

Impact of technological parameters of threshing apparatus on grain damage

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Abstract. The paper describes the impact of the feed rate of cereals to the threshing apparatus, the movement speed of rasp bars and the clearance between the drum and the concave on the grain damage. When the feed rate of the cereals into the threshing apparatus is increased the grain damage decreases. Estimating the crop harvesting conditions the permissible flow of cereal is from 0.70 to $0.96 \text{ kg (s m)}^{-1}$ for one meter of rasp bars length of the combine-harvester with four threshing-separation drums. The rasp bar speed of the threshing drum has the greatest impact on grain damage. When dry crop or cereals grown for seed (with moisture content of 12–14%) were harvested and the permissible limit crop flow was fed into the threshing apparatus the rational speed of drum rasp bars was 25 m s^{-1} ; when wet crop (moisture > 18%) was harvested the rational speed of drum rasp bars was from 31 m s^{-1} to 34 m s^{-1} . Grain separation and their damage rate through all concave length increased when the clearance between the drum rasp bars and concave transverse bars at the beginning and at the end of the threshing apparatus was reduced. When combine-harvesters *New Holland* were used for the threshing of very dry crops (moisture content < 12%) the optimum clearance between the threshing drum rasp bars and the concave were 12–12 mm, for dry crops (moisture content 12–14%) the optimum clearance was 11–11 mm, and medium (14–16%) or high moisture (moisture content > 16%) the optimum clearance was 10–10 mm. The grain threshing losses were minimized until permissible (0.05%) by increasing the speed of the threshing drum rasp bars.

Key words: threshing apparatus, crop flow, grain separation, grain damage

INTRODUCTION

Combine-harvesters were used for crop harvesting where the cereal mass flow was delivered perpendicular to or in parallel with the drum shaft (Rademacher, 2003). When the crops were fed perpendicular to the drum shaft the grain from the ears were threshed under the impact of the rasp bar impulses, and when they were fed in parallel with the drum axis the cereals were deformed in the clearance between the axial threshing drum and the concave (Wacker, 1987).

The most significant qualitative indices of the estimation of operation of the threshing apparatus of combine harvesters were the grain threshing loss, grain damage and the part of the trash in the grain (Rademacher, 2007). They are closely related and depend on the design characteristics of the threshing apparatus, the cereal flow fed into the threshing apparatus, and technological parameters, such as drum rasp bars speed and the clearance between the drum and the concave (Špokas, 2007). Additionally,

the crop species, moisture and biometrical indices that change during harvesting also influence the threshing process (Feiffer et al., 2001).

The threshing process can be controlled by changing the load and technological parameters of the threshing apparatus after grain loss and trash amount in grain is estimated. But the load of the threshing drum is related not only to the thickness of the threshed crop layer but also to the biometrical indices and physical-mechanical characteristics.

There are no reliable means of determining grain loss. The records of the combine-harvester should be adjusted several times during the day. The threshing process is best reflected by the grain damage change (Shpokas et al., 2007). Thus the grain damage causes should be related to feed crop flow, technological parameters, grain separation through the concave, drum rasp bars speed and the clearance between the drum and the concave (Kutzbach et al., 2003; Shpokas et al., 2005).

Grain kernel damage occurs most often because it is not sufficiently protected from the impact of the drum rasp bars (Valge et al., 1985). When the kernel shell is broken, the grain germination is minimized by 10% approximately. Despite the fact that damaged grain germinates in the field more quickly than the undamaged ones (Ostrauskienė, 1974), their yield is significantly smaller. Grain damage also depends on the crop species characteristics and harvest timer (Wacker & Schneider, 2000; Wacker, 2003). Grain damage was by 3% higher when the wheat species 'Oretes' was harvested if compared with 'Toronto' species. Grain damage was by 2% higher at noon than in the morning or in the evening. There is an exponential relationship between the grain damage and their moisture content (Waelti & Buchele, 1969).

Design and technological parameters of the threshing apparatus influence grain damage. Today, crops are harvested with combines with one or two threshing apparatus. The rotor separator also damages the grain while separating it from the straw. Drum rasp bars account for the greatest damage to the threshed grain (Kalikadze et al., 1974). Tests showed that when the speed of the drum rasp bars was increased from 28.3 m s^{-1} to 35.2 m s^{-1} , the grain damage increased by 2.1%. Rasp bars speed is related to grain deformation and the crop flow through the concave surface (Roi et al., 1984). Crop flow at the beginning of the concave is by 1.1 m s^{-1} slower than at its end thus when a greater number of grains is threshed from the ears, they are separated through the concave more quickly and are less damaged. Estimates of the impact of the combine design on the operation qualitative indices (Feiffer et al., 2005) concluded that technological parameters of the threshing apparatus had the greatest impact on the grain damage. They should be revised and corrected every day after estimation of the harvesting situation, biometrical indices of the crop, and the species characteristics.

The investigation goal is to determine biometrical indices of the threshed crop, the permissible load of the threshing drum rasp bars, and the impact of the technological parameters of the threshing apparatus on the grain damage.

MATERIALS AND METHODS

The threshing process of wheat species 'Zentos' was tested with the test bench (Fig. 1) that consisted of the eight-rasp-bar type threshing drum 3, the width of which was 1.2 m and the diameter was 0.6 m.

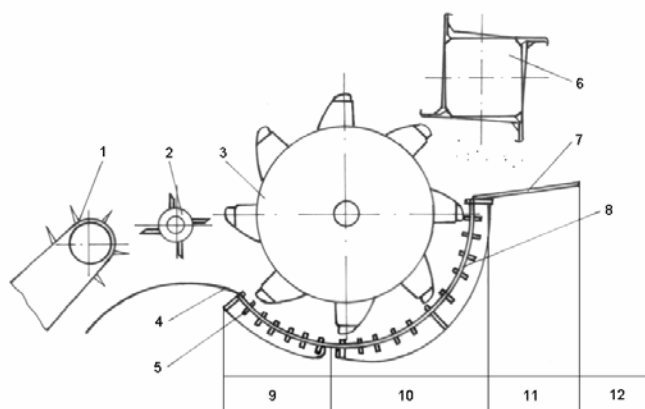


Fig. 1. The scheme of single cylinder threshing apparatus test bench:
1 – feeder conveyor; 2 – front beater; 3 – threshing cylinder; 4 – cover of stone trap;
5 – supplementary section of concave; 6 – rear beater; 7 – rod grate; 8 – main concave; 9, 10
and 11 – tanks for the remain gathering after threshing; 12 – tank for straw collection

The concave made of two sections 5 and 8 surrounded the drum at the angle of 146 degrees. The area of the main concave section 8 was 0.64 m², and that of the additional section 5 was 0.3 m². The beater drum 6 was behind the threshing drum followed by the rod grates 7 the width of which was 0.27 m². Tanks 9, 10 and 11 for trash gathering were under both concave sections and the rod grates. Straw was collected into tank 12. Cereals were fed into the threshing apparatus by the feeder conveyor 1.

Conclusions of laboratory tests were checked in the field using combine-harvester *New Holland* (Table 1).

Table 1. Main technical data of combine harvesters *New Holland*.

Indicators	Measurement unit	Type of combine harvesters	
		<i>New Holland CSX 7080</i>	<i>New Holland CX 860</i>
Width of cutting bar	m	7.3	7.3
Drum width	m	1.56	1.56
Drum diameter	m	0.6	0.75
Number of rasp bars	number	8	10
Concave area	m ²	1.04	1.18
Concave wrap	grad	121	111
Diameter of back beater	m	0.395	0.47
Rod grates area	m ²	0.34	0.29
Diameter of straw separator drum	m	0.59	0.72
Straw separator concave area	m ²	1.01	1.07
Total separation area	m ²	2.38	2.54
Area of straw walkers	m ²	6.45	6.68
Cleaning area	m ²	5.21	6.50

Weighed crop samples were evenly distributed on every 2 m length segment of the feeder conveyor. Trash separated through two concave sections 5 and 8 (Fig. 1) and through the rod grades 7 of the beater drum were gathered in tanks 9, 10 and 11. Grain separation percentage through 0.1 m² area of the concave and rod grades was estimated after weighing the trash and the separated grain with the scales (Scaltec SPO 51, record accuracy 0.01 g) to compare the grain separation through separators with various surface areas. The amount of separated grain gathered from the straw walkers in tank 12 was calculated after the grain that was mixed with straw was weighed. To estimate the grain threshing loss fifty ears were taken from the straw in five replications. The grain threshing loss was calculated after weighing the grain from the threshed ears.

Determination of grain damage. Five 50 g grain samples were taken in the laboratory during the threshing test. The grain was separated through concaves, rod grades and straw. The damaged grain was also weighed and the damage percentage was calculated (weighing accuracy 0.01 g). Combine-harvester speed, grain moisture content and yield were recorded by computer during crop harvesting in the field. Samples of 2 kg were taken from the grain flow fed into the hopper. Five 50 g grain samples were taken from this batch in the laboratory. The damaged grains taken from each of the sample were weighed (record accuracy 0.01 g) and the average percentage in the grain mass was counted.

Experimental data were processed according to the statistical method recommended by the international Standard ISO 7256-1.2. The average values of the data and their validity intervals are presented. In order to establish correlation of two factors, the curvilinear correlation coefficient R^2 was calculated. The curvilinear correlation of two factors was established according to the Fisher criteria. In order to establish the direction and size of factor correlation, the regression equations were made.

RESULTS AND DISCUSSION

Crop biometrical indices. Grain damage was tested during harvesting and threshing wheat of species 'Zentos', 'Bussard' and barley of species 'Henni' (Table 2) with combine-harvesters *New Holland* (Table 1).

Table 2. Grain biometrical indices

Indices	Measure units	Meaning		
		barley	wheat	
		'Henni'	'Zentos'	'Bussard'
Plant density	unit m ⁻²	524±13.1	513±24.1	460±10.5
Stem length till ear	m	0.51±0.01	0.83±0.1	0.73±0.1
Grain number in the ear	number	22.8±0.27	27.6±1.5	36.6±0.9
Single ear mass (moisture 14%)	g	0.81±0.02	1.15±0.1	1.45±0.1
Straw mass (moisture 18%)	g m ⁻²	374± 83.7	540.2±30.2	689.4±49
Grain mass (moisture 14%)	g m ⁻²	428.5±11.8	588±26.2	670.7±22.4
1000 grains weight (moisture 14%)	g	36.1±2.5	41.7±2.0	39.1±0.9

Suitable crop feed rate. It is closely related with grain separation in the threshing apparatus (Fig. 2) and the grain damage (Fig. 3). When the crop flow rate fed to the length of 1 m of the threshing drum rasp bar was increased the grain separation through the thicker crop layer at the beginning of the concave minimized (Fig. 2, curve 1).

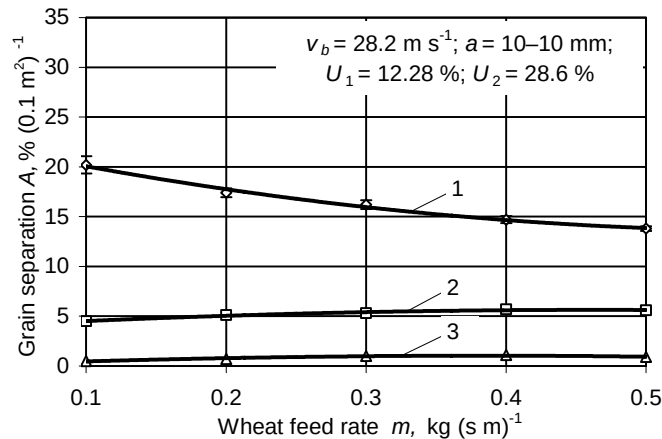


Fig. 2. Impact of wheat species 'Zentos' flow rate m on grain separation A : A_1 – through the additional segment of the concave; A_2 – through the main concave; A_3 – through the rod grades (v_b – threshing drum flail speed; a – the clearance between the threshing drum rasp bars and at the beginning and the end of the concave transverse bar; U_1 – grain moisture content; U_2 – straw moisture content).

$$\begin{aligned} A_1 &= 25 m^2 - 30.5 m + 22.86; & R_1^2 &= 0.99; \\ A_2 &= -8.57 m^2 + 7.94 m + 3.8; & R_2^2 &= 0.97; \\ A_3 &= -7.14 m^2 + 5.48 m - 0.02; & R_3^2 &= 0.93 \end{aligned}$$

Grain separation remained unchanged through the main concave because threshed grain remaining in the ears after the separation from the additional segment part of the concave were separated later (Fig. 2, curve 2). Approximately 1% of grain was separated through rod grades (Fig. 2, curve 3).

During the threshing of the thicker wheat layer the impulses of the drum rasp bars were more suppressed (Wacker, 1990), their impact on ears was less and fewer grains were damaged for this reason (Fig. 3). In the grain separated through the additional part of the concave (Fig. 3, curve 1), the least amount number of damaged grain was found because the rasp bars had some impact on ears only at the very surface of the layer. The greatest amount of damaged grain (Fig. 3, curve 3) was found in the grain separated through the rod grades as there was air flow in the rotated threshing drum that blew off the smaller mass grain particles from the concave.

Similar results were achieved during harvesting of wheat species 'Bussard' with combines *New Holland CX 860* (Fig. 4, curve S_1) and *New Holland CSX 7080* (Fig. 4, curve S_2) where the grain damage was influenced not only with the threshing apparatus but ear beater and grain augers and elevators as well. In both tests when the wheat flow rate into combine-harvester was increased the grain damage was reduced but it started to increase again when the permissible threshing drum rasp bars load ($0.72 \text{ kg (s m)}^{-1}$) was exceeded.

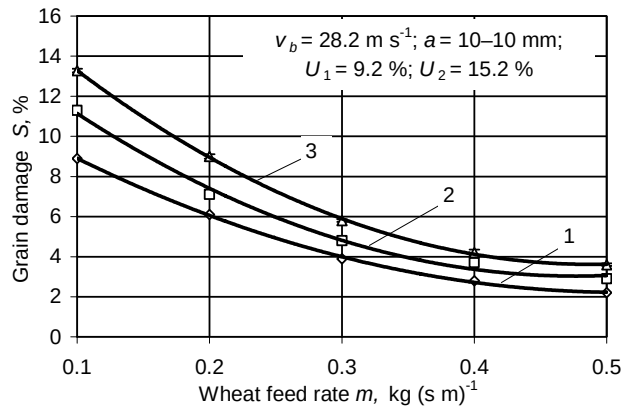


Fig. 3. Impact of wheat species 'Zentos' flow rate m on grain damage S : S_1 – percentage of damaged grain in the grain mass separated through the additional segment of the concave; S_2 – separated through the main concave; S_3 – separated through the rod grades.

$$\begin{aligned}
 S_1 &= 39.3 m^2 - 40.3 m + 12.5; & R_1^2 &= 0.99; \\
 S_2 &= 57.1 m^2 - 54.5 m + 16.0; & R_2^2 &= 0.99; \\
 S_3 &= 64 m^2 - 62.6 m + 18.9; & R_3^2 &= 0.99
 \end{aligned}$$

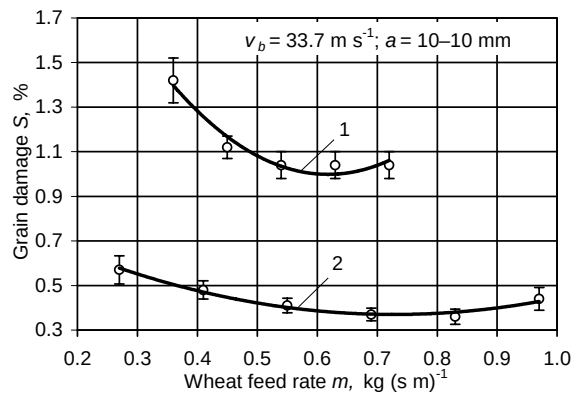


Fig. 4. The impact of the wheat species 'Bussard' flow rate m on the grain damage S during the harvesting with combines *New Holland CX 860* (S_1) and *New Holland CSX 7080* (S_2): 1 – combine-harvester *New Holland CX860*, $U_1=18.2\%$, $U_2=31.5\%$; 2 – combine-harvester *New Holland CSX 8070*, $U_1=12.61\%$, $U_2=17.9\%$

$$\begin{aligned}
 S_1 &= 5.99 m^2 - 7.41 m + 3.29; & R_1^2 &= 0.95; \\
 S_2 &= 0.99 m^2 - 1.446 m + 0.896; & R_2^2 &= 0.97
 \end{aligned}$$

Combine-harvester *New Holland CSX 7080* damaged fewer wheat grains than combine-harvester *New Holland CX 860* because the trash from the ear auger was returned not into the ear beater but into the threshing apparatus that was less harmful.

The comparison results of laboratory and field tests showed that the grain was less damaged when the thicker crop layer was threshed but the permissible flail load could not be exceeded. Crop harvesting conditions have impact on the permissible load of the one-meter length of the rasp bar. For this reason this load can be varied from 0.7 to 0.96 kg (s m)⁻¹ for combines *New Holland*.

Clearance between the threshing drum and the concave. To increase the performance of the threshing apparatus, equal clearance was set between the threshing drum rasp bars and concave transverse bars at the beginning and the end of the concave or approximately 2 mm smaller clearance at the end of the concave. When the dry wheat species ‘*Zentos*’ was threshed in the laboratory (Fig. 5) it was determined that the grain damage could be minimized by changing the ratio of the clearance between the drum and the concave at the beginning or at the end of the concave.

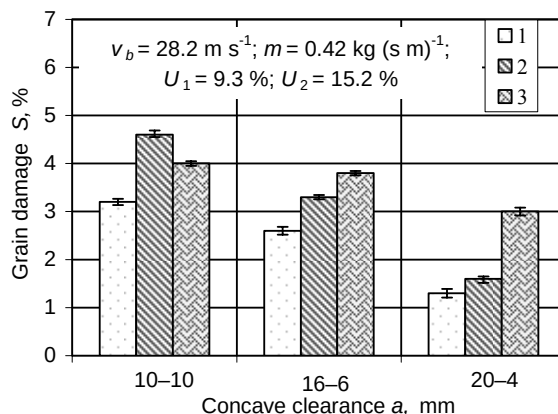


Fig. 5. The impact of the clearance between the drum rasp bars and the concave transverse bars on the grain damage of wheat species ‘*Zentos*’: 1 – the percentage of the damaged grain in the grain mass separated through additional part of the concave; 2 – grain damage in the grain mass separated through the main concave; 3 – grain damage in the grain mass separated through the rod grades; $LSD_{0.05}(1)=0.0757$; $LSD_{0.05}(2)=0.0681$; $LSD_{0.05}(3)=0.0834$; $LSD_{0.05}(1;2;3)=0.0707$.

When the clearance was increased at the beginning of the concave more grain was threshed at the concave end, they were not separated through the concave and were thrown on the straw walkers together with the straw (Shpokas & Steponavičius, 2006). To minimize the grain damage and straw crumble when very dry cereals are harvested with combines *New Holland CSX 7080*, increasing the clearance between the threshing drum and the concave from 10–10 mm to 12–12 mm had no significant influence on the grain damage.

When very dry wheat yield was harvested with combine *New Holland CX 860* (Fig. 6) and the clearance between the drum and the concave was increased above 10–10 mm the grain damage started to increase. This is explained by the crop flow rate change in the clearance between the drum and the concave (Roi et al., 1984).

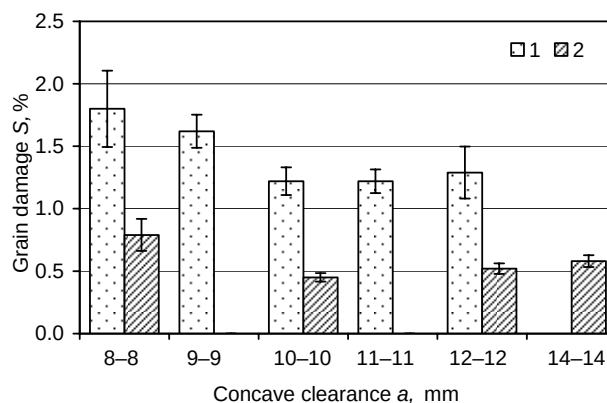


Fig. 6. The impact of the clearance a between the threshing drum and the concave on the grain damage of wheat species 'Bussard' S: 1 – combine-harvester *New Holland CSX 7080* ($v_b = 31.4 \text{ m s}^{-1}$; $m = 0.67 \text{ kg (s m)}^{-1}$; $U_1 = 10.4\%$; $U_2 = 23.6\%$); 2 – combine-harvester *New Holland CX 860* ($v_b = 29.4 \text{ m s}^{-1}$; $m = 0.67 \text{ kg (s m)}^{-1}$; $U_1 = 12.6\%$; $U_2 = 17.9\%$)

The estimation of test results from 2005–2007 showed that when combine-harvesters *New Holland* were used to harvest very dry crops (grain moisture content $<12\%$) the optimum clearance between the threshing drum rasp bars and the concave was 12–12 mm, and for the dry crops (moisture content between 12% and 14%) the clearance was 11–11 mm and for the medium dry crops the clearance was 10–10 mm, accordingly. When harvesting the wet crop, the clearance should be 10–10 mm. If the grain loss was $>0.05\%$ the flail speed must be increased.

Threshing drum rasp bars speed. When harvesting wet crop (moisture content $> 16\%$) the grain loss was reduced by maximizing the threshing drum speed. (Wacker, 1990) stated that when the speed of the threshing drum rasp bars was increased more damaged grain was separated through the concave. When the crop was harvested the threshing drum rasp bars speed was from 30 m s^{-1} to 32 m s^{-1} .

Grain damage depends not only on the threshing drum speed (Fig. 7) but on the crop species, grain and straw moisture content, etc. (Eimer, 1988). Barley grain was less damaged if compared with wheat grain (Fig. 7, curve S_2) as the shell protected the grain.

Combine-harvester *New Holland* had four drum threshing-separation apparatus thus a lower drum rasp bars speed could be selected during crop harvesting because the rotor-type straw separator threshed part of the grain from the ears. After the estimation of the threshing grain loss that had wide variation limits the conclusion was made that the optimum drum rasp bars speed when dry crop was harvested should be 25 m s^{-1} and when wet crop was harvested the rasp bars speed should be from 31 m s^{-1} to 34 m s^{-1} .

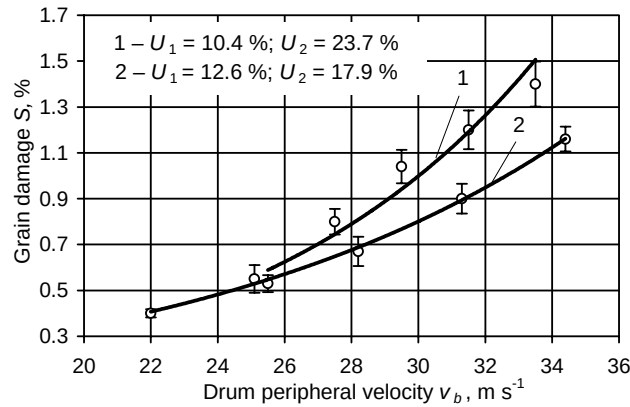


Fig. 7. The impact of the threshing drum rasp bars speed v_b of combine-harvester *New Holland CX 860* on the grain damage of wheat species 'Bussard' (S_1) and the threshing drum speed of combine-harvester *New Holland CSX 7080* on the grain damage of barely species 'Henni' (S_2); $a = 10\text{--}10$ mm; $m = 0.69$ kg (s m)⁻¹

$$S_1 = 0.0295e^{0.1174v_b}; \quad R_1^2 = 0.95;$$

$$S_2 = 0.061e^{0.086v_b}; \quad R_2^2 = 0.99$$

The comparison of the laboratory and field test results showed that when the crop flow rate fed into the threshing apparatus and its technological parameters were changed the grain damage variation character was similar but laboratory tests showed that more grain was damaged because drier crop was threshed.

CONCLUSIONS

The grain damage decreases when the speed of the crop flow rate fed into the threshing apparatus is increased up to the permissible load of the threshing drum. The permissible load of the threshing drum rasp bars one meter length segment of the threshing-separation apparatus with four drums is from 0.7 to 0.96 kg (m s)⁻¹.

In the multi-drum threshing-separation apparatus the change of the clearance between the threshing drum and the concave from 10–10 mm to 12–12 mm had no significant influence on the grain damage. The clearance size was changed during the day because the crop moisture content varied. When harvesting very dry crop (grain moisture content <12%) the rational clearance between the threshing drum rasp bars and the concave was 12–12 mm, with dry crop (moisture content between 12% and 14%) the clearance was 11–11 mm and with average moisture crop (moisture content between 14% and 16%) the clearance was 10–10 mm. When harvesting wet crop (moisture content >16%) the clearance was 10–10 mm. Threshing grain loss was minimized to permissible (0.05%) by increasing the threshing drum rasp bars speed.

The greatest impact on grain damage is the threshing drum rasp bars speed. When the permissible dry crop flow was fed into the threshing apparatus the maximum rasp bars speed was 25 m s⁻¹ and when wet crop was fed the maximum rasp bars speed was from 31 to 34 m s⁻¹. When the trash from the combine ear auger was returned to the ear beater drum more grain was damaged than when the trash was returned to the threshing apparatus.

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