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Effect of additional elements on breaking-up of maize grain harvested with forage harvester with the chopping unit

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Abstract: *Effect of additional elements on breaking-up of maize grain harvested with forage harvester with the chopping unit.* There was investigated the operational effect of additional elements used in the chopping unit of forage harvester on breaking-up of maize grain harvested for silage. It was found that application of bottom beater plate and plain thrower paddles, working at working clearance between them set to 8 mm at the inlet and 2 mm at the outlet, allowed for effective increase in grain breaking-up. Application of other additional elements in the form of bottom plate with beater and bar notches, the thrower paddles of notched and plain surfaces, and the radial notched and plain bars resulted in lower effectiveness of maize grain breaking-up.

Key words: forage harvester, chopping unit, additional breaking-up elements, maize grain breaking-up index.

INTRODUCTION

The chopping unit has been used in forage harvesters of small capacity, where number of maize harvesting sections is not bigger than three (Lisowski, 2003). In order to increase effectiveness of maize grain breaking-up without a decrease in the chaff length, in chopping units of that type there are used additional working elements in the form of bottom plate and bars mounted under the cutting knives.

In forage harvesters with the chopping unit there are used exchangeable plates of ribbed surface. These plates are placed in cylindrical part of chopping unit housing. The working elements can include the notched bars arranged perpendicularly or diagonally or shed roof type bars. There are used single plates, the sets of plates separated by the part of housing or sectional elements (Lisowski, 2005).

The thrower paddles mounted on a knife disk differ in working element design, creating the end surface. The thrower paddles with constant or exchangeable elements of plain or notched surfaces are most often used. The number of them varies, but in agricultural practice the thrower paddles are mounted between each pair of knives. To obtain the high effectiveness of grain breaking-up, different working surfaces of exchangeable bottom and the end elements of thrower paddles are mounted together.

The increased effectiveness of grinding of the maize grain and plant particles in working clearance between these elements can be additionally achieved by application of radial guides (bars) mounted under the knives.

Information on the elements assisting in maize grain breaking-up can be found in machine technical documentation, however, there is lack of investigations proving operational effectiveness of particular technical solutions.

This work aimed at designing, fabrication and investigating of various notched bottom plates, thrower paddles and radial bars mounted in the chopping unit for breaking-up, crushing, crumbling and defibering of the cut maize grain and plant particles. The quality effects of additional working element's operation were investigated at various working clearance between the bottom plate and thrower paddles. The index of maize grain breaking-up was taken as evaluation criterion.

MATERIAL AND METHODS

The investigations were carried out on a stationary stand consisted of forage harvester with chopping unit and belt conveyor, on which the maize plants of San variety were placed over the distance 4 m. The machine working units were driven through PTO shaft of tractor Ursus 1234 of nominal power 85 kW. The investigation results under medium working conditions were analyzed. The mass of each maize plant sample of medium moisture content 45% amounted to 15 kg. The belt conveyor speed was equal to 1 $m \cdot s^{-1}$, while rotational speed of knife disk to 660 rpm. The remaining forage harvester's units were set according to recommendations of machine manufacturer SIPMA SA.

In investigations there were used three bottom plates of working surface formed by beater bars or welded rods; for the contrast there was used also the plain surface. The thrower paddles differed in working surface, which had the form of notches created by the beater bars with left hand or right hand bevel, while the third set was of plain surface. The radial bars had notched or plain surface; for the contrast, the investigations were also carried out without these elements. The working clearance between bottom plate and thrower paddles was set to 8 mm at the inlet, while at the outlet it was adjusted to the three levels: 2, 5 and 8 mm.

To determine the index of maize grain breaking-up there was taken a chaff sample of 100 g, which was screened on a set of sieves included in the sieve classifier (shaker) driven by electric motor through the crank mechanism.

The randomly chosen chaff sample was screened through the sieves of aperture size (from the top) 9, 8, 7, 6, 5, 4, 3, 2 mm during 4 minutes. Basing on preliminary investigations, the time was selected so, that the mass of particular fractions was changed no more. The content of each sieve was weighed on electronic scale with accuracy 0.01 g.

The whole and broken-up grains were selected from the sieves of aperture size 6, 7, 8 and 9 mm, and then weighed. Since it was difficult to separate the broken-up grains remained on the sieves of aperture size 5–2 mm and at the last container bottom from cut particles of other maize components, this part of broken-up grain was determined on the basis of grain percent ratio in the entire maize mass, determined during hand grain shelling of the corncobs from 30 plants. The obtained results were used in further analyses.

The effect of maize grain breaking--up was evaluated using the breaking-up index:

$$k_z = \frac{m_p u_z - \sum_{i=6}^{9} m_{ci}}{m_p u_z} \cdot 100 \qquad (1)$$

where:
k_z – index of maize grain breaking-up [g],
m_p – mass of chaff sample [100 g],
u_z – mass ratio of grain in the entire maize plant,
m_{ci} – mass of unbroken-up maize grain on *i*-sieve [6–9 mm].

RESULTS OF INVESTIGATIONS AND DISCUSSION

Basing on carried out statistical analysis it was found that the maximal relative error between rotational speed of tractor PTO and the assumed values for particular levels of the knife disk rotational speed was lower than 2%, while the maximal relative difference in the knife disk rotational speed between the test runs amounted to 2.6%; it proved good repeatability of investigation results.

The analysis of variance proved that the values of maize grain breaking-up index were significantly different for bottom plate types (significance level $\alpha = 0.0007$), thrower paddles ($\alpha = 0.0063$) and working clearance ($\alpha = 0.0002$). However, the arrangements of forage harvester operation with application of various radial bars did not influence this index significantly ($\alpha = 0.2746$).

Application of ribbed bottom plates resulted in better breaking-up of maize grain, when compared to operation of the plain bottom plate. The maximal value of this index was found for the beater bottom plate (65.11%), the significantly lower value for the rod type (58.63%) and the least value for the plain plate (45.78%) (Fig. 1). Application of the beater bottom plate enabled to increase the average breaking-up index value by over 19%, when compared to the plain bottom plate.

The average value of maize grain breaking-up index for the beater thrower paddles with left hand bevel of notches amounted to 52.57%, while for right hand bevel notches it amounted to 53.99%; the highest value of this index (62.96%) was found for the plain paddles (Fig. 2). Therefore, application of plain paddles

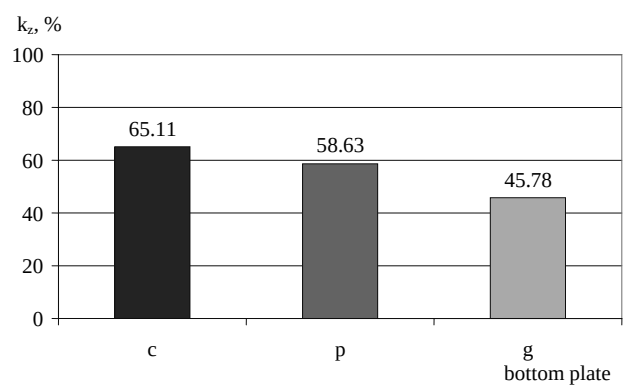

FIGURE 1. Average values of maize grain breaking-up index for various bottom plates: c – beater plate, p – rod plate, g – plain plate

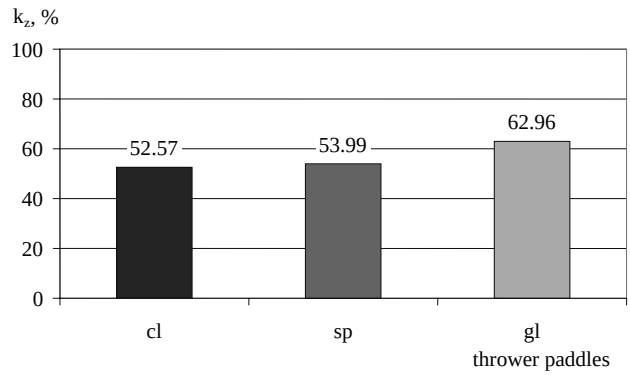

FIGURE 2. Average values of maize grain breaking-up index for various thrower paddles: cl – beater paddle with left hand bevel of notches, sp – beater paddle with right hand bevel of notches, gl – plain paddle

gave the best breaking-up of maize grain, although operational effects of paddles with notches were comparable. The significantly worse grain breaking-up by notched paddles can be caused by bigger amount of grain entering the grooves between notches; therefore, the grains were not grounded, crushed or crumbled by edges of cooperating elements, namely the bottom plate and thrower paddles. The working edges of thrower beater paddles were slightly rounded and set an angle 45° to direction of the knife disk movement. Besides, the rake angle of beater paddles differed significantly from the right angle in the flat thrower paddles. Both the inclination angles resulted in bigger grain slip in relation to bottom plate surfaces and in a decrease of the breaking-up effect. The increased transverse slip of grains eliminated the expected operational effects of the wedge clearance between the inclined surface of thrower beater paddles and the surface of bottom plate.

Application of thrower beater paddles with right hand bevel of notches improved inconsiderably only the grain breaking-up when compared to left hand bevel of notches. It was expected that the thrower beater paddles with right hand bevel would allow for more uniform chaff distribution across the cooperating working elements. When the plant batch was cut off by the disk set knife, the chaff was partially thrown away to opposite side and the notches with right hand bevel shifted the material in opposite direction, improving uniformity of the layer's thickness, leading to improvement of these elements' operation. However, the effect of application of thrower paddle design solutions of right hand bevel notches on the changes in grain breaking-up index was insignificant, when compared with left hand bevel notches.

The plain thrower paddles were made in the form of rectangular plates bolted to the grippers fixed to the knife disk. During operation the sharp edges of plates well cooperated with bottom plate surfaces. Te sharp edges, arranged perpendicularly to direction of disk rotational movement, allowed for easier tearing, crushing and crumbling of

maize grains, especially with connection with the bottom plate notched surfaces, including the rod bottom plate of edges perpendicular to direction of the knife disk rotational movement.

Application of both the notched and plain radial bars did not improve the maize grain breaking-up; the differences in average values of grain breaking-up index for the bars were insignificant in relation to forage harvester operation without bars (Fig. 3).

The work of chopping unit at the least working clearance between the bottom plate and thrower paddles was most effective. The setting of working clearance to 2 mm at the outlet enabled to increase the value of average grain breaking-up index by over 29%, when compared to 8 mm clearance (Fig. 4), although dynamics of this increment was not identical. The change of outlet clearance from 8 to 5 mm caused an increase in average index value by 50%, while the change from 5 to 2 mm only by 15%.

Therefore, application of proper additional elements assisting in maize grain breaking-up was purposeful. It was found that the best additional elements

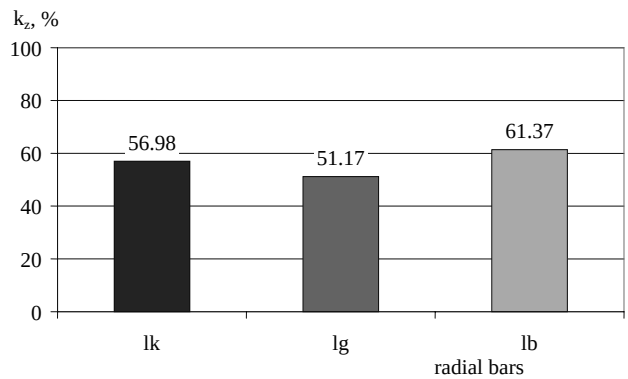

FIGURE 3. Average values of maize grain breaking-up index for various radial bars: lk – notched bar, lg – plain bar, lb – no bar

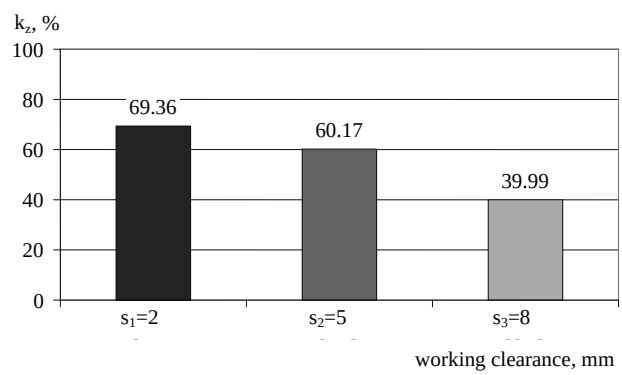

FIGURE 4. Average values of maize grain breaking-up index for various working clearance between bottom plate and thrower paddles

included the beater bottom plate and the plain thrower paddles. It was also found that application of the wedge working clearance between bottom plate and thrower paddles increased effectiveness of maize grain breaking-up. Under such conditions, the grain grinding, crumbling and crushing was better.

CONCLUSION

It was found that application of beater bottom plate and plain thrower paddles working at working clearance equal to 8 mm at the inlet and 2 mm at the outlet allowed for effective improvement of grain breaking-up. Application of other additional working elements in the form of bottom plate with the beater and rod notches, thrower paddles with notched and plain surfaces and radial notched and plain bars resulted in lower effectiveness of maize grain breaking-up.

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Streszczenie: *Wpływ dodatkowych elementów na rozdrabnianie ziaren kukurydzy zbieranej sieczkarnią polową z toporowym zespołem tnącym.* Przeprowadzono stacjonarne badania sieczkarni polowej z toporowym zespołem rozdrabniającym, który wyposażono w dodatkowe elementy robocze w postaci płytki dennej, łopatek rzutnika i listew promieniowych różniących się powierzchnią roboczą. Stwierdzono, że spośród płytek dennych o powierzchni karbowanej i gładkiej najlepsze efekty rozdrabniania ziaren kukurydzy osiągnięto podczas pracy zespołu roboczego wyposażonego w płytkę denną o powierzchni ukształtowanej z listew cepowych. Ostre krawędzie gładkich łopatek rzutnika pozwoliły na znacznie lepsze rozdrobnienie ziaren kukurydzy niż łopatki rzutnika o powierzchniach karbowanych. Okazało się również, że zastosowanie klinowej szczeliny roboczej między płytką denną a łopatkami rzutnika zwiększyło efektywność działania współpracujących elementów. Nie stwierdzono natomiast jednoznacznie, że działanie listew promieniowych poprawiło skuteczność rozdrabniania ziaren.

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