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DETERMINATION OF THE PATTERNS OF CHANGES IN THE QUALITY INDICATORS OF CRUSHING CORN AND SUNFLOWER STEMS BY WORKING BODIES OF TECHNICAL EQUIPMENT

The object of research is the technological processes of crushing plant residues, corn and sunflower stalks, working bodies of single and double roll crushers, disk harrow, as well as combined unit consisting of disk harrow and single roll crusher. The relevance of the research is due to the need to solve the problem of increasing the efficiency of technological crushing operations by intensifying (increasing) the effects of the working bodies of the tools on the plant environment.

A prototype of double roll crusher was developed and manufactured, the cutting knives of which are placed across 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 6–10°. The highest value of the relative frequencies of corn crushing by double roll crusher belonged to the ranges of 51–100 mm and 101–150 mm, the sum of which was 56% and 52%, respectively. The largest share of 48.25% of crushed sunflower stalks by double roll crusher was established for the range of 51–100 mm. The sum of the percentages of crushed sunflower stalks in the ranges less than 50–100 mm was 77.62%, which is 2.36 times more than the similar indicator of single roll crusher, 3 times more than that of a harrow, and almost coincided with the indicators of a combined unit. In a disk harrow, the largest number of shares of crushed corn stalks 42.2% belonged to the range of 151–200 mm, and sunflower stalks 35.2% to the range over 201 mm. In a combined unit, the largest value of the percentage of crushed stalks was established in the range less than 50 mm. For corn, the specified value was 65.4%, for sunflower 41.5%, respectively. The contribution of single roll crusher to the total percentage of crushed stems in the range of up to 150 mm in a combined unit was 44.7% for corn and 47.7% for sunflower.

The results of the research are recommended for crop growing systems under the conditions of choosing rational technical and technological solutions for crushing plant residues.

Keywords: *stalk crushing, single and double roll crushers, disc harrow, combined unit, crushing quality indicators, corn and sunflower stalks.*

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1. Introduction

Plant residue crushers are among the key technical and technological factors of modern technologies for growing various agricultural crops. Roll crushers are used for processing rapeseed, sunflower, corn, industrial hemp stubble, as well as for harvesting green manure. The use of roll crushers makes it possible, with a minimum level of maintenance, high durability even in drought, to ensure high efficiency of organic mass distribution on the field surface, fine-grained soil structure, and combing out carrion and weed shoots [1, 2]. Rollers are characterized by versatility, and can be used with a front or rear attachment [3, 4].

There are one-section and two-section roll crushers. All these types of machines have a closed type of drums (rotors). The design features and determination of quality indicators of crushing of coarse-stemmed crops by one-section roll crushers are discussed in detail in [5, 6].

Two-section (double) roll crushers with knives attached directly to the shaft are known, which allows for maximum stability, optimal crushing, high productivity, and low fuel consumption [7]. Roller designs use shafts with diameter of 280 mm (TSW 600, Germany), 300 mm (Cultro 6 TC, Germany; HIT 3, Ukraine), 350 mm (Terra Tandem 600, Germany), 375 mm (Pro Cut 3, Poland). Shafts with diameter of 480 mm are used in rollers (GRIZZLY AL420D, Bulgaria), 560 mm (WN Tandem HD 6.0H, Poland) and up to 650 mm (Volta 9000-LS, Ukraine). The number of rows of knives can be 6–12 pieces, with a loading of up to 7.1 kN [8, 9]. It should be noted that the force per meter of the working width also varies. For example, the Vibrocut 6000 (Germany) chopper roller has 11.7 kN, Volta 9000-LS (Ukraine) 5.9 kN, MAXICUT3 (Poland) 3.8 kN, GRIZZLY AL420D (Bulgaria) 4.4 kN. The advantages of double roll crushers include the fact that the cross arrangement of the roller sections prevents the formation of untreated areas of the field. The working width is 3–12 m. With a working width of 9 m and more, only rear attachment is possible. High productivity is ensured by an operating speed of up to 20 km/h [10].

There are known designs in which the knives are mounted at an angle to the roller axis, which achieves uniform load distribution [11, 12]. In addition, these design conditions prevent the machine from swaying. For maximum stability and reliability of operation, the knives are fixed directly to the shaft. For optimal copying of the soil surface, the sections with knives are attached to the frame using rubber belts. Thanks to this, the working bodies copy the soil surface well, and the shafts with knives are protected from overloads [13]. If necessary, the chopper rollers are additionally equipped with compacting rollers or a heavy harrow [14].

A design of two consecutively arranged drums with a diameter of 390 mm, having opposite blades [15]. This provides a very thin cross-section in the soil. The design of the drums without an internal axis performs particularly well in conditions of contact with a large amount of plant residues or on wet soil [16]. The material is literally thrown into the center. The advantages of the designs include short drum sections. Each element has a width of only 75 cm [17, 18]. This optimizes the adaptation of the tool to the soil culture. Irregularities caused by the tractor tracks are also amenable to processing. It can be used at speeds up to 25 km/h with extremely low fuel consumption [19].

The aim of research is to determine the patterns of changes in the quality indicators of crushing corn and sunflower stalks by the working bodies of technical means. This will make it possible to increase the efficiency and level of controllability of technological processes of crushing plant residues by single and double roll crushers, disc harrows and combined units.

To achieve the set aim, the following objectives were solved:

– to propose a design and manufacture a prototype of double roll crusher with variable angles of inclination of the cutting knives relative to the axis of rotation;

– to determine the quality indicators of crushing corn and sunflower stalks by the working bodies of single roll crusher, double roll crusher, BDVP-3.8 disk harrow, combined unit consisting of BDVP-3.8 disk harrow and single roll crusher.

2. Materials and Methods

The object of research is the technological processes of crushing plant residues, corn and sunflower stalks, working bodies of single and double roll crushers, disk harrow, as well as a combined unit consisting of disk harrow and single roll crusher.

The subject of research is the interaction of the working bodies of a one-section, two-section roller, a disk harrow, as well as a combined unit with plant material (corn, sunflower stalks).

The scientific hypothesis is that there are such technical and technological solutions, the implementation of which will make it possible to carry out the technological process of crushing with the greatest efficiency.

Experimental samples of the above-mentioned rollers and the combined unit were studied in the conditions of the experimental plots of the State Enterprise Research Farm "Olenivske" of the Institute of Mechanics and Automation of Agroindustrial Production of the National Academy of Agrarian Sciences of Ukraine. The study was also conducted in the conditions of the experimental plots of LLC "Krasnyanske SE "Agromash" (Vinnytsia region, Ukraine).

Table 1 shows the average values of the indicators according to which the study was conducted.

According to the research program, a single pass was made over the agrobackground, which was a flat area of the field after harvesting corn and sunflower. During the research, the indicators of crushing and incorporation of plant residues into the soil were determined. The aggregation of the one-section and two-section chopper rollers was carried out by the MTZ-80 tractor. The aggregation of the BDVP-3.8 disk harrow and the combined unit was carried out by the Case IH MAGNUM 290 tractor.

Table 1

Conditions of research of rollers and the combined chopper roller unit

No.	Parameter	Value (sunflower)	Value (corn)
1	Ambient temperature, °C	18	23
2	Air humidity, %	64	34
3	Wind speed, m/s	2.1	1.3
4	Crop	sunflower	corn
5	Predecessor	corn	sunflower
6	Soil humidity, %	24–25	20–22
7	Soil type	Black soil	Black soil
8	Moving speed, km/h	7.0–7.5	7.0–7.5
9	Working width, m	3.8	3.8
10	Row spacing, mm	700	750
11	Stalk spacing in a row, mm	220	200
12	Average stalk diameter, mm	310	225
13	Average stalk height, mm	853	297
14	Average crop residue weight, g	462	367
15	Tractor power, kN	3	3
16	Roll crusher assembly	hinged	hinged

The collection of samples of crushed plant mass was carried out in different places of the field both along the width of the working bodies of the roller and along the length of the swath. In the places determined in this way, a wooden control frame measuring 1 × 1 m was placed. From the area of the frame, plant residues located both on the soil surface and at the entire depth of cultivation were collected in specially prepared and signed bags.

Sorting of the selected crushed stems into fractions, determination of their lengths, weight and humidity was carried out in laboratory conditions. The length of the fractions of crushed stems was determined with a ruler. The value of the determined length of each stem particle was entered in the table. The number of stem particles that entered the selected size intervals made it possible to establish the frequency of particle occurrence in each interval. The grouping of data was smoothed by random fluctuations that are inherent in a small amount of data capable of preserving the main, characteristic features of the collected experimental material as a whole. Setting the number and size of group intervals did not lead to significant losses in relation to the process. Experimental data were grouped by 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 these conditions, tables of all lengths of plant residue fractions were compiled.

The study was conducted at speeds of 7.2 km/h with three repetitions of each experiment.

The length of the accounting area was determined with a RT-30 tape measure, error ± 0.5 cm, the length of the crushed stems – by equally accurate measurements with 100 cm metal ruler, error ± 0.2 mm. It should be noted that according to the law of large numbers of probability theory, with a large total number of experiments with a probability close to certainty, the relative frequency (statistical probability) of an event differs little from the probability of this event itself [20].

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 laboratory conditions.

The moisture content of the raw material was determined by the weighing method according to DSTU ISO 6496:2005.

The analysis of the processes of crushing and processing of plant residues was carried out by statistical methods. The analysis was carried out on a sample of stem particles formed in certain predetermined ranges. The results were processed in the Microsoft Excel environment.

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It is known that in agricultural production for many stationary random processes (which include the quality of crushing of plant residues) it is characteristic that one implementation of sufficient duration completely represents the entire function. Such processes are called ergodic, and this property is called ergodic. In ergodic processes, the average values of the characteristics in any implementation are the same. Therefore, the characteristics of such a random function can be determined by one sufficiently long implementation [20]. Graphical dependences of asymptotic relative frequencies of each result were constructed, as well as the accumulated sum of relative frequencies [21].

Correct determination of quality indicators of crushing corn and sunflower stalks in experimental studies implied the following assumptions:

1. The direction of movement of the energy source in all experiments was assumed to be the same.
2. The frame on the studied agrobackgrounds was installed in areas outside the possible direction of movement of the energy source and technological transport.

3. Results and Discussion

3.1. Development of double roll crusher

The research results on single roll crusher of plant residues, developed and manufactured earlier, are detailed in [1, 2, 4, 6].

The double roll crusher was developed to increase the efficiency of crushing and partial incorporation of plant residues, surface stubble cultivation with low traction resistance.

Fig. 1 shows a side view of double roll crusher under conditions of operation with two drums.

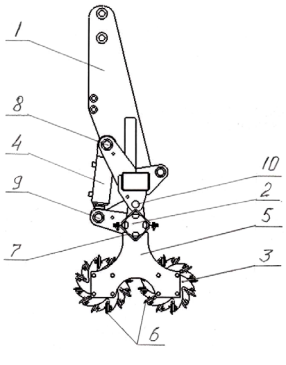

Fig. 1. Scheme of double roll crusher of plant residues (side view):
1 – frame; 2 – subframe; 3 – drums; 4 – hydraulic cylinders; 5 – brackets;
6 – cutting knives; 7 – flanges; 8, 9, 10 – fingers

The double roll crusher of plant residues consists of a frame 1, on which a subframe 2 is hingedly fixed through fingers 10. Two sections 5 with two drums 3 are installed on it using flanges 7, on which cutting knives 6 are installed in a staggered manner across the entire width of the grip. In the upper part of the chopper, two hydraulic cylinders 4 are hingedly fixed using fingers 8, 9, which perform radial lowering and raising of sections 5 in a vertical plane. Sections 5 with two drums 3 are rigidly fixed on the subframe 2 using flanges 7.

The double roll crusher works as follows. Pressed to the ground under its own weight, or by means of the tractor's hydraulic system in the "floating" position, sections 5 with drums 3 with cutting knives 6 roll over the stubble of the harvested field. On the surface of the field there are remains of corn, sunflower, rapeseed or other plant stalks. Drums 3 with cutting knives 6 of section 5 come into contact with plant residues, as a result of which they are cut. Cutting of residues into fractions can be regulated by means of two hydraulic cylinders 4, which carry out radial lowering and raising of one or two drums 3 in a vertical plane.

The double roll crusher of plant residues can work both as part of a trailed combined unit for crushing and processing plant residues with simultaneous tillage and autonomously as a trailed machine aggregated with a tractor.

The technical characteristics of the single and double roll crushers of plant residues are given in Table 2.

The features of the proposed design of double roll crusher of plant residues include the fact that the cutting knives are placed across 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 6–10°. In addition, the double roll crusher of plant residues is distinguished by the fact that the sections with two drums are rigidly fixed to the subframe using flanges, and the drums are the supporting element of the machine with the ability to adjust the depth of soil cultivation.

The structural and functional diagram of the combined unit containing single roll crusher in combination with BDVP-3.8 disk harrow is shown in Fig. 2, and the technical characteristics are in Table 3.

Table 2

Technical characteristics of the single and double roll crushers of plant residues

No.	Indicator	Value	
		One-section	Two-section
1	Diameter of the roller drum, mm	330	330
2	Length of the roller drum, mm	2000	2000
3	Width of the experimental sample, mm	4200	4200
4	Weight of the experimental sample, kg	1200	1500
5	Number of drums, pcs.	2	4
6	Number of rows of knives, pcs.	6	6
7	Distance between the blades of the knives, mm	165	165
8	Knife size (length, width, thickness), mm	505/76/8	505/76/8
9	Number of knives in a row, pcs.	4	4
10	Knife sharpening angle, °	30	30
11	Knife tilt angle, °	12	12

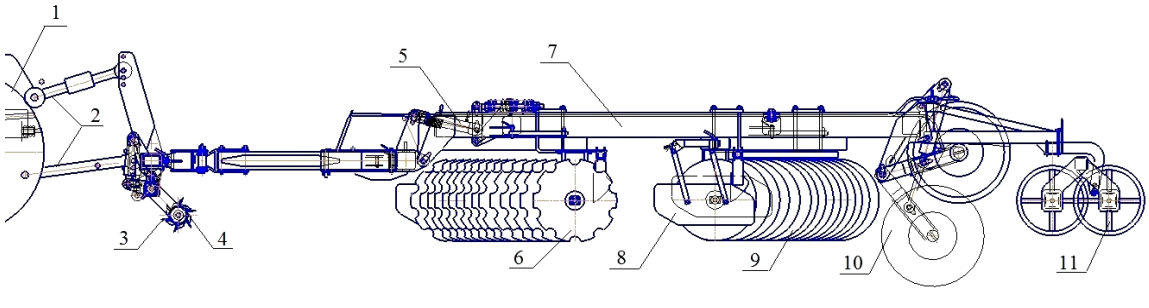

Fig. 2. Structural and functional diagram of the combined unit consisting of disk harrow BDVP-3.8 and single roll crusher:
1 – power unit; 2 – coupling device; 3 – roll crusher knives; 4 – section of roll crushers; 5 – hydraulic cylinder; 6 – section of cut spherical discs; 7 – frame;
8 – side screens; 9 – section of solid spherical discs; 10 – support wheels; 11 – compacting rollers

Table 3

Technical characteristics of the combined unit for tillage and mulching soil with plant residues (disk harrow BDVP-3.8 + single roll crusher)

No.	Parameters	BDVP-3.8 + single roll crusher
1	Machine type	semi-trailer
2	Working width, m	3.8–4.2
3	Productivity, ha/h	3.0–4.6
4	Working speed, km/h	8–12
5	Soil cultivation depth, mm	up to 22
6	Transport speed, km/h	up to 20
7	Transport width, mm, no more	4200
8	Disk diameter, mm	710
9	Disk thickness, mm	7
10	Square shaft, mm	40 × 40
11	Load per disk, kg	110
12	Fuel consumption, l/ha	10–15
13	Tractor power, hp	140–150
14	Roller drum diameter, mm	330
15	Roller drum length, mm	2000
16	Width of experimental sample, mm	4200
17	Weight of experimental sample, kg	1200
18	Number of drums, pcs.	2
19	Number of knife rows, pcs.	6
20	Distance between knife blades, mm	165
21	Knife size (length, width, thickness), mm	505 × 76 × 8
22	Number of knives in a row, pcs.	4
23	Knife sharpening angle, °	30
24	Knife tilt angle, °	12

3.2. Results of research on determining the quality indicators of crushing corn and sunflower stalks by working bodies of technical means

3.2.1. Results of research on crushing corn and sunflower stalks by single roll crusher

The research program provides for determining the quality indicators of the technological operation of crushing stalks of coarsely stemmed crops, including the previously developed and manufactured single roll crusher. The above, in addition to expanding the information databases, made it possible to create conditions for correct comparison of the obtained research results. The main advantages of the proposed methodological approach include the same type of research conditions for crushing corn and sunflower stalks, minimal impact of differences in growing, harvesting technologies, natural and climatic zones, etc.

Analyzing the results of crushing corn stalks by single roll crusher, it was noted that the largest percentage of crushed stalks belonged to the range of 51–100 mm and amounted to 38.1%. The specified indicator is 2.67 times greater than the range of 101–150 mm, 2.67 times greater than the range of 151–200 mm, and 4.0 times greater than the range of over 201 mm.

The crushing of sunflower stalks by single roll crusher made it possible to establish the largest proportion of 46.34% for the range of 151–200 mm. The specified indicator is 3.17 times greater than the corresponding indicator for the range of less than 50 mm, 2.53 times greater than the range of 51–100 mm, 2.71 times greater than the range of 101–150 mm, and 12.7 times greater than the range of over 201 mm.

The crushing of corn and sunflower stalks by single roll crusher was characterized by different probability distribution functions for the crushing into shares of the general population. For corn, the largest proportion of crushed stems was 38.1% and belonged to the range of 51–100 mm. For sunflower, this figure was 46.34% and belonged to the range of 151–200 mm (Fig. 3).

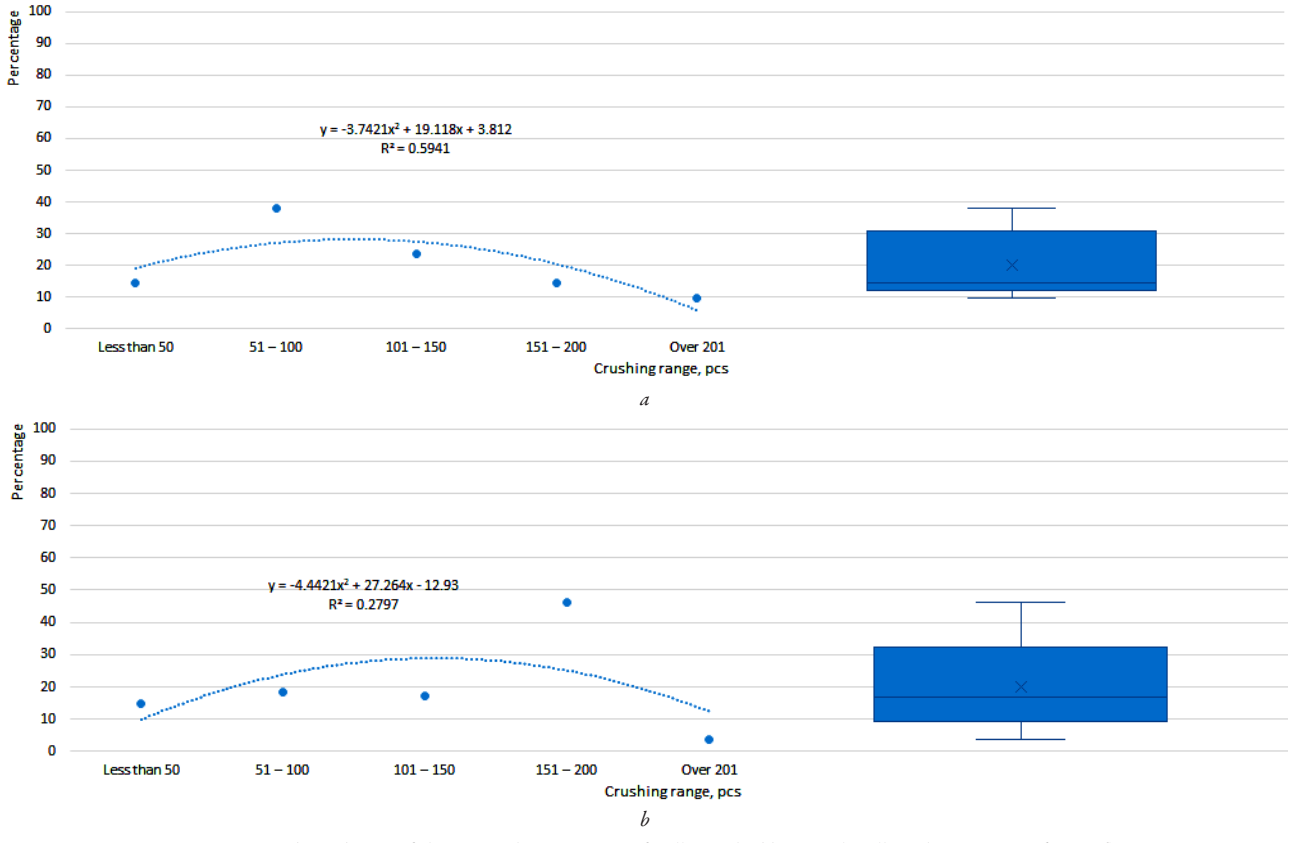

Fig. 3. Regression dependences of changes in the percentage of stalks crushed by a single roll crusher: *a* – corn; *b* – sunflower

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To some extent, these results are a consequence of differences in harvesting technologies for corn and sunflower. The density of crops, the cutting height for them are different, which significantly affected the crushing indicators. The crushing quality indicators depend on the initial indicators of the stalks of the crops being crushed.

3.2.2. The result of research on crushing corn and sunflower stalks by double roll crusher

Analyzing the table of asymptotic relative frequencies of the given ranges of corn crushing, it was noted that their largest values occur, equally, in the ranges of 51–100 mm and 101–150 mm, the sum of which is 56% and 52%, respectively (Fig. 4). The accumulated sum of relative frequencies of ranges less than 50–200 mm is 93.48%.

Analyzing the results of crushing sunflower stalks by double roll crusher, it was noted that the largest share fell on the range of 51–100 mm and amounted to 48.25%. The sum of the percentages of crushed sunflower stalks in the ranges less than 50–100 mm was 77.62%, which is 2.36 times more than in the similar range of single roll crusher. This indicator is 3 times more than in the harrow, and almost coincided with the indicators of the combined unit (78.8% versus 77.62% in the double roll crusher).

The probability distribution of crushing corn stalks by the established ranges in double roll crusher compared to single roll crusher is given in Tables 4, 5.

3.2.3. Results of research on crushing corn and sunflower stalks with disk harrow BDVP-3.8

The results are shown in Fig. 5. It was noted that the largest number of particles of crushed corn stalks 42.2% belongs to the range of 151–200 mm. This number exceeded the number of particles in the range of less than 50 mm by 3.61 times, the range of 101–150 mm by 1.81 times, and the range of more than 201 mm by 5 times.

Under the conditions of crushing sunflower stalks by a harrow, the largest share of 35.2% was those classified as more than 201 mm. Their number exceeded the number of the range less than 50 mm by 3.17 times, the range 51–100 mm by 2.38 times, the range 101–150 mm by 2.11 times, the range 151–200 mm by 1.58 times, respectively. A shift of the median (average value) in the range over 201 mm was noted in sunflower compared to corn, where the average value was set in the range 151–200 mm.

3.2.4. Results of research on crushing corn and sunflower stalks with a combined unit consisting of BDVP-3.8 disk harrow and single roll crusher

Analysis of the operation of the BDVP-3.8 disk harrow in combination with single roll crusher (Fig. 6) on the crushing of corn and sunflower stalks showed a coincidence of the patterns of distribution of particles of crushed stalks. The highest value of the percentage of crushed stalks was established in the range of less than 50 mm (Fig. 7). For corn, the specified value was 65.4%, for sunflower 41.5%, respectively. For corn, the highest value of the percentage of crushed stems exceeded the share of the range 51–100 mm by 2.78 times, the share of the range 101–150 mm by 12.1 times, the range 151–200 mm by 18.7 times, and the range over 201 mm by 29.7 times.

For sunflower, the observed ratio was characterized by the following indicators of exceeding the percentage of stalks crushed in the range of less than 50 mm:

- 1.11 times for the range of 51–100 mm,
- 3.61 times for the range of 101–150 mm,
- 6.01 times for the range of 151–200 mm,
- 14.8 times for the range of more than 201 mm.

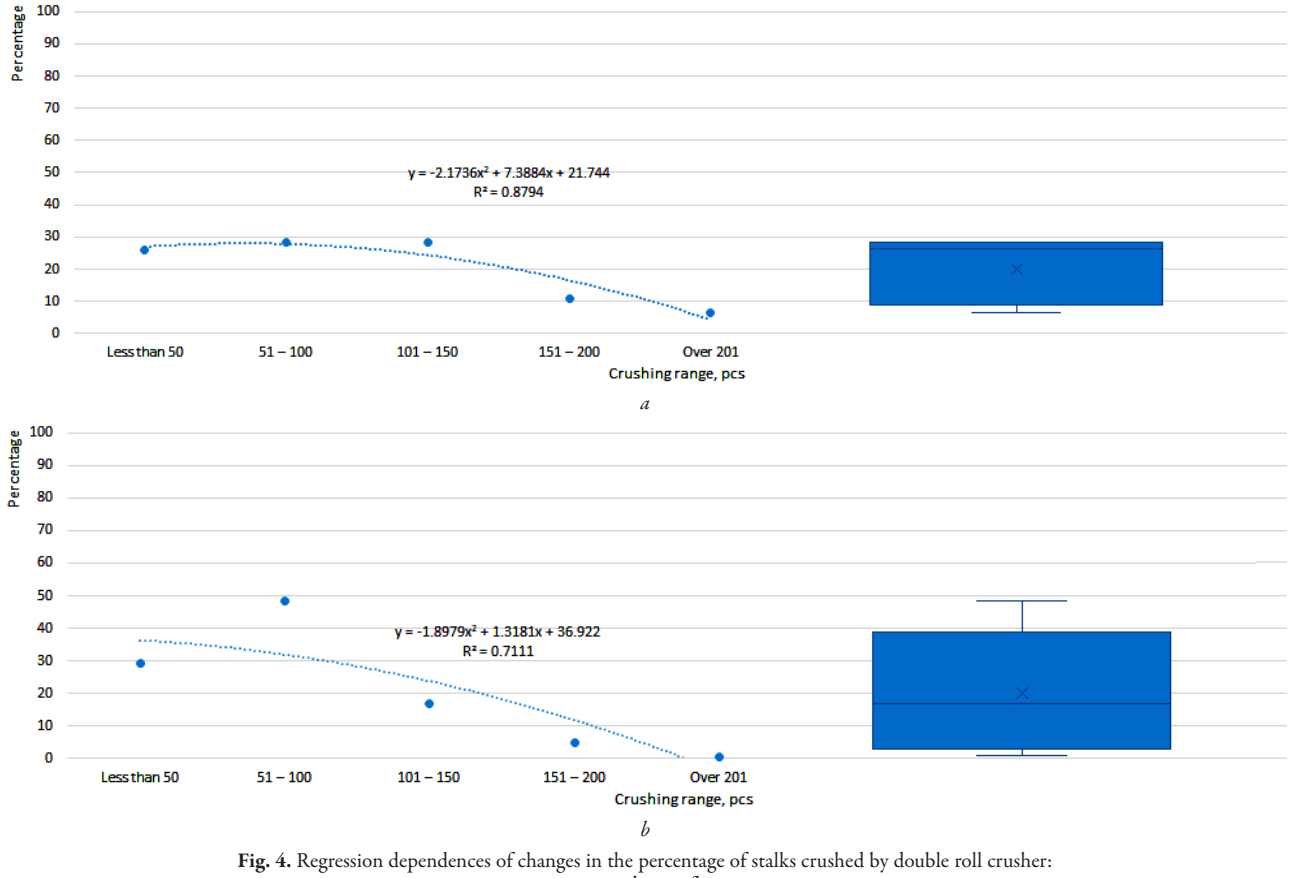

Fig. 4. Regression dependences of changes in the percentage of stalks crushed by double roll crusher:
a – corn; *b* – sunflower

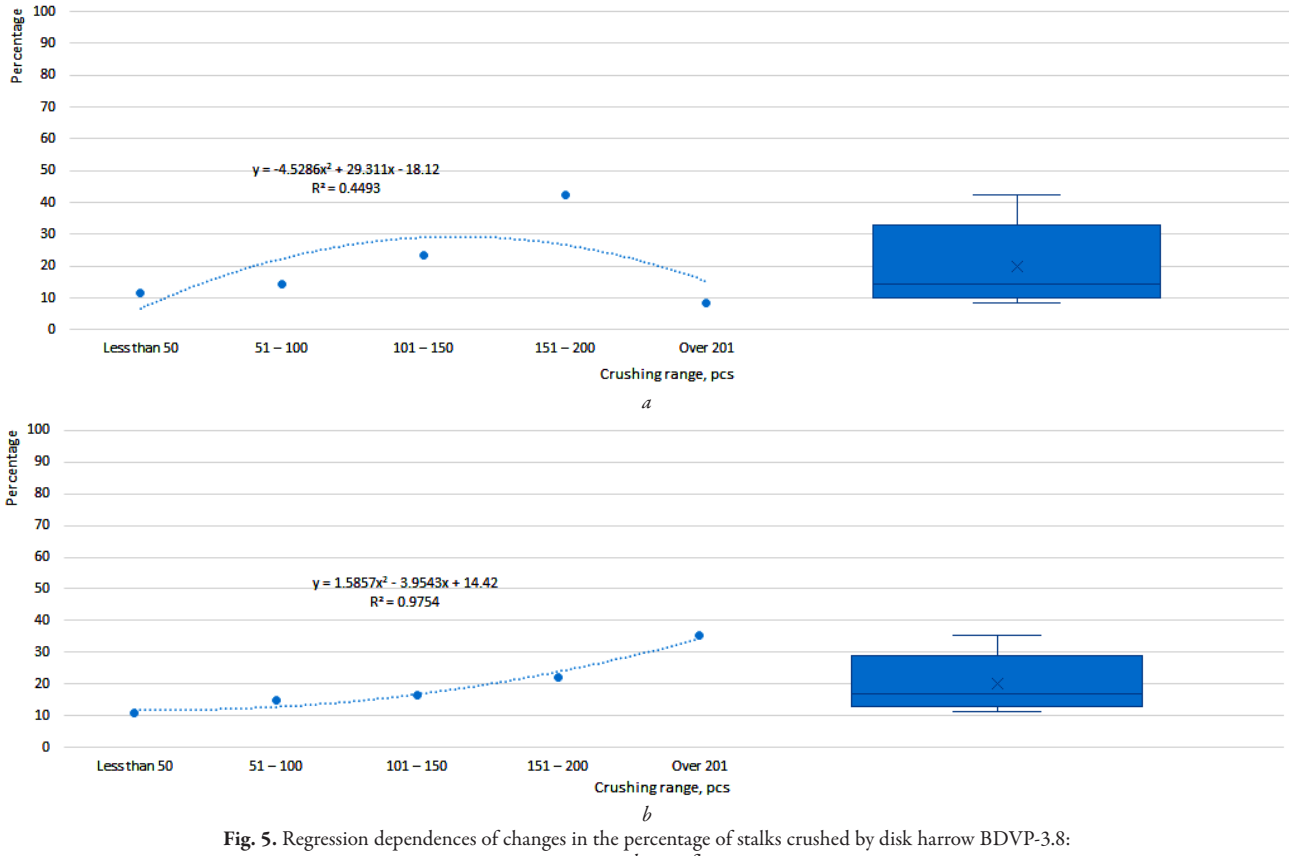

Fig. 5. Regression dependences of changes in the percentage of stalks crushed by disk harrow BDVP-3.8:
a – corn; *b* – sunflower

The use of the roll crusher as part of the combined unit made it possible to increase the percentage of crushed stalks of corn in comparison with the harrow indicators for the range of less than 50 mm by 5.63 times, for the range of 51–100 mm by 1.63 times. For sunflower stalks, the combined unit's performance exceeded the corresponding disc harrow's performance in the range of less than 50 mm by 22.8 times, and in the range of 51–100 mm by 2.36 times.

It was noted that the sum of the percentages of crushed stalks in the range of less than 50–150 mm in the combined unit for corn crushing was 94.3%, and for sunflower crushing was 90.3%. The similar indicator of the disc harrow for corn was 49.4%, and for sunflower crushing was 42.6%, respectively. The contribution of the chopper roller to the total percentage of crushed corn stalks in the range of up to 150 mm in the combined unit was 44.7% for corn and 47.7% for sunflower.

The probability distribution of corn stalk crushing according to the established ranges for single and double roll crushers, combined unit consisting of disk harrow BDVP-3.8 and single roll crusher, as well as a serial disk harrow BDVP-3.8 are given in Tables 4, 5.

The established patterns of changes in the indicators of the technological operation of crushing corn and sunflower stalks by the working bodies of the tools, disk harrow and combined unit are attributed to the main scientific and practical results of the research.

Fig. 6. Combined unit for tillage and mulching soil with plant residues (BDVP-3.8 + single roll crusher)

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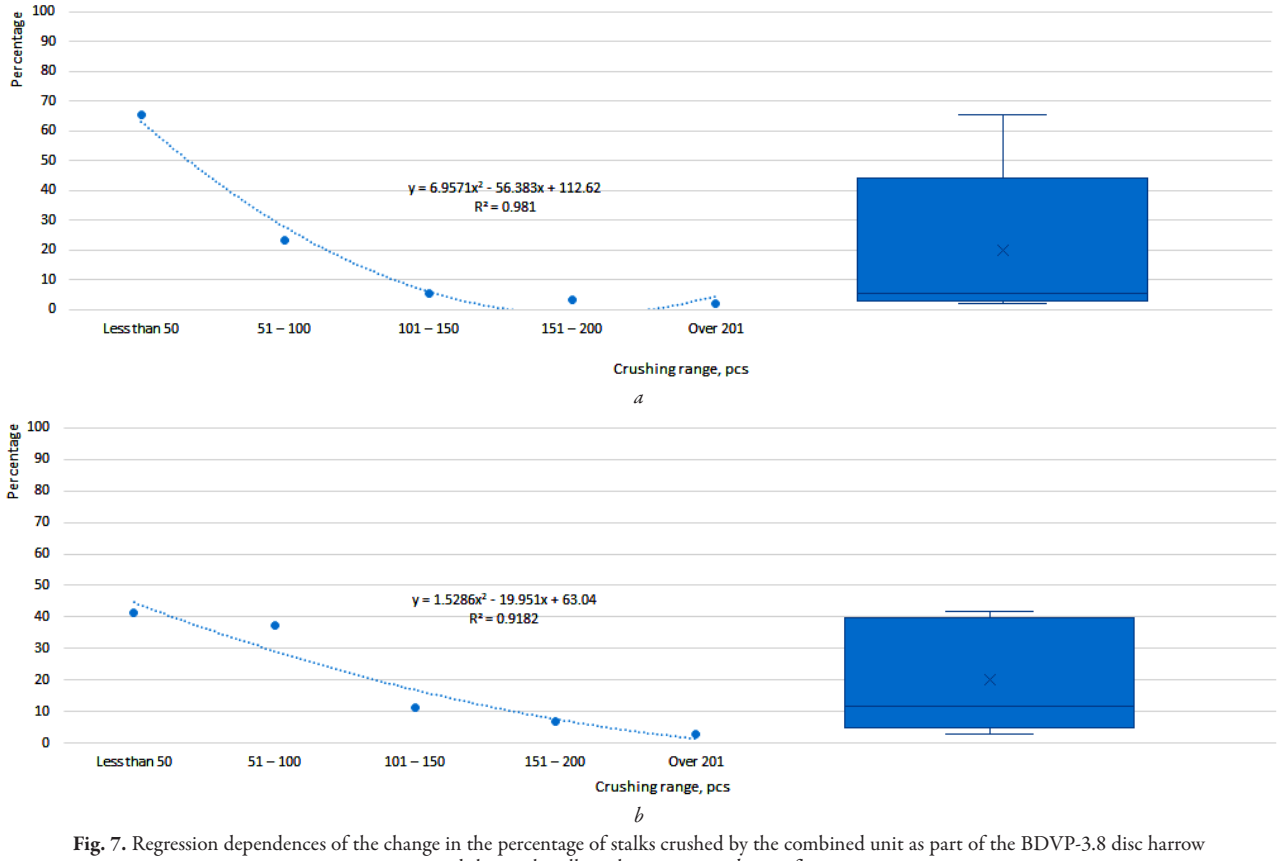

Fig. 7. Regression dependences of the change in the percentage of stalks crushed by the combined unit as part of the BDVP-3.8 disc harrow and the single roll crusher: *a* – corn; *b* – sunflower

Table 4

Generalized results of the determined asymptotic relative frequencies of corn stalk crushing by single and double roll crushers, disk harrow, and combined unit (Comb. unit + single roll crusher)

Stem segments	Statistical series of the distribution of crushed corn stalks			
	Harrow BDVP-3.8	Single roll crusher	Double roll crusher	Comb. unit + single roll crusher
Less than 50 mm	11.6%	14.29%	26.09%	65.4%
51–100 mm	14.4%	38.1%	28.26%	23.5%
101–150 mm	23.4%	23.81%	28.26%	5.4%
151–200 mm	42.2%	14.29%	10.87%	3.5%
Over 201 mm	8.4%	9.52%	6.52%	2.2%

Table 5

Generalized results of the determined asymptotic relative frequencies of sunflower stalk crushing by single and double roll crushers, disk harrow, and combined unit

Stem segments	Statistical series of the distribution of crushed sunflower stalks			
	Harrow BDVP-3.8	Single roll crusher	Double roll crusher	Comb. unit + single roll crusher
Less than 50 mm	11.1%	14.63%	29.37%	41.5%
51–100 mm	14.8%	18.29%	48.25%	37.3%
101–150 mm	16.7%	17.07%	16.78%	11.5%
151–200 mm	22.2%	46.34%	4.9%	6.9%
Over 201 mm	35.2%	3.66%	0.7%	2.8%

3.3. Limitations of research and prospects for its further development

The results presented are a continuation of previously conducted studies of the efficiency of crushing corn and sunflower stalks developed by single roll crusher [1, 2], as well as the crushing of corn stalks by a combined unit containing BDVP-3.8 harrow and single roll crusher [4, 6].

The features of the presented studies include the determination of crushing efficiency indicators at speed of 7.2 km/h with the same physical and mechanical properties of corn and sunflower stalks. These methodological differences lead to a more correct determination of the comparative characteristics of tools and units.

To solve these problems, the options for using double roll crushers, which are characterized by versatility, high productivity and energy efficiency, look promising. However, systematic conclusions and recommendations regarding the most rational modes of using these rollers will be formed after conducting a number of studies. Among the factors that require additional special research, the following are noted: determining the influence of the speed of movement of the energy resource on the quality indicators of the technological operation; determining the critical speed value at which slipping of the roll crushers is prevented; determining the influence of the additional load on the roller quality indicators.

The research results will acquire more significant features under the conditions of systematic determination of parameters characterizing the efficiency, reliability and economy of the functioning of technical means (fuel consumption, speed of movement, reliability, stability of the technological operation and safety), which are installed in different natural and climatic zones of real operation.

The features of the interaction of the working bodies of single roll crusher are considered in detail in [2, 4]. The technological operation of crushing the vegetation layer with knives of double roll crusher can be presented in several options. If the knives of both the first and

second drums do not penetrate the soil $h_v \geq h_k$ (h_k – length of the knife of the crusher roller, h_v – thickness of the layer of vegetation medium). The plant mass is crushed by knives and scattered over the soil surface. The knives do not penetrate the soil medium. A layer of mulch is formed on the soil surface from carefully crushed plant residues. In the case of $h_k \geq h_v$, the knives of the first drum begin, and the knives of the second drum complete the crushing of plant residues and their partial incorporation into the soil. Naturally, the degree of crushing of double roll crusher is higher than that of single roll crusher. The penetration depth of the knives into the soil, the degree of crushing of plant residues, and the depth of their incorporation depend on the physical and mechanical characteristics of the plant and soil medium.

Under the conditions of $h_k < h_v$, the plant residues are crushed only to the depth of penetration of the knives. The implementation of such a scenario in a two-section roller is possible under conditions of uneven soil surface, when the layer of plant material is located in places inaccessible to the knives of the roller, or the layer of plant medium has a large thickness.

The engines of the power tool that aggregates the roller make a significant contribution to the results of crushing the stems. The width of two wide-profile tires of a tractor of the 4th traction class is about 1080 mm. Under the conditions of aggregating a tool with a width of 4200 mm, 25% of the field surface before the start of interaction of the working parts of the tool is exposed to the influence of the engines of the power tool. Naturally, the degree of crushing of the stems of coarse-stemmed crops by the engines of the power tool and the working parts of the tools (rollers-choppers) is different. Under equal conditions, the contribution of the energy source drivers should be equal to both the distribution of corn stalks and sunflower stalks.

The results obtained are of particular importance in the context of substantiating rational technical and technological solutions related to the fight against the corn borer. Under such conditions, the most effective seems to be the use of a combined unit, which includes a disk harrow and a one-section roll crusher. The share of crushed corn stalks of a range of less than 50 mm by the combined unit was 65.4%, which made it impossible to create comfortable conditions for the development of pests.

The research results are recommended for use in crop growing systems under the conditions of choosing rational technical and technological solutions for crushing plant residues.

In the future, experimental studies to determine the effectiveness of the use of tools and combined units for crushing industrial hemp stalks, rapeseed stubble, and the production of green manure crops seem appropriate. The research results will complement the information databases of indicators of the quality of crushing of stems of various agricultural crops in the natural production zones of their production under different combinations of influencing factors.

4. Conclusions

1. The design is proposed and a prototype of double roll crusher is manufactured. The features of its design include the fact that the cutting knives are placed across 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 6–10°. The double roll crusher is distinguished by the fact that the sections with two drums are rigidly fixed to the subframe using flanges, and the drums are the supporting element of the machine with the ability to adjust the depth of soil cultivation.

2. The quality indicators and the regularity of their change under the conditions of crushing corn and sunflower stalks by the working bodies of technical means are determined. It was noted:

– in the single roll crusher, the largest share of crushed corn stalks was 38.1% and belonged to the range of 51–100 mm. Sunflower – 46.34% and belonged to the range of 151–200 mm;
– in the double roll crusher, the highest values of the relative frequencies of crushing corn stalks belonged to the ranges of 51–100 mm and 101–150 mm, the sum of which was 56% and 52%, respectively. Sunflower – to the range of 51–100 mm and amounted to 48.25%;
– in the disk harrow, the highest proportion of crushed corn stalks belonged to the range of 151–200 mm and amounted to 42.2%. Sunflower – to the range of over 201 mm and amounted to 35.2%;
– in the combined unit, the highest value of the percentage of crushed stalks was set in the range of less than 50 mm. For corn – 65.4%, for sunflower 41.5%, respectively.

The sum of the percentages of crushed stalks in the range of less than 50–150 mm in the combined unit for corn crushing was 94.3%, in sunflower crushing – 90.3%. The contribution of the single roll crusher to the total percentage of crushed corn stalks in the range of up to 150 mm in the combined unit was for corn – 44.7%, for sunflower – 47.7%.

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Conflict of interest

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Data availability

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Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies in creating the presented work.

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