

This paper reports a study of the technological process of grinding plant residues of sunflower and the causal relationships of factors that form the system of quality indicators. The necessary prerequisites for determining rational modes and parameters of the roll crusher have been devised.

A prototype of the roll crusher was designed and fabricated, in which the cutting knives are arranged along the entire width of the grip in a staggered manner, with the possibility to change the angle of inclination to the axis of drum rotation in the range of 5...20°.

It was established that in the case of the right-side arrangement of the cutting edge of knives, the highest total level of the percentage of crushed stems in the range of 101–150 mm with an additional load weighing 800 kg exceeded by 1.58 times the corresponding indicators of the roll with an additional load of 600 kg. The largest overall value of the percentage of crushed stems in the range of 0–200 mm when additionally loading the roll with 800 kg was 1.13 times higher than the corresponding indicators of the roll with an additional load of 600 kg.

In the range of 0–200 mm, with an additional load on the roll of 600 kg, at the left-side arrangement of the cutting edge of the knives of the roll, higher total percentage of crushed stems was observed compared to the right-side arrangement. At a speed of 7.45 km/h, 13.6 km/h, the cumulative value of the percentage of crushed stems exceeded the corresponding indicators at the right-side arrangement of knives by 1.09 times, at the speed of 18.6 km/h – by 1.04 times, at the speed of 22 km/h – by 1.04 times, respectively.

It has been noted that at the left-side arrangement of the cutting edge of the knives of the roll, the percentage of crushed stems in the range of 51–100 mm, with an additional load of 600 kg, exceeded the corresponding indicators with an additional load of 800 kg. At the speed of 10.08 km/h, it was exceeded by 1.9 times; at the speed of 13.6 km/h – by 1.44 times; at the speed of 18.6 km/h – by 1.96 times; at the speed of 22 km/h – by 1.99 times, respectively

Keywords: crushing of sunflower stems, plant residues, processing of plant residues, tillage, roll crusher, grinding quality indicators

UDC 633.522

DOI: 10.15587/1729-4061.2021.244903

DESIGN OF A ROLL CRUSHER FOR SUNFLOWER STEMS AND SUBSTANTIATION OF THE RATIONAL MODES OF ITS OPERATION

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Received date 29.10.2021

Accepted date

Published date

How to Cite: Sheichenko, V., Volskyi, V., Kotsiubanskyi, R., Dnes, V., Shevchuk, M., Bilovod, O., Drozhchana, O. (2021).

Design of a roll crusher for sunflower stems and substantiation of the rational modes of its operation. Eastern-European

Journal of Enterprise Technologies, 6 (1 (114)), 28–37. doi: <https://doi.org/10.15587/1729-4061.2021.244903>

1. Introduction

Technological operations of grinding residues of corn, sunflower, rapeseed, green manure, and a series of other crops are carried out by special machines. The roll crusher in combination with a disc harrow is an extremely effective tool on such an agricultural background. Its action contri-

butes to the grinding, partial wrapping of plant residues, as well as the formation of a well-mulched upper layer of soil. This soil layer is characterized by an agronomically valuable structure. Uniform mixing of plant residues with the soil is also advisable in terms of their rapid decomposition, the formation of favorable conditions for sowing, and preventing early clogging.

It should be noted that climate change significantly affects the expansion of forms, types of pests, and plant diseases. When growing corn, farmers are increasingly experiencing a negative impact on the corn by corn butterfly. The use of chemicals does not solve this problem. As practice shows, corn stem choppers are effective in combating this pest.

A series of agrotechnical requirements are put forward to the quality of grinding of residues of coarse-stem crops, the observance of which is possible only if the dependence of quality indicators on technological parameters is taken into consideration. These conditions are basic when designing new machines and tools.

Scientists are constantly searching for new technical and technological solutions and improving the designs of roll crushers. However, the lack of a general methodology for substantiating the rational technological parameters of both combined machines containing disk rotary tools and roll crushers, as well as roll crushers in the form of a mono tool, leads to further serious miscalculations that arise when designing new ones. Blind copying of other people's technological advancements, which is often observed under modern production conditions, leads to the accumulation of problems and the subsequent use of unreasonable solutions.

The quality of operation of roll crushers largely depends on the correct choice of their rational parameters and operating modes, which are fully determined not only by structural features but also by operating conditions.

Therefore, investigating the mechanism of influence of the physical and mechanical properties of plant material on the quality of its grinding is a prerequisite for substantiation and development of technological parameters of roll crushers and modes of their operation.

2. Literature review and problem statement

The dependence of the quality of roll crusher performance on operating conditions is sometimes so noticeable that there is a need to develop a model range of tools for each soil and climatic zone [1]. A wide range of changes in most properties of plant material, even for the same field, is the cause-and-effect factor that predetermines the quality of operation [2].

The use of special machines, which include roll crushers, is advisable only if they are loaded to the full [3]. It should be noted that in addition to sunflower and corn stubble, it is also advisable to carry out operations of grinding and processing green manure, processing of rapeseed stubble, cereals, etc. [4].

On arable lands of many countries, it is most likely that at the same time as the temperature increases in the summer months, we should expect an increase in the deficit of moisture available to plants in the soil [5]. In such climatic changes, the most urgent issues are related to the maximum accumulation of precipitation during the year and the most rational utilization of moisture in the warm period. This can be achieved by wide implementation of such soil cultivation systems that make it impossible to turn the arable layer annually. Such measures improve the preservation and accumulation of mulch soil surfaces, reduce the speed of movement of the ground layer of air, and contribute to better preservation of moisture accumulated during the autumn-winter period [6].

When mechanically processing stubble of coarse-stem crops, the degree of grinding of stems is an important indicator of the quality of the technological operation [7]. For corn, the evaluation criterion is the number of non-damaged parts of stems

longer than 5 cm, in which corn butterfly pupae can winter. For other cultures, this indicator is not so important [8].

Under such conditions, we note the absence in the above publications of quantitative assessment of the quality of operations of grinding of coarse-stem crops in the entire range of sizes of plant residues.

Paper [9] reports the results of studying a machine-tractor assembly, which simultaneously performs technological operations of grinding and soil wrapping of plant residues (sunflower stubble). The first operation is carried out using a shredder of plant residues installed in front. The plow installed at the back performs a wrapping operation. It is noted that the number of crushed particles less than 15 cm long increased by 1.5 times, and the number of particles longer than 30 cm decreased by 3 times. When analyzing the entire volume of plant residues in the soil, their non-damaged part did not exceed 1 %. However, the authors ignored the question of determining the impact exerted on the quality of grinding plant residues by the assembly's movement speed.

Study [10] noted that the return and deep burying of agricultural straw in the soil is an effective way to use and process straw resources, reduce pollution, and increase soil fertility. The authors of [10] designed a combined unit for deep harrowing, stubble grinding, turning, and burying crushed straw. Thus, the machine combined the functions of cleaning the stubble and opening the furrow. According to the results of statistical analysis, it was concluded that the speed of rotation of the blade, which destroys the stubble, did not affect the resistance to tillage. However, the depth of soil cutting both by the guide blade and the destruction of the stubble affected the resistance and, therefore, affected the soil cultivation capacity. It is noted that the optimal efforts on soil cultivation and the quality of stubble grinding were, respectively, 21.6 kN and 96.3 % at a rotational speed of 340 rpm. The proposed design of the combined unit is believed to be effective in deep furrowing, soil destruction, stubble breaking, and burying crushed corn straw with good operating quality. However, the authors ignored the issues of influencing the quality indicators of the technological operation of grinding additional vertical weight applied to the chopper.

In order to improve the quality of work and reduce the energy consumption by the machine for grinding straw, a scheme and mechanism of operation of a two-rolling tiller [11] was proposed. According to the results of experimental studies of the proposed design, high quality of work on grinding corn stems was noted. The rate of grinding of stems reached almost 90 %. However, the authors do not give specific values of the degree of grinding of corn stems in the range exceeding 50 mm.

Based on the constructed mathematical model, work [12] analyzed the conditions of interaction of the stem with the cob. Two types of possible options for the arrangement of knives are proposed, which creates the preconditions for designing a new type of narrow-band rotary cultivators and plant residue shredders. However, the authors did not consider an experimental study of the proposed structure.

Mulchers or roll crushers in the solo version, despite their high efficiency in the destruction of stems, on the contrary, do not have the above additional advantages [13]. On the contrary, their unsystematic use can lead to the accumulation of large masses of plant residues on the soil surface, which slows its warming up in spring. Uniform mixing of plant residues with the soil is also advisable in terms of their rapid decomposition, the formation of favorable conditions for sowing, and preventing early clogging [14].

That is why it is necessary to develop roll crushers both in mono-execution and as part of special units. Due to this, it would be possible to subsequently use them for surface tillage with intensive mixing. Among the above-mentioned operations are stubble peeling, field cultivation with a large number of plant coarse residues, pre-sowing tillage, and wrapping of organic fertilizers.

3. The aim and objectives of the study

The purpose of our study is to design a roll crusher of sunflower stems and to substantiate the rational modes of its operation. This would make it possible to improve the quality of technological operations of crushing sunflower stems by reducing unevenness, reducing energy costs, and intensifying the grinding process.

To accomplish the aim, the following tasks have been set:

- to design and fabricate a roll crusher with angles of inclination of cutting knives variable to the axis of rotation;
- to investigate the effect of additional vertical weight applied above the center of mass of the roll crusher on the quality indicators of grinding and wrapping of sunflower stems;
- to investigate the impact of the arrangement of the cutting edge of a crushing knife of the roll crusher on the quality indicators of the operations of grinding and wrapping sunflower stems;
- to investigate the impact of the speed of energy unit on the quality indicators of grinding and wrapping sunflower stems.

4. The study materials and methods

An experimental sample of the roll crusher of plant residues was investigated at the research sites of TOV «Krasnyanskye SP «Agromash» (Vinnitsia oblast) and DP DG «Oleynivske» NNTs «IMESG» (Kyiv oblast). The test conditions are given in Table 1.

According to the research program, a one-time run through the agro phone was carried out, which was represented by equal areas of the field after harvesting sunflower. During our research, the indicators of crushing and processing plant residues in the soil were determined. The assembly of the roll crusher included the MTS-80 tractor (manufactured at the Minsk Tractor Plant, Republic of Belarus).

In the field, the speed of movement of the energy unit was determined as follows. The plots of the field were in advance divided into sections of length l ($l=100-150$ m). The time it took for the unit to travel the plot was determined by a stopwatch. The data acquired were entered in the table. Speed was determined from the following dependence:

$$v = \frac{l}{t}, \text{ m/s}, \tag{1}$$

where t is the time of operation execution at this length of the plot, s.

We collected samples of crushed plant mass at different sites of the field both in the width of grip by working bodies of the roll and in the length of the run. At the sites determined in this way, a wooden control frame measuring 1x1 m was placed. Plant residues located both on the soil surface and at the entire depth of cultivation were collected from the frame area in specially prepared and signed packages.

Table 1
Conditions to study the roll crusher

No. of entry	Parameter	Value
1	Ambient temperature, °C	6.6
2	Air humidity, %	84.6
3	Wind speed, m/s	2.5
4	Crop	sunflower
5	Predecessor	corn
6	Soil moisture, %	24–25
7	Type of soil	Black soil
8	Speed of movement, km/h	7.45–22
9	Width of capture, m	3.8
10	Row spacing between stems, mm	700
11	The distance between the stems in a row, mm	220
12	The average diameter of the stems, mm	18.6
13	Average height of stalks, mm	762.87
14	The average weight of plant residues, g	493.6
15	Tractor power, kN	3
16	Roll crusher assembly	mounted

Sorting of selected crushed stems into fractions, determining their length, weight, and humidity, were carried out in the laboratory. The length of the fractions of crushed stems was determined by the ruler. The value of the defined length of each particle of the stem was entered in the table. The number of stem particles that fit the selected size intervals made it possible to determine the frequency of occurrence of the event of particles in each interval. Data grouping was smoothed out by random fluctuations inherent in a small amount of data capable of storing the main, characteristic features of the collected experimental material in general. Determining the number and size of group intervals did not result in significant losses in relation to the process. Experimental data were grouped at intervals of the same size (50 mm) in the ranges of 0–50 mm, 51–100 mm, 101–150 mm, 151–200 mm, over 201 mm. Under such conditions, tables of all lengths of fractions of plant residues were compiled.

Our study was carried out at speeds of 7.45 km/h, 10.08 km/h, 13.6 km/h, 18.6 km/h, and 22.0 km/h. At each speed, three repetitions were made.

The weight of the package with selected plant residues, as well as the weight of individual fractions of crushed residues, was determined by scales in the laboratory.

The moisture content of raw materials was determined by a weight method according to DSTU ISO 6496:2005.

We analyzed the processes of grinding and processing plant residues by statistical methods according to [15]. The analysis involved a sample of stem particles, which were formed in certain predetermined ranges: 0–50 mm, 51–100 mm, 101–150 mm, 151–200 mm, over 201 mm. According to the results of the research, graphical dependences were built, where the axis of ordinate hosted the quantity $m/n+1$, which represented a dependent variable (where n is the full sample volume, m is the average rank value determined for each value of the stem particle). The axis of abscissa hosted the intervals of groups of particles of crushed stems. Since the plot of the accumulated probability determines the probability that the variable «equals, or less than», the value of the dependent variable was marked above the upper limit of each interval.

5. Results of the study on designing a roll crusher of sunflower stems and substantiating the rational modes of its operation

5.1. Designing and fabricating a roll crusher with the angles of inclination of cutting knives variable to the axis of rotation

In order to increase the efficiency of grinding coarse plant residues and reduce the energy intensity of the corresponding technological operations of grinding and processing crop residues that remain after harvesting corn, sunflower, rapeseed, and other crops, a roll crusher has been designed and manufactured.

The roll crusher has a frame (Fig. 1), on which a stretcher is hinged through the fingers, where two drums with cutting knives are installed with the help of brackets, arranged along the entire width of the grip in a checkered manner. The knives can change the angle of inclination to the axis of rotation of the drum in the range of 5...20°, and the stretcher together with the drums can fall and rise in a vertical plane thanks to two hydraulic cylinders, which are fixed hinged. The specifications of the roll crusher can be found in Table 2.

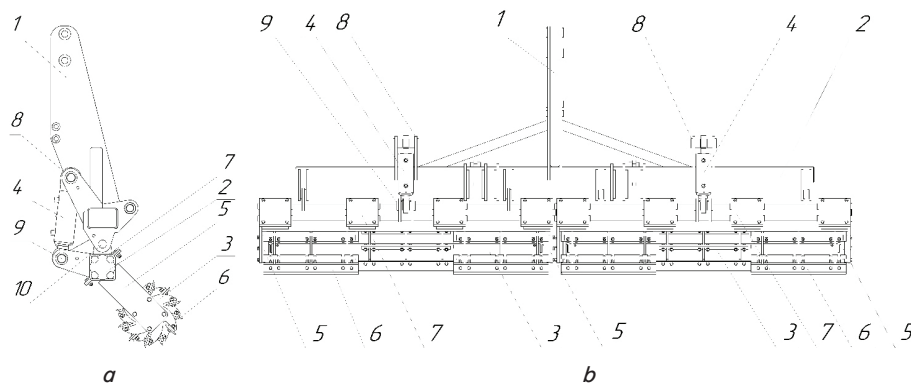


Fig. 1. Scheme of the roll crusher of plant residues: a – side view; b – top view; 1 – frame; 2 – stretcher; 3 – drums; 4 – hydraulic cylinders; 5 – brackets; 6 – cutting knives; 7 – flanges; 8–10 – fingers

Table 2

General specifications of the experimental sample of a roll crusher

No. of entry	Parameter	Value
1	The diameter of the roll crusher drum	330 mm
2	Roll crusher drum length	2,000 mm
3	The width of the experimental sample	4,200 mm
4	The mass of the experimental sample	1,200 kg
5	Number of drums	2 pieces
6	Number of rows of knives on the drum	6 pieces
7	The distance between the blades of the knives	165 mm
8	Knife size (length, width, thickness)	505 mm/ 76 mm/8 mm
9	The number of knives in a row of drum	4 pieces
10	Knife sharpening angle	30°
11	The angle of the knife to the axis of the drum	10°

The roll crusher of plant residues can work both as part of a trailer combined unit for grinding and processing plant residues, and autonomously, as a mounted machine assembled with a tractor.

The structural execution of knives of the roll crusher makes it possible to install them with external (right-side arrangement) or by orienting the cutting edge of the knife inside the drum (left-side arrangement) (Fig. 2).

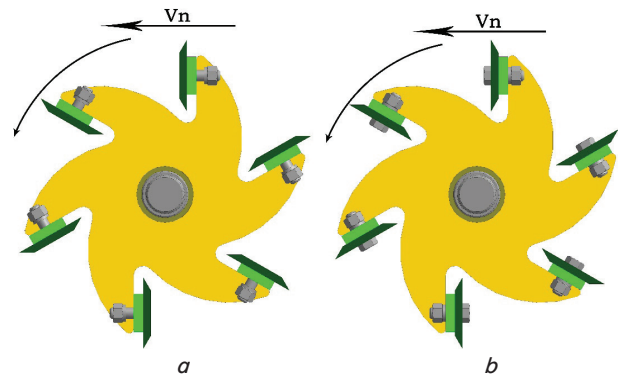


Fig. 2. Scheme of arranging knives on the drums of a roll crusher: a – left; b – right

This structural feature was used to determine the effect of the knife cutting edge orientation option (knife installation option) on the quality indicators of grinding and burying plant residues.

5.2. Results of determining the effect of additional weight on the quality indicators of grinding sunflower stems

Our study was carried out in order to determine the effect of additional vertical weight on the quality indicators of the technological process of grinding plant residues of sunflower with a roll crusher at the right-side and left-side arrangement of the knife cutting edge.

5.2.1. Results of the study on the right-side arrangement of the knives of the roll

The roll crusher was additionally loaded with vertical force. The strength values were changed depending on the mass of the liquid with which the container was filled. The liquid tank was placed in the middle part of the symmetrically longitudinal plane of the roll. The experiments implied filling the container with water in the amount of 600 and 800 kg (5.88 and 7.84 kN) (Fig. 3, a).

The results of the experiment were used as a control in which the roll crusher at a speed of 7.2 km/h was assembled with the disc harrow BDVP-3.8 (manufactured at TOV Krasnyanske SP «Agromash», Ukraine). The tractor loading was 43.4 kF/m per meter of the unit’s grip width. Under such conditions, the possibility of taking samples in the form of crushed stems, both after the roll and after the disc harrow (Fig. 3, b, c), has been implemented. Each experiment was repeated three times.

We estimated the efficiency of grinding stems according to the accumulated frequency of events (the number) of the established sizes of stem particles in a certain range of their sizes. This length range is identical to the sizes defined for other experiments.



a



b



c

Fig. 3. Roll crusher in operation on sunflower: *a* – general view; *b* – the condition of the field before cultivation; *c* – the condition of the field after a single cultivation by the roll crusher

Tables 3, 4 give the percentage of crushed sunflower stems at a speed of 7.45 km/h at the right-side arrangement of the cutting edge of the knife. It was established that in the range of 0–50 mm, the percentage was 12.9 % per 600 kg of an additional load, 12.5 % for 800 kg, 18.6 % for the roll in a disc harrowing unit. The increase in the last experiment by almost 15 % of the values of particles of crushed fractions compared to others is due to the structural differences of the units that carried them out. The width of the tractor drive in the assembly of the roll crusher with a disc harrow is 1.35 times (full equipped weight, 1.38 times) larger than the indicators of tractor drives with a roll crusher.

The increase in the percentage of crushed stems in the range of 51–100 mm for a speed of 7.45 km/h was 25.8 % for an additional loading of 600 kg (it reached the level of 38.7 %). With an additional load of 800 kg – 22.2 % (it reached 34.7 %). For a unit containing a roll crusher and a disc harrow, this indicator was 25.4 % (it reached 44 %).

Note that the largest total level of crushed stems in the range of 101–150 mm is established with an additional load of the roll of 800 kg. An increase in the value of the additional loading force led to a corresponding increase in the percentage of crushed parts of the stems. The accumulated value of the percentage of crushed stem particles for this state of the roll exceeded by 1.58 times the corresponding value of the roll with an additional load of 600 kg and by 1.33 times for the assembly of the roll crusher and disc harrow.

Note that the largest total value of the percentage of crushed stems in the range of 0–200 mm was established when additionally loading the roll with 800 kg. These values were 1.13 times higher than the indicators of the roll with an additional load of 600 kg and 1.05 times higher than the unit in the assembly of the roll crusher and disc harrow.

In the range exceeding 201 mm, the increase in the percentage of crushed stems amounted to 600 kg – 19.3 % (it reached the level of 93.5 %). With an additional load of 800 kg – 12.9 % (it reached 97 %). For the assembly consisting of a roll crusher and a disc harrow – 15.5 % (it reached 95.6 %).

The increase in the five defined ranges for changing the length of the particles of crushed stems was: for a roll with an additional load of 800 kg – 12.5 %, 22.2 %, 44.7 %, 4.7 %, 12.9 %. For a roll with an additional load of 600 kg: 12.9 %, 25.8 %, 12.9 %, 22.6 %, 19.3 %. For the assembly of the disc harrow and roll crusher – 18.6 %, 25.4 %, 15.7 %, 20.4 %, 15.5 %, respectively.

An increase in the additional mass at a movement speed of 7.45 km/h from 600 to 800 kg led to a corresponding increase in the total value of the percentage of crushed stems in the ranges of 101–150 mm, 151–200 mm, and exceeding 201 mm.

Analyzing the results of studies in the range of 0–50 mm for a roll with an additional load of 800 kg at all speed intervals, we note that the greatest (20.2 %) value was established at a speed of 18.6 km/h. The total accumulated percentage of crushed stems in the range of 0–200 mm at the level of 84.1 % was established at a movement speed of 7.45 km/h. This value is 1.08 times higher than at the speed of 13.6 km/h, 1.05 times more than at a speed of 10.08 km/h, 1.01 times at the speed of 18.6 km/h, 1.03 times at the speed of 22 km/h.

We analyzed the results of studying the indicators of crushing sunflower stems at different values of movement speed. In the range of 0–50 mm with an additional load of the roll of 600 kg at a speed of 7.45 km/h, the percentage of crushed stems was 12.9 %. At the speed of 10.08 km/h – 18.6 %, at the speed of 13.6 km/h – 12.7 %, 18.6 km/h – 16.4 %, 22 km/h – 12.6 %, respectively. The total accumulated value of the percentage of crushed stems in the range of 0–50 mm was: at the speed of 7.45 km/h – 51.6 %, 10.08 km/h – 72.6 %, 13.6 km/h – 60.8 %, 18.6 km/h – 67 %, 22 km/h – 62.2 %, respectively.

The largest total value of the percentage of crushed stems in the range of 0–150 mm at the level of 72.6 % was established at a speed of 10.08 km/h. This indicator exceeded the corresponding values at a speed of 7.45 km/h by 1.41 times, at a speed of 13.6 km/h – by 1.19 times, at the speed of 18.6 km/h – by 1.08 times, at the speed of 22 km/h – by 1.17 times.

In the range of 0–200 mm, similar to the range of 0–150 mm, the largest total value of the percentage of crushed stems was established at 88.5 % at a speed of 10.08 km/h.

Note that with an additional load of the roll of 600 kg, the largest total value of the percentage of crushed stems in the range of 0–150 mm and 0–200 mm was established at a speed of 10.08 km/h. With an additional load of the roll of 800 kg, the largest total value of the percentage of crushed stems in the range of 0–150 and 0–200 mm was established at a speed of 7.45 km/h. Increasing the additional load of the roll from 600 to 800 kg does not lead to a corresponding increase in the total value of the percentage of crushed stems. At a speed of 7.45 km/h, the roll crusher with an additional load of 800 kg demonstrated better performance compared to the corresponding indicators of the roll, additionally loaded with 600 kg. However, according to absolute total values, the percentage of crushed stems in the ranges of 0–150 mm and 0–200 mm rolls additionally loaded with a mass of 600 kg at a movement speed of 10.08 km/h had higher performance. These indicators were, respectively, 72.6 % and 88.5 % (Tables 3, 4).

5. 2. 2. Results of studying a roll crusher with the right-side arrangement of the knife cutting edge

The distribution of sunflower residue fractions at the left-side arrangement of the knives of the roll is given in the summarized tables, which establish the corresponding indicators of the passage of the roll with an additional load of 800 kg (Table 3) and an additional load of 600 kg (Table 4).

Analyzing the results of the research given in Tables 3, 4, note that in the range of less than 50 mm, the highest percentage of crushed stem particles (31.6 %) was established at a speed of 22 km/h with an additional load of 600 kg. An increase in the additional load from 600 to 800 kg did not lead to a corresponding increase in the percentage of crushed sunflower particles at all the speeds studied. At a speed of 7.45 km/h, the percentage of crushed sunflower particles with an additional load of 600 kg was 14.5 % against 12.4 % with an additional load of 800 kg. At a speed of 10.08 km/h, the percentage of crushed particles was, respectively, 21 % with an additional load of 600 kg and 11 % for 800 kg. The percentages of crushed sunflower stems at a speed of 10.08 km/h with an additional load of 600 kg exceeded the corresponding indicators with an additional load of 800 kg. At a speed of 13.6 km/h, this ratio was 1.44 times, at a speed of 18.6 km/h – 1.96 times, at a speed of 22 km/h – 1.99 times, respectively.

An increase in speed both in terms of additional load of 600 kg and 800 kg led to a corresponding increase in the percentage of crushed sunflower stems.

In the range of 51–100 mm with an additional load of the roll of 600 kg, the largest percentage of crushed stems was established at 50.6 % at a speed of 13.6 km/h. With an additional load of 800 kg – at the level of 41.3 % at a speed of 22 km/h.

The increase in the percentage of crushed stems from the range of less than 50 mm to 51–100 mm ranged from 15–25.4 %. The largest 25.4 % increase in the percentage of crushed stems was established at a load of 800 kg at a speed of 22 km/h. According to this value of an additional load, the increase in the percentage of crushed stems amounted to 7.45 km/h – 24.1 %, at a speed 10.08 km/h – 15 %, at a speed of 13.6 km/h – 24 %, 18.6 km/h – 22.4 %, 22 km/h – 25.4 %. Additionally loading the roll with 600 kg led to a corresponding increase in indicators at all the speeds studied. Thus, at a speed of 7.45 km/h, these values were 15.8 %, 10.08 km/h – 29 %, 13.6 km/h – 31.8 %, 18.6 km/h – 32.6 %, 22 km/h – 11.4 %.

In the range of up to 150 mm (the sum of the percentage of crushed stems of the ranges less than 50 mm, 51–100 mm, 101–150 mm), the largest value (at the level of 75.3 %) of the percentage of crushed stems was established at an additional load of 600 kg and a speed of 13.6 km/h. This indicator exceeded the highest value of the percentage of crushed stems with an additional load of 800 kg and a speed of 22 km/h by 1.19 times. It is worth noting the dominant excess of the accumulated percentage of crushed stems in the range of 0–150 mm in the roll crusher with an additional load of 600 kg above the corresponding values of indicators with an additional load of 800 kg.

Analyzing the uniformity of the increase in the percentage of crushed stems according to the established ranges, depending on the speed of movement, these indicators were characterized by the following values: with an additional load of 600 kg and a movement speed of 7.45 km/h – 15.8 %, 26.3 %, 25 %, 14.5 %. At the speeds of 10.08 km/h – 29 %, 19 %, 19 %, 10 %; 13.6 km/h – 31.8 %, 24.7 %, 15.3 %, 8.2 %; 18.6 km/h – 32.6 %, 22 km/h – 25.4 %.

Generalized results of studying the distribution of sunflower residues when using a roll crusher with an additional load of 800 kg

Fraction	7.45 km/h	10.08 km/h	13.6 km/h	18.6 km/h	22 km/h
	percentage	percentage	percentage	percentage	percentage
The right-side arrangement of knives					
Less than 50	12.5	13.1	5.9	20.2	14.8
51–100	34.7	37.7	23.96	53.6	41
101–150	79.4	57.4	49.3	72.6	62.3
151–200	84.1	80.3	77.6	83.3	82
Exceeding 201	97	96.7	95.5	97.6	96.7
The left-side arrangement of knives					
Less than 50	12.4	11	13	10.5	15.9
51–100	36.5	26	37	32.9	41.3
101–150	60.6	37	60	52.6	63.5
151–200	84.1	63	85	76.3	85.7
Exceeding 201	97.3	89	–	96.1	98.4

Table 3

Generalized results of studying the distribution of sunflower residue fractions using a roll crusher with an additional load of 600 kg

Fraction	7.45 km/h	10.08 km/h	13.6 km/h	18.6 km/h	22 km/h
	percentage	percentage	percentage	percentage	percentage
The right-side arrangement of knives					
Less than 50	12.9	18.6	12.7	16.4	12.6
51–100	38.7	50.4	37.2	43	38.6
101–150	51.6	72.6	60.8	67.0	62.2
151–200	74.2	88.5	83.3	86.0	85.0
Exceeding 201	93.5	98.2	98.0	97.5	99.2
The left-side arrangement of knives					
Less than 50	14.5	21	18.8	20.6	31.6
51–100	30.3	50	50.6	53.2	43.0
101–150	56.6	69	75.3	72.3	67.1
151–200	81.6	88	90.6	89.4	88.0
Exceeding 201	96.1	98	98.8	–	98.7

Table 4

19.1 %, 17.1 %; 22 km/h – 11.4 %, 24.1 %, 20.9 %, 10.7 %, respectively.

An increase in the percentage of crushed sunflower stems was established depending on the speed of movement under the conditions of loading the roll with 800 kg. At a speed of 7.45 km/h, this increase amounted to 24.1 %, 24.1 %, 23.5 %, 13.2 %. At the speeds of 10.08 km/h, respectively, 15 %, 11 %, 26 %, 26 %. At the speeds of 13.6 km/h – 24 %, 23 %, 25 %. At the speeds of 18.6 km/h – 22.4 %, 19.7 %, 23.7 %, 19.8 %. At the speeds of 22 km/h – 25.4 %, 22.2 %, 22.2 %, 12.7 %, respectively. Note the pronounced uniformity of the increase in the percentage of crushed stems in the ranges up to 200 mm with an additional load of 800 kg at all the speeds studied. At this level of additional loading, the percentage of crushed stems in the range of more than 201 mm is much lower than the percentage of crushed stems with an additional load of 600 kg. That is, an increase in the additional load makes it possible to increase the total average value of the percentage of crushed stems in the range of 0–201 mm by 1.5 times compared to the corresponding indicators with an additional load of 600 kg.

We analyzed the results of the study into the crushing of sunflower stems with a roll crusher at various options for installing knives (left and right). It is noted that in the range of less than 50 mm, the roll with the left-side arrangement of knives with an additional load of 600 kg demonstrated higher values of the percentage of crushed stems at all speeds (Tables 3, 4).

At a speed of 7.45 km/h, these indicators exceeded the corresponding values of the roll with the right-side arrangement of knives by 12 %. At a speed of 10.08 km/h – by 13 %, at 13.6 km/h – by 48 %. At the speeds of 18.6 km/h – by 26 %, at 22 km/h – by 151 %, respectively. In the same range of 0–50 mm with an additional load of 800 kg, exceeding the percentage of crushed stems for the left-side arrangement of knives was established at a speed of 13.6 km/h – by 2.2 times, and at a speed of 22 km/h – by 1.07 times.

The largest total value of the percentage of crushed stems in the range of 0–100 mm was established at the right-side arrangement of the knives, with an additional load of 800 kg at a speed of 18.6 km/h – 53.6 %.

In the range of 0–150 mm, we established the excess of the total (accumulated) values of the percentage of crushed stems with an additional load of the roll of 800 kg at the right-side arrangement of knives at all (except for the speed of 13.6 km/h) speeds studied. With an additional load of 600 kg, this pattern changed significantly. The roll with the left-side arrangement of knives in the range of 0–150 mm was characterized by greater values of the total percentage of crushed stems at almost all (except the speed of 10.08 km/h) speeds of experimental studies.

In the range of 0–200 mm, with an additional load of 600 kg, the roll with the left-side arrangement of knives was also characterized by higher total percentages of crushed stems compared to the right-side arrangement of knives. Thus, at a speed of 7.45 km/h, the accumulated value of the percentage of crushed stems in the range of 0–200 mm exceeded the corresponding indicators with the right-side arrangement of knives by 1.09 times. At a speed of 13.6 km/h – by 1.09 times, at 18.6 km/h – 1.04 times. At 22 km/h, this ratio was 1.04 times, respectively.

At a speed of 10.08 km/h, these indicators were almost the same (88 %, the left-side arrangement; 88.5 %, the right-side arrangement).

The additional loading of the roll with 800 kg changed the pattern of differences in the distribution of percentages of crushed sunflower stems for the right-side arrangement and the left-side arrangement of knives. There was no pronounced pattern of dominance of the knife installation direction in the pattern of changing the percentage of crushed stems. At a speed of 7.45 km/h, the total value of the percentage of crushed stems was the same (84.1 %). At the speeds of 10.08 km/h and 18.6 km/h, the rolls with the right-side arrangement of the knives were characterized by higher total values. This ratio was 80.3 % against 63 % at 10.08 km/h, 83.3 % vs. 76.3 % at 18.6 km/h. At 13.6 km/h and 22 km/h, the highest percentage of crushed stems were demonstrated by rolls with the left-side arrangement of knives. Accordingly, at a speed of 13.6 km/h – 75 % against 77.6 %, and at a speed of 22 km/h, 85.7 % against 82 % at the right-side arrangement.

The energy costs for various installation of the cutting edge were not determined.

5.3. Results of studies to determine the effect of the arrangement of the knife cutting edge on the quality indicators of the grinding of sunflower stems

When analyzing our results (Tables 3, 4), we note that at the left-side arrangement of the drum knife at all intervals studied, there was an increase in the percentage of crushed fractions. Thus, in the range of 0–50 mm, the average value of the percentage of crushed fractions at the left-side arrangement of the knife was 12.46 % against 10.52 % at the right-side arrangement. In the range of 51–100 mm, the specified indicator was 34.7 % at the left-side arrangement and 30.2 % at the right-side arrangement, and in the range of 101–150 mm, respectively, 62.4 % and 52.9 %. Exceeding the percentage of crushed particles at the left-side arrangement of the knife compared to the right-side arrangement in the interval of 0–150 mm was about 18 %.

It was established that the percentage of sunflower stems crushed into fractions at the left-side arrangement of the knife at all intervals studied exceeded by 4 % the value at the right-side arrangement of the knife. It should be noted that these values were established with an additional load of the roll with a vertical force of 7.8 kN (weight 800 kg) at a speed of 7.45 km/h.

5.4. Results of studies on determining the impact of movement speed on the quality indicators of sunflower stem grinding

It was established (Fig. 4, a) that at the right-side arrangement of the knife, the percentage of crushed stems of the fraction up to 50 mm at a speed of 7.45 km/h was 12.5 %, at a speed of 10.08 km/h – 13.1 %, 13.6 km/h – 5.9 %, 18.6 km/h – 20.2 %, 22 km/h – 14.8 %, respectively.

For the grinding range of 51–100 mm, the percentage of crushed stems at a speed of 7.45 km/h – 34.7 %, 10.08 km/h – 37.7 %, 13.6 km/h – 23.9 %, 18.6 km/h – 53.6 %, 22 km/h – 41 %.

In the range of 101–150 mm, the percentage of crushed stems for a speed of 7.45 km/h was 79.4 %, at 10.08 km/h – 57.4 %, 13.6 km/h – 49.3 %, 18.6 km/h – 72.6 %, 22 km/h – 62.3 %.

In the range of 151–200 mm, the percentage of crushed stems at a speed of 7.45 km/h was 84.1 %, at 10.08 km/h – 80.3 %, 13.6 km/h – 77.6 %, 18.6 km/h – 83.3 %, 22 km/h – 82 %, respectively.

In the range of 201–250 mm (over 201 mm), the percentage of crushed stems at the speed of 7.45 km/h was

97 %, at 10.08 km/h – 96.7 %, 13.6 km/h – 95.5 %, 18.6 km/h – 97.6 %, 22 km/h – 96.7 %, respectively.

Analyzing the results of our studies (Fig. 4, 5) we note that an increase in speed leads to a corresponding increase in the percentage of crushed stems in all defined ranges. This is especially true at the speeds of 18.6 km/h and 22 km/h. The highest value (20.2 %) of the crushed stems of the fraction up to 50 mm was established at a speed of 18.6 km/h, which exceeds the speed of 7.45 km/h (12.5 %) by 1.61 times, at the speed of 13.6 km/h (5.9 %) – by 3.42 times.

In the range of 51–100 mm, the highest value of the percentage of crushed stems at the speed of 18.6 km/h (53.6 %) exceeds similar speeds of 7.45 km/h by 1.54 times, 10.08 km/h – 1.42 times, 13.6 km/h – 2.24 times, 22 km/h – 1.3 times.

In the range of 101–150 mm, the highest percentage of crushed stems was established at the lowest speed values – 7.45 km/h (79.4 %). These values exceeded the corresponding values of the percentage (accumulated) of crushed stems at a speed of 10.08 km/h by 1.38 times, at 13.6 km/h – 1.61 times, at 18.6 km/h – 1.1 times, at 22 km/h – 1.27 times.

Tables 3, 4 give the results of studies to determine the impact of the speed of energy unit on the quality indicators of the grinding operations and the burying of sunflower stems at the left-side arrangement of the cutting edge of the chopping knife of the roll crusher.

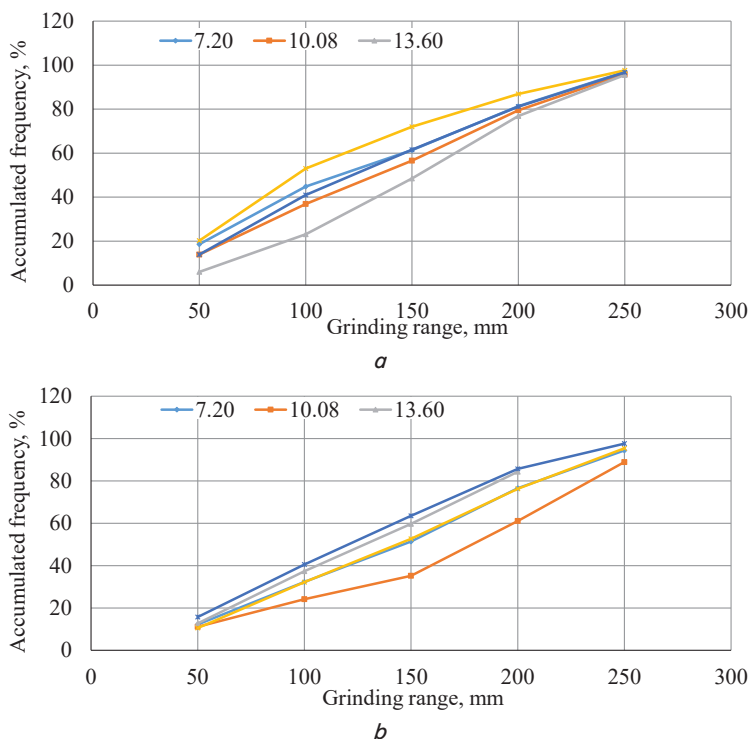


Fig. 4. Dependence of the grinding range of the stems of plant residues of sunflower on the accumulated frequency at different values of the speed of movement of the energy unit with a roll crusher with an additional load of 800 kg: *a* – at the right-side arrangement of knives; *b* – at the left-side arrangement of knives

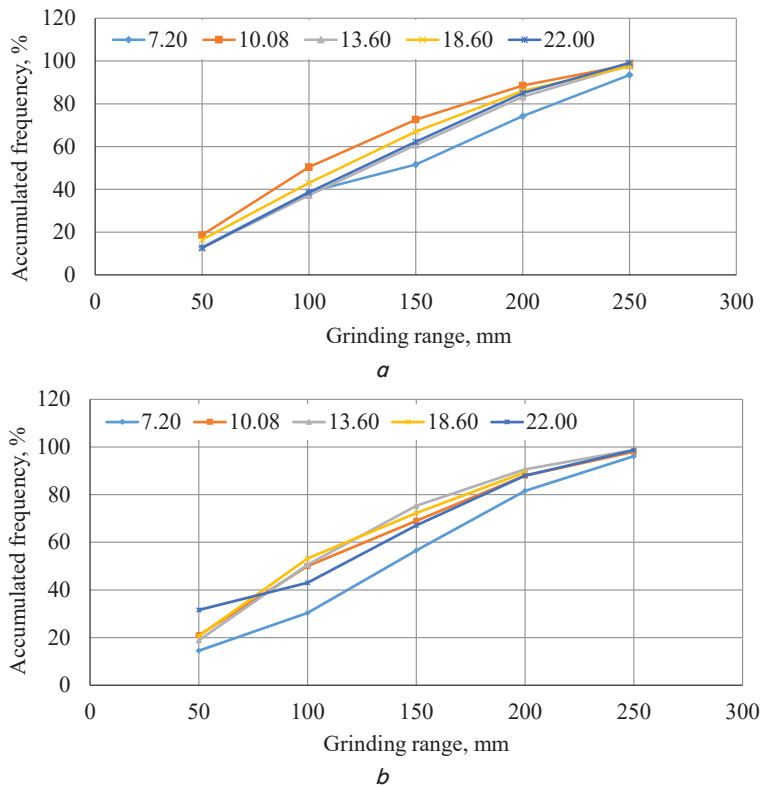


Fig. 5. Dependence of the grinding range of the stems of plant residues of sunflower on the accumulated frequency at different values of the speed of movement of the energy unit with a roll crusher with an additional load of 600 kg: *a* – at the right-side arrangement of knives; *b* – at the left-side arrangement of knives

At left-side arrangement of the cutting edge of the chopper knife in the range of 0–50 mm at a movement speed of 7.45 km/h, the average percentage of crushed stems was 12.5 %, at the speed of 10.08 km/h – 11 %, at 13.6–13 %, at 18.6 – 10.5 %, at 22 km/h – 15.9 %, respectively.

It should be noted that at small (7.45 km/h) speed values, at the left-side arrangement of knives, the largest increase in the percentage of crushed stems was established in the range of 101–150 mm and amounted to 44.7 % of the total. For a speed of 10.08 km/h in the range of 151–200 and exceeding 201 mm, the same growth values were registered (at the level of 26 %) of the crushed stems. For large speed values, the range increase in the percentage of crushed stems was characterized by the same dynamics (at the level of 22.4–25.4 %).

6. Discussion of results on determining the effect of additional weight on the quality indicators of grinding sunflower stems

Our studies showed significant prospects for the use of roll crushers in order to solve a problem to improve the quality of grinding of coarse-stem plant residues. Based on the results of examining a roll crusher, both in the mono version and in the disc harrow unit, it was established that the performance indicators of the technological

process involving these machines are quite acceptable. Their application for grinding coarse-stem plant residues, which remain after harvesting corn, sunflower, rapeseed, and other crops, looks promising.

When mechanically processing corn stubble, the degree of grinding of stems is an important indicator of the quality of the technological operation. The evaluation criterion used is the indicator of the number of non-damaged parts of stems longer than 5 cm, in which corn butterfly pupae can winter. From these pupae, adults are formed in the spring. It is worth noting that the corn butterfly is considered an extremely dangerous pest. Technological methods of dealing with it have not yet been sufficiently worked out. Therefore, modern technologies of cultivation of this crop provide for a series of operations aimed at grinding the particles of stems, followed by wrapping them to a sufficient depth (more than 10 cm).

In addition to green manure, intensive grinding of plant residues by roll crushers in combination with surface cultivation is very important when cutting rapeseed stubble. A thin layer of mulch on the surface draws moisture well and is favorable for the emergence of rapid shoots of carrion seeds. For farms with a high concentration of this crop, the roll crusher is as important a tool for maintaining a decent level of agriculture as for the reliable grinding of corn and sunflower stems.

It was found that an increase in the load of the roll at the right-side arrangement of the cutting edge of knives from 600 to 800 kg did not lead to a corresponding increase in the total value of the percentage of crushed stems. At a speed of 7.45 km/h, the roll crusher with an additional load of 800 kg demonstrated better performance compared to the corresponding indicators of the roll with an additional load of 600 kg. However, according to absolute total indicators, the percentage of crushed stems in the range of 0–150 mm and 0–200 mm, the roll with an additional load of 600 kg at a speed of 10.08 km/h demonstrated better performance. These indicators were, respectively, 72.6 % and 88.5 %.

It should be noted that for the speed of 7.45 km/h, which is the lowest value studied, the percentage of crushed stems in fractions increased much more dynamically than in experiments of relatively higher velocity values. This is natural, since at low speeds the conditions of contact (copying) by the knives of the roll crusher of soil relief are more stable. That is, the implementation of the technological process of grinding occurs under conditions when there is no (not significant) separation of individual parts of the roll crusher from the soil surface due to significant components of vertical dynamic excitations. At low speed values, stable vertical pressing force, which levels (extinguishes) vertical dynamic movements, the quality of grinding operations and, accordingly, the burying in the range of 101–200 mm of the crushed fractions of stems is the highest.

Note the absence of a pronounced pattern of dominance of the direction of installing knives on the total value of the percentage of crushed stems. However, the search and research in this direction should be continued while establishing the quality indicators of grinding coarse plant residues that remain after harvesting corn, sunflower, rapeseed, and other crops.

7. Conclusions

1. We have designed and fabricated a prototype of the roll crusher, in which the cutting knives are arranged along

the entire width of the grip in a staggered manner with the ability to change the angle of inclination to the axis of rotation of the drum in the range of 5...20°. Lifting and lowering of drums with cutting knives in a vertical plane is carried out thanks to two hinged hydraulic cylinders.

2. The causal relations of factors that determine the system of formation of indicators of quality of grinding of sunflower stems and form the necessary prerequisites for determining rational modes and parameters of the roll crusher have been investigated. It was established that at the left-side arrangement of the cutting edge of knives, an increase in loading from 600 to 800 kg in the range of 0–50 mm did not lead to a corresponding increase in the percentage of crushed sunflower particles at all the speeds under study.

3. It has been noted that at the left-side arrangement of the cutting edge of the knives of the roll, the percentage of crushed stems in the range of 51–100 mm with an additional load of 600 kg exceeded the corresponding indicators with an additional load of 800 kg. This excess at a speed of 10.08 km/h was 1.9 times, at a speed of 13.6 km/h – 1.44 times, at a speed of 18.6 km/h – 1.96 times, at 22 km/h – 1.99 times, respectively.

It was established that at the right-side arrangement of the cutting edge of the knives of the roll:

- the largest total level of the percentage of crushed stems in the range of 101–150, with an additional load of 800 kg, exceeded by 1.58 times the corresponding indicators of the roll with an additional load of 600 kg, and by 1.33 times those of the roll crusher in an assembly with a disc harrow;

- the largest total value of the percentage of crushed stems in the range of 0–200 mm with an additional load of the roll of 800 kg was 1.13 times higher than the corresponding indicators of the roll with an additional load of 600 kg and 1.05 times the roll in the disc harrow unit;

- with an additional load of the roll of 600 kg, the largest total value of the percentage of grinding of stems in the range of 0–50 mm and 0–200 mm was established at a speed of 10.08 km/h, and, with an additional load of 800 kg – at a speed of 7.45 km/h.

No pronounced pattern of dominance of the direction of installing a knife on the total value of the percentage of crushed stems was established.

4. The percentage of crushed particles at a speed of 10.08 km/h and with an additional load of 600 kg was 1.9 times higher than the corresponding indicators with an additional load of 800 kg. At a speed of 13.6 km/h, this excess was 1.44 times, at a speed of 18.6 km/h – 1.96 times, at 22 km/h – 1.99 times, respectively. In the range of 0–150 mm, the highest (at the level of 75.3 %) value of the percentage of crushed stems with an additional load of 600 kg and the speed of 13.6 km/h exceeds by 1.19 times the corresponding indicators of the roll with an additional load of 800 kg and at a speed of 22 km/h. In the range of 0–200 mm, with an additional load of 600 kg, the roll with the left-side arrangement of knives was characterized by higher total percentages of crushed stems compared to the right-side arrangement of knives. At a speed of 7.45 km/h, the accumulated value of the percentage of crushed stems exceeded the corresponding indicators at the right-side arrangement of knives by 1.09 times, at a speed of 13.6 km/h – 1.09 times, at 18.6 km/h – 1.04 times, at 22 km/h – 1.04 times, respectively.

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