capture of stems by rollers within 1-10 and soil conditions; the height of the roller axes relative to the field surface;

– the speed of movement of the rollers in the direction of pulling stems (speed of movement of the unit);

– roller rotation frequency (provided by an additional attached motor);

– by the coefficient of friction of the stems to the surface of the rollers (humidity of the stems).

Discarding the last two as the least significant in influencing the pulling quality, the following factors were used in the creation of the mathematical model: pulling effort (X_1), the height of the axes of rotation of the rollers (X_2) and the

Table 2. Results of the average value of the effort of pulling stems in the field during the 2021 harvest season between the early yellow and full ripeness phases

Number of stems	Angle of force application, α_0, deg.	The effort of pulling, $P_{бр., Н}$	Number of stems	Angle of force application, α_0, deg.	The effort of pulling, $P_{бр., Н}$
With a support surface d = 250mm			Without support surface		
One stem	0	10	One stem	30	68
	15	45		45	56
	30	38		75	40
	45	48		90	12
Five stems	0	102	Five stems	30	53
	15	138		45	45
	30	156		75	57
	45	145		90	16
Ten stems	0	168	Ten stems	30	30
	15	102		45	42
	30	89		75	61
	45	104		90	23

a b

Fig. 2. Modeling of the process of pulling linseed stems in a soil channel:
a – soil channel; *b* – a pairof rollers

speed of movement of the rollers in the direction of pulling the stems (X_3). In planning the experiment was used a symmetric non-positional Box-Behnken Experimental Design (Aziz & Aziz, 2018). In order to implement a three-factor experiment up to this plan, it is necessary to conduct 15 experiments.

For the purpose of compiling the factors and levels of variation table (Table 3) we took into account the previous studies results and information available from written sources. The Box-Behnken plan is designed to use three levels for each factor: upper (+1), main (0), and lower (-1).

Table 3. Variables and their levels in Box-Behnken Design

Levels of variation	X_1 – pulling effort P, Н	X_2 – the height of the roller axes relative to the field surface H, м	X_3 – the speed of movement of the rollers in the direction of harvesting the stems V, м/с
Upper (+1)	168	0.5	2.16
Main (0)	89	0.3	1.26
Lower (-1)	10	0.1	0.36
Range of variation	79	0.2	0.90

The experiment planning matrix is presented in Table 4 in a coded form. The order of experiments was established using a table of random numbers. The response function (Pulling efficiency) in the area of factor, space is presented as a nonlinear regression equation (1):

$$Y_i = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_{12}X_1X_2 + b_{13}X_1X_3 + \\ + b_{23}X_2X_3 + b_{11}X_1^2 + b_{22}X_2^2 + b_{33}X_3^2 \quad (1)$$

The obtained data were processed using the developed program in the Mathcad.-2015 environment. The experiment made it possible to obtain a mathematical model that describes the process of pulling *Oleaginous Flax* stems using a pair of rollers depending on the given parameters: pulling effort, the height of the rollers' rotation axes above the field surface, and the speed of movement of the rollers in the direction of pulling the stems. The feedback function is the cleanliness of pulling (purely picked stems with roots, broken stems were considered unpicked).

Table 4. Design of experiment

Run	The effort of pulling P, H	The height of the roller axes relative to the field surface H, м	The speed of movement of rollers in the direction of pulling stems V, м/с
1	-1	-1	0
2	-1	1	0
3	1	-1	0
4	1	1	0
5	-1	0	-1
6	-1	0	1
7	1	0	-1
8	1	0	1
9	0	-1	-1
10	0	-1	1
11	0	1	-1
12	0	1	1
13	0	0	0
14	0	0	0
15	0	0	0

Results and Discussion

The effective operation of the stem pulling mechanism will be ensured taking into account the moment when the root ends of the stems are released from the soil. At the same time, their path is the distance from point B to point A in the direction of the *y* axis (Figure 3).

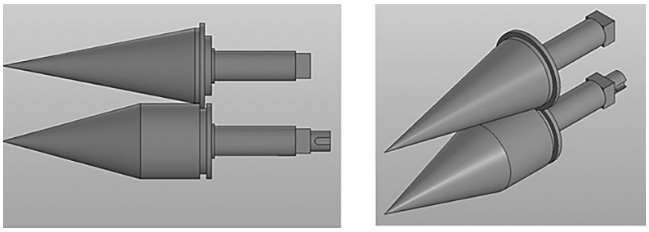
The movement in the vertical direction should be faster than the movement of the grain harvester. After that, the stems are directed to the platform of the harvester by means of a conveyor reel through the support surface.

The condition of pulling stems:

$$\acute{\omega}_1 \geq 2\pi\, V_м / (L_c + L_к),$$

where L_c – the distance from the point of initial contact (creating the pulling force) of the stems with the rollers to the field surface, m; $L_к$ – root length, m; $V_м$ – working speed of the grain harvester, m/s

The corresponding values were obtained as a result of the calculations L_c = 0.05 m, $L_к$ = 0.1 m and the length of the working zone of the rollers l_p =0.032….0.047 m. With the specified parameters and the use of computer simulation, a 3-D model of a pair of rollers was developed (Figure 4). This model served as the basis for the development of a device for pulling flax for a grain harvester.



a b

Fig. 4. General view of a pair of rolle (*a*) and their 3D model (*b*)
Source: authors

As a result of the conducted research, data were obtained (Table 5) on the values of the quality of pulling the stems of *Oleaginous Flax*.

Then, the regression equation to determine change for *Oleaginous Flax* residues elasticity properties is as follows (3):

$$Y(P,H,V) = 106{,}28 - 0.13P - 12.51H - 4.75V + 0.0005P^2 - 24.3H^2 + 1.89V^2, \quad (3)$$

where *P* – the pulling force, *H* – the height of the roller axes relative to the field surface, *V* – the speed of the rollers moving in the direction of stem pulling.

The response surfaces (Figure 5a) and their contour plots (Figure 5b) are constructed using the regression equation (3).

Harvesting Oleaginous Flax in the phase of full ripeness has its own characteristics. Without the use of a roller working body, it is impossible to ensure high pulling quality. The

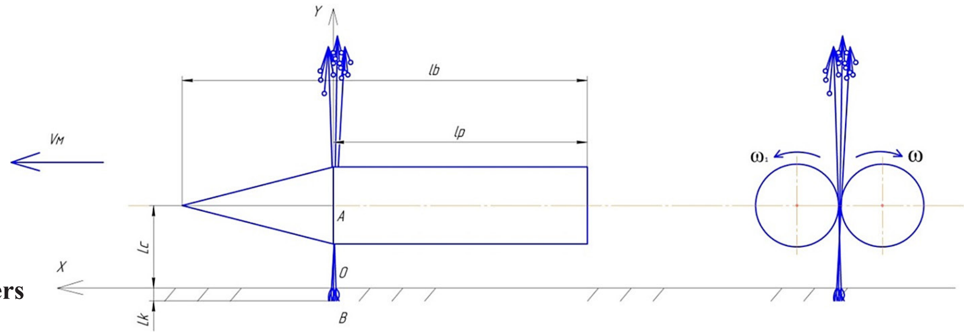


Fig. 3. Basic geometric parameters of a pair of rollers

Table 5. The results of the experiment. Pulling quality

Run	The effort of pulling P, H	The height of the roller axes relative to the field surface H, м	The speed of movement of rollers in the direction of pulling stems V, м/с	Feedback function (purity of pulling) Y, %
1	10	0.1	1.26	99
2	10	0.5	1.26	94
3	168	0.1	1.26	91
4	168	0.5	1.26	82
5	10	0.3	0.36	97
6	10	0.3	2.16	96
7	168	0.3	0.36	91
8	168	0.3	2.16	92
9	89	0.1	0.36	99
10	89	0.1	2.16	96
11	89	0.5	0.36	81
12	89	0.5	2.16	84
13	89	0.3	1.26	91
14	89	0.3	1.26	90
15	89	0.3	1.26	87

drum support surface, which rotates freely on two supports, will allow to reduce the number of broken stems and, accordingly, the loss of seeds. The conducted research made it possible to develop a layout diagram of the device for use as a wide-grip pulling device for installation on a grain harvester (Figure 6).

This construction (Busnyk et al., 2018) it is installed on the body of the harvesting part of the grain harvester and is intended for harvesting the stems of *Oleaginous Flax* of any stage of ripeness. It is attached using an additional support frame. It consists of three main nodes, each of which has its own functional purpose (Figure 7). The total width of the harvesting device is equal to the width of the grip of the header of the basic grain harvester.

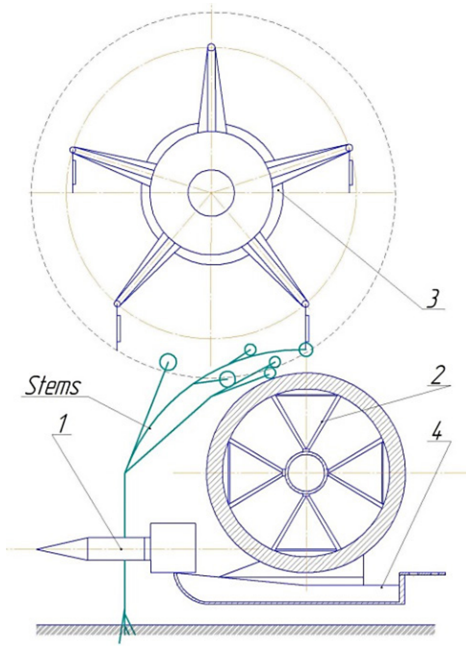


Fig. 6. Layout of the main components of the pulling device for harvesting Oleaginous Flax: *1* – finger pulling device; *2* – support surface; *3* – reel; *4* – seed catcher
Source: authors

The basis of the device for collecting *Oleaginous Flax* installed on the harvester (1) is a pair of rollers (2). At the same time, one of the rollers is the leading roller and the

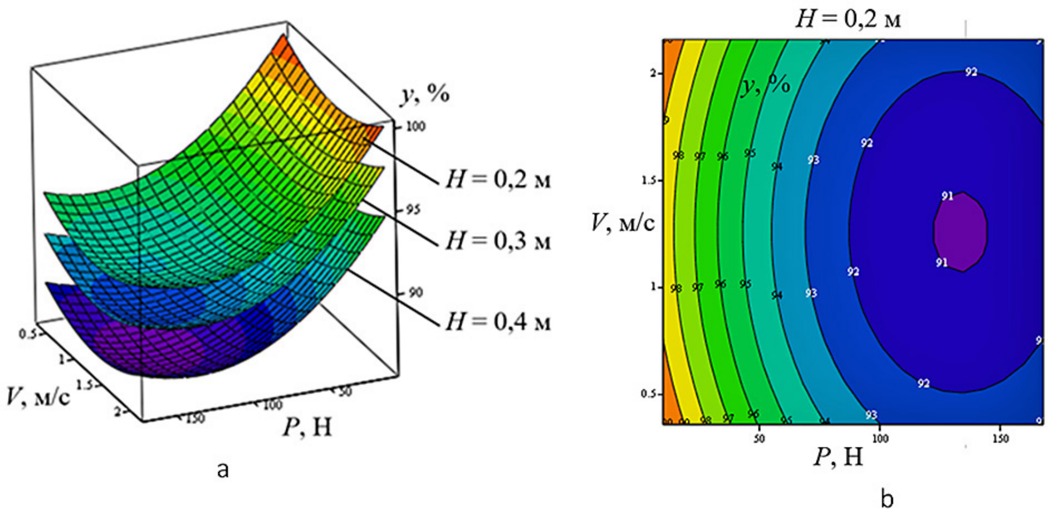


Fig. 5. Response surface(a) and surface section at H = 0.2 m (b)
Source: authors

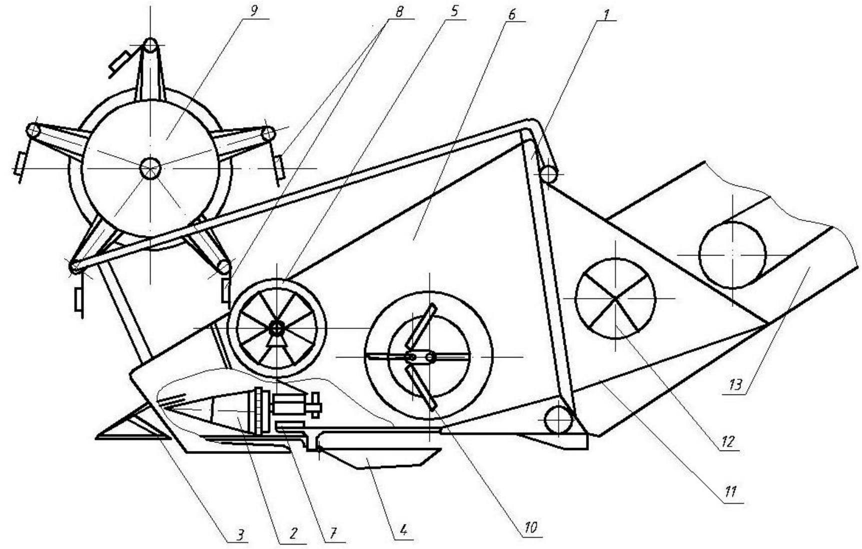


Fig. 7. Structural and layout diagram of the arrangement of the device on the harvester of a grain harvester for harvesting Oleaginous Flax
Source: authors

other is driven. Thus, the number of pairs of rollers should be binate and take into account the width of the harvester. This approach makes it possible to manufacture devices for harvesters of any width by increasing the number of pairs. Making the rollers conical helps to divide the stems into strips or to select stems from one row. If there is a shift in the area where the stems are captured by the rollers, the function of directing the stems is performed by dividers (3). To reduce the height of stem capture relative to the field surface, it is important to provide ski tires on the harvester (4). The leading rollers and the driven rollers are set to rotate towards each other due to crown engagement. The drive of the leading rollers is provided by the systems of the combine harvester. In turn, the cylindrical support surface (5) also has a length corresponding to the grip width of the harvester and rotates freely in two bearing nodes mounted in the side walls (6) of the header (1). All other nodes of the header do not change. At the same time, the segment-finger cutting device does not need to be dismantled, which should be covered with a casing (7). The device for collecting *Oleaginous Flax* works as follows.

During the movement of the grain harvester through the field, the rake (8) of the reel (9) separates the stem portions and presses the stems to the support surface (5). At the same time, the dividers (6) and the rollers (2) separate the stem of the oil flax by the width of the harvester (1) according to the number of pairs of rollers. The conical surfaces of the rollers direct the stems into the space between the leading rollers and the driven rollers. As a result of the rotation of the leading rollers of the driven rollers towards each other, the stems are pulled out of the soil. Due to the forced rotation of the reel (9), the selected stems are directed to the auger (10) of the harvester, which narrows the flow according to the dimensions of the receiving chamber (11) and the beater (12). With the help of the last stems, it enters the threshing apparatus of the grain harvester.

Conclusions

The increased humidity of the environment does not contribute to the efficient operation of the segmental finger cutting device of the grain harvester, especially when harvesting flax in the phase of full ripeness. Conducted studies on the cultivation of *Oleaginous Flax* in field conditions of various varieties in the conditions of the North-Western Polissia indicate the formation of up to 25% of short non-oriented fiber in the stems. It is better to pick such stems from the soil for further use as raw materials. The study of the process of pulling stems in field conditions and its simulation in laboratory conditions made it possible to propose a device for a grain harvester without changing the design of the harvester part.

The obtained results indicate the prospect of using a sampling device with a support surface in the form of a cylindrical drum with a diameter of 250 mm. The supporting surface helps to pull the stems out of the soil in a continuous, uninterrupted flow, regardless of the angle of application of force. At the same time, the main functional purpose of the support surface together with the reel is to create conditions for the effective operation of the pick-up rollers.

With a harvesting width of 4.5 m or more, the recommended height of stem clamping by pairs of rollers should not exceed H = 0.3 m, and the speed of movement of the grain harvester within 0.5–2 m/s. The choice of speed will depend on the state of the stem at the time of harvesting. If during the execution of this process, the broken stems from the root are also taken into account, then the proposed construction of the harvesting apparatus is workable. Studies have shown that with the pulling effort P = 50–70 N (corresponding to the simultaneous pulling of 5–7 stems) and the speed of movement of the rollers in the direction of pulling stems V = 1.26 m/s, the pulling quality approaches 100 percent.

References

Alsharifi, S. K. A., Arabhosseini, A., Kianmeher, M. H. & Kermani, A. M. (2017). Effect of moisture content, clearance, and machine type on some qualitative characterstics of rice on (Tarm Hashemi) cultivar. *Bulg. J. Agric. Sci., 23*(2), 348-355.

Aziz, R. A. & Aziz, S. A. (2018). Application of Box Behnken Design to Optimize the Parameters for Kenaf-Epoxy as Noise Absorber, *IOP Conference Series: Materials Science and Engineering, 454*, 1-11. https://iopscience.iop.org/article/10.1088/1757-899X/454/1/012001/pdf.

Busnyk, V., Didukh, V. & Bodak, M. (2018). Pulling device for collecting oilseed flax. Patent on KM No. 129695. Application. 25.04.2018. Publ. 11/12/2018. No. 21 (Ukr).

Didukh, V., Yaheliuk, S., Artyukh, T., Albota, D. & Goliy, O. (2022). Decrease of elastic properties of Oleaginous Flax residues by decortication. *INMATEH – Agricultural Engineering, 67*(2), 285-292.

Didukh, V., Busnyuk, V. & Bodak, M. (2022). Ustification of the equipment for harvesting oil flax with a combine harvester. *Collection of scientific papers "Central Ukrainian Scientific Bulletin. Technical Sciences", Kropyvnytskyi, 5*(36), 226-235 (Ukr).

Dudarev, I. (2015). Theoretical foundations of modernization of machines for the production of flax: monograph. Lutsk (Ukr).

Dudarev, I. & Say, V. (2020). Development of resource-saving technology of linseed harvesting. *Journal of Natural Fibers*, *17*(9), 1307-1316. DOI: 10.1080/15440478.2018.1558161 (Ukr).

FAOSTAT (n.d.) (2021). Compare Data URL: https://www.fao.org/faostat/en/#compare.

Hamzah, I. J. & Alwan Alsharifi, S. K. (2020). Innovative harvesting methods about the harvest losses for two machines. *Bulg. J. Agric. Sci*., *26*(4), 913–918.

Onyuh, Y., Didukh, V. & Taraimovich, I. (2016). Study of the conditions for growing oilseed flax. *Agricultural Machinery, 34,* 104–111 (Ukr).

Ouagne, P., Barthod – Malat, B., Evon, P., Labonne, L. & Placet, V. (2017). Fibre extraction from Oleaginous Flax for technical textile applications: influence of pre-processing parameters on fibre extraction yield, size distribution and mechanical properties. *Procedia Engineering*, *200,* 213-220.

Rudik, N. (2020). Potential of oil bearing flax production in Ukraine. *Agrosvit, 2*, 61-68 (Ukr).

Tretjakova, R., Martinovs, A., Avisane, M. & Kolcs, G. (2018). Lake blue clay – sapropel – flax shive briquettes for water absorption and desorption. *Agronomy Research, 16(S1),* 12661277. 2018. https://doi.org/10.15159/AR.18.091.

Wendel, C. (2004). Farm Implements & Antiques.- USA: *Krause Publication*, 497.

Yaheliuk, S., Didukh, V., Busnyuk, V., Boyko, G. & Shubalyi, O. (2020). Optimization on efficient combustion process of small-sized fuel rolls made of Oleaginous Flax residues. *INMATEH – Agricultural Engineering, 62*(3), 361–368. DOI: https://doi.org/10.35633/inmateh-62-38.

Received: **February, 05, 2023**; *Approved*: **July, 20, 2023;** *Published:* **June, 2024**