

Substantiation of technological parameters of wet maize ear threshing

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Abstract. The paper presents the test results of wet maize ear threshing process during the period of 2003–2005. Grain biometrical indices, technological parameters of threshing apparatus, and the feed rate of the maize ears appeared to be the most significant causes of threshing drum losses, grain damage, and the threshed amount of grains thrown to the straw walkers. The concave clearance of the threshing apparatus is related with and depends on the internal diameter of the maize ears and cores. The concave clearance at the beginning should be approximately 10 mm smaller than the average ear diameter, and at the end it should be equal to core diameter. The clearance between the rasp bars and the transverse bar at the concave end should be controlled by the computer because the ears of different diameters are fed into the threshing apparatus. When wet ears (grain moisture content >35%) are threshed the drum losses are reduced by varying the speed of the drum rasp bars and the clearance between the drum and the concave. Rational rotational speed of the drum rasp bars is 17 m s^{-1} . When wet ears are threshed the even ear flow rate should be supplied into the threshing apparatus. The medium load of one meter rasp bar length should be $0.82 \text{ kg (s m)}^{-1}$.

Key words: maize ears, threshing, biometrical indices of ears, technological parameters

INTRODUCTION

At the end of October the maize of early ripeness of hybrid varieties reach the yellow grain ripeness stage in Lithuania. In a beneficial meteorological situation the grain moisture content is about 31% during the maize yield harvest. When the meteorological situation is worse the grain moisture content can be from 35% to 40% (Špokas et al., 2006). Drying the maize grain to 14% moisture content is not economically viable. It should be crushed for preservation in the hose or chopped for preservation in the trench.

In Western countries maize ears are harvested at grain moisture content from 28% to 35% ; after that, they do not accumulate additional nutritional value (Ackermann, 1997). Many researchers have investigated the threshing process of maize yield. The most significant qualitative estimation parameters of the maize ear threshing process are drum losses (0.5%), the grain damage (5%), and the grain separation through the concave (>85%) (Petunina, 2006). When wet maize ears are being threshed the grain damage can exceed the permissible limit because the grain will be crushed or the maize ears will be chopped before preservation.

The maize ear threshing process is closely related with biometrical parameters (Gokoev, 1966), physical-mechanical characteristics (Huszar, 1982). The maize ears have conical and less often cylinder form (Shpokas et al., 2007). The grain form depends on the maize variety. Pedicels connect grains with the maize core. The grain bottom is incased in the blossom corona. The strength of the grain and core connection depends on the maize variety, humidity and the grain position in the ear (Shpokas et al., 2007). The grain connection with the core is the strongest at the ear bottom and the weakest at the peak. When the rasp bars of the threshing drum deform the ear the grains are separated from the core (Kravchenko & Molofeev, 1984). The design and technological parameters of the threshing apparatus (the speed of the drum rasp bars, the clearance between the drum and the concave) have the greatest impact on the ear threshing process.

Grains are least damaged by the axial threshing-separation apparatus because the ears are crushed and ground between the drum and the concave (Byg & Hall, 1968). Grains with 18–25% humidity are successfully threshed when the speed of the drum rasp bars is 7 m s^{-1} . Lithuania has few combines with an axial threshing-separation drum.

Ears are threshed by the pulses of drum rasp bars (at the speed of 16 m s^{-1}) in the tangential threshing apparatus. Ears are deformed between the drum and the concave. Grain separation through the concave is more intensive in comparison with the axial threshing-separation apparatus because the rasp bar pulses are harder (Wacker, 2005). Humid grain (moisture content from 12–20%) are most severely damaged, because the dry grain elasticity is approximately 1000 MPa, and that of the wet is 180 MPa (Kustermann, 1987).

Technological parameters of the threshing apparatus have the greatest impact on the maize ear threshing process. When the threshing of cereals and maize crops is compared the clearance between the drum and the concave is more important for the qualitative indices of the maize threshing process estimation. The clearance between the drum and the concave should be from 10–15 mm smaller than the ear diameter (Danilevich, 1961; Kravchenko & Kuceev, 1987). The drum rasp bar speed must correspond to the clearance between the drum and the concave because it has the greater impact on grain damage in comparison with the variation of the clearance between the drum and the concave (Nalbant, 1990). The core inhibits the rasp bar pulses, thus less grain is damaged when the more humid ears are being threshed. Most authors (Surilova, 1970; Kutzbach, 1989; Kosilov, 1999) indicated that the technological parameters of the combine threshing apparatus should be adjusted with the change of the characteristics of the harvested crops. This is very important while threshing wet maize ears.

The investigation goal is to specify the main biometrical parameters of the wet maize ears and the technological parameters of the threshing apparatus.

MATERIALS AND METHODS

In 2003–2005 the trials were fulfilled at the Department of Agricultural Machinery of Lithuanian University of Agriculture. The meteorological situation was as forecast by Kaunas Meteorological Station.

Biometrical indices of maize ears. One hundred (100) maize ears were randomly chosen from hybrid maize variety 'G12' collected from the experimental field. The length and diameter of each ear was measured in the laboratory. The grains in vertical rows and horizontal rings were counted. The core dimensions and the mass of 1000 grains were calculated. The mass of the ear (relative humidity 14%), the core and grains was measured. Average data and its statistical indices were estimated.

Trials of the ear flow threshing. The threshing of the maize ears was tested with the test bench at Lithuanian Agricultural University (Fig. 1). The test bench consisted of a 10 m length belt conveyor and threshing drum of 0.6 m diameter and 1.2 m width with 8 rasp bars, the grate concave made of two sections surrounding the threshing drum at the angle of 146° , a wire grate bar and a beater drum. The threshed grain and piths separated from the additional section of the concave, through the concave and a wire grate bar were collected into various capacities. Tests revealed the impact of the drum rotation frequency and the clearance between the drum and the concave on the grain damage, threshing grain losses, grain separation through the concave, the length of pith pieces, etc.

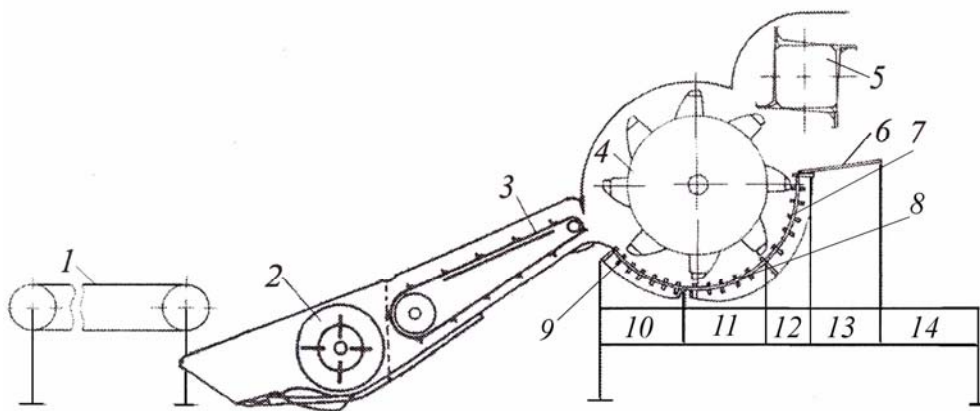


Fig. 1. Test bench for the maize ear threshing:

1 – belt conveyor; 2 – auger; 3 – inclined conveyor; 4 – threshing drum; 5 – beater drum; 6 – wire grate bar; 7 – second part of the main concave; 8 – first part of the main concave; 9 – additional part of concave; 10;11;12;13 and 14 – capacities for threshed materials.

The ear flow fed into the threshing apparatus was varied by supplying various numbers of ears onto the belt conveyor. Weighed samples of maize ears were evenly distributed on the conveyor belts of 2 m lengths.

Grain separation. Threshed materials collected into the first three capacities were individually weighed (record accuracy 0.1 g). Grains were separated from the threshed material and weighed. The grain separation through 0.1 m^2 area of individual concave parts was calculated. The threshed material from the tray 12 was weighed, and the grains and pith pieces were separated, weighed and the amount of grains separated from the concave was estimated. The grains still trapped in the pith pieces were separated, weighed and drum losses were calculated.

Grain damage. Five samples of 50 g were taken from the grains separated through the concaves and wire grate bars. Damaged grains from these samples were separated and weighed (record accuracy 0.01 g), and the portion of damaged grains was calculated.

Experimental data estimation. 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 [$\bar{x} \pm (t_{05} \times s_x)$] are presented. In order to establish correlation of two factors, the curvilinear correlation coefficient R^2 was calculated. To establish the direction and size of factor correlation, the regression equations were arranged.

RESULTS AND DISCUSSION

Biometrical indices. The diameter and humidity of ears and cores has the greatest impact on the threshing process of maize ears (Table 1). The clearance between the drum and the concave at the beginning of the concave should be less than the external diameter of the ear, and at the end of the concave it should be not smaller than the medium core diameter for the drum rasp bars to thresh and not damage the grains. The optimum clearance size can be substantiated by the trials after the estimation of the biometrical ear parameters.

The comparison of biometrical indices of the maize ears of variety 'G12' in the trials of 2003–2005 specified that the average external diameter of the ear varied from 39.4 ± 1.7 mm to 42.3 ± 0.5 mm, and the core diameter varied from 21.9 ± 0.42 mm to 24.1 ± 0.4 mm. Thus when the optimum clearance between the drum and the concave was adjusted it should be corrected only after significant change of the maize ear harvesting situation.

Table 1. Biometrical indices of maize ears of variety 'G12' in the trials of 2003–2005.

Indices	Measurement units	2003	2004	2005
Ear diameter	mm	41.0 ± 1.3	39.4 ± 1.7	42.3 ± 0.5
Ear length	mm	177 ± 5	177 ± 5	201 ± 4
Number of vertical grain rows	unit	14.0 ± 0.3	13.1 ± 0.4	13.5 ± 0.3
Number of horizontal grain rings	unit	31.0 ± 1.1	30.3 ± 1.6	30.0 ± 0.5
Grain number in the ear	unit	395 ± 17	350 ± 29	482 ± 22
Grain mass in the ear (moisture 14%)	g	117 ± 7	97.0 ± 10.2	132 ± 6
1000 grain mass (moisture 14%)	g	301 ± 6	277 ± 16	273 ± 11
Core mass (moisture 14%)	g	16.8 ± 1.8	14.2 ± 0.8	27.2 ± 0.9
Core diameter	mm	21.9 ± 0.4	22.6 ± 0.9	24.1 ± 0.4
Difference between the ear and the core diameter	mm	19.1	16.8	18.2

The clearance between the drum and the concave, and the speed of the drum rasp bars depends on the grain humidity that varies via the ear length. It was specified that at the ear bottom the grain moisture content was the greatest, and it reduced closer to the ear top. When the grains of medium humidity (33%) were harvested the difference between the grain humidity at the beginning of the ear and its top was about 10%. Humid grains have stronger relationship with the core thus pulses of rasp bars should be harder.

Maize ear flow rate fed into the threshing apparatus. The position of the maize ears fed into the threshing apparatus by the inclined conveyor of the combine harvester from the point of view of the drum shaft was different. Their interrelation hindered the ear movement in the clearance between the drum and the concave. Thus they exerted more rasp bar pulses than the individual ears being threshed. This was validated by the grain separation variation along the concave length (Fig. 2).

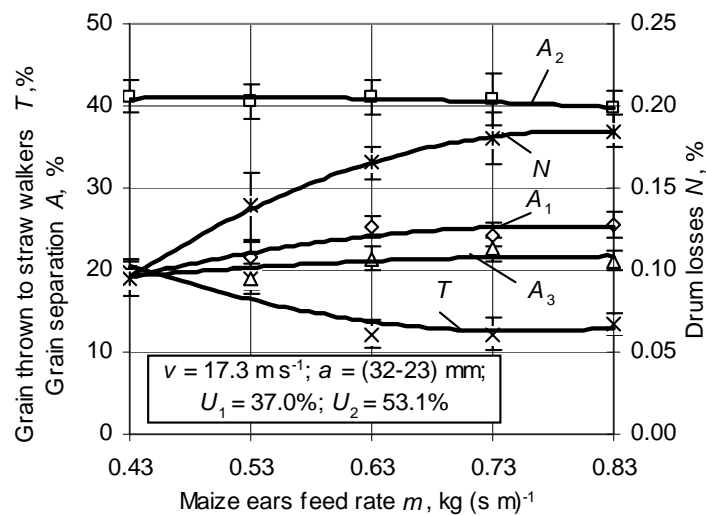


Fig. 2. The influence of maize ‘G12’ ears feed rate (m) to the grain separation (A), grain thrown to straw walkers (T) and grain losses (N):

A_1 – grain separation through the additional part of the concave; A_2 – grain separation through the first part of the main concave; A_3 – grain separation through the second part of the main concave; T – grain thrown to straw walkers; N – grain losses

$$N = -0.645 m^2 + 1.03 m - 0.225; \quad R^2 = 0.98;$$

$$T = 77.6 m^2 - 116 m + 56.0; \quad R^2 = 0.82$$

When more ears were fed the grain separation at the beginning and at the end of the concave increased thus the part of the threshed grains thrown from the concave surface did not exceed the permissible 20% limit. The flow of the fed maize ears had more significant influence on the drum losses (N) that did not exceed the permissible limit at the load of $0.83 \text{ kg (m s)}^{-1}$ of one meter length of drum rasp bar because the drum rasp bar speed was 17.3 m s^{-1} .

When wet maize ears were threshed (Fig. 3) and more ears were fed into the threshing apparatus fewer grains were damaged. Most maize ears were broken into two pieces during the threshing and spiked parts of cores were broken off. The average length of the core pieces was about 70 mm.

When more ears were fed into the threshing apparatus their interaction time with drum rasp bars and the concave surface was longer and the average length of core parts was smaller (Fig. 3) but more threshed grains passed through the concaves (Fig. 2).

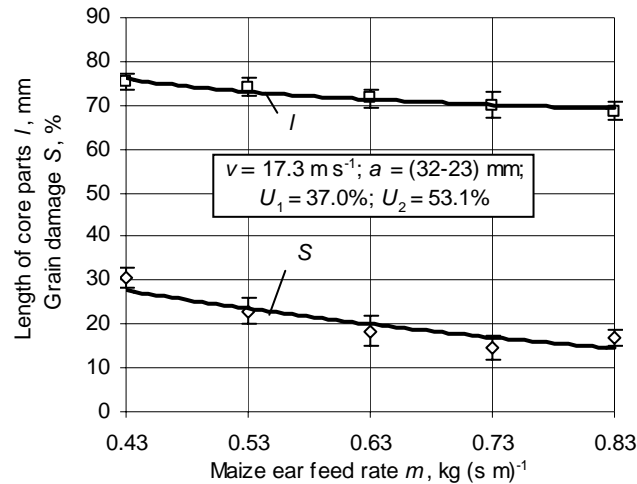


Fig. 3. The impact of the maize ear variety ‘G12’ flow (m) of the fed into the threshing apparatus on the average length of core parts (l) and the grain damage (S):

$$l = 67.1 m^{-0.17}; \quad R^2 = 0.94;$$

$$S = 61.6 e^{-1.75 m}; \quad R^2 = 0.80$$

Drum peripheral velocity. Combine manufacturers and the researchers of maize ear threshing processes (Danilevich, 1961; Arnold, 1964; Kravchenko & Kuceev, 1987; Kustermann, 1987) specified that when ears were threshed the drum peripheral velocity should be approximately 14 m s^{-1} , but the speed had to be greater when wet ears were threshed (Fig. 4) because drum losses exceeded 4%.

Drum losses were less than 0.5% when the speed of rasp bars was 16 m s^{-1} . When the speed of rasp bars was increased the grain separation through the concaves maximized, the drum losses, and the grain separation through the first part of main concave (A_2) and second part of main concave (A_3) were minimized. When the speed of drum rasp bars was 16 m s^{-1} , less than 20% of the threshed grains were thrown from the threshing devices onto straw walkers. Having in mind that the ears of various humidity contents were threshed the speed of the drum rasp bars should be not less than 17 m s^{-1} . The speed of the rasp bars of the threshing drum was closely related with the grain damage (Fig. 5). When wet ears were threshed at the drum rasp bar speed of 16 m s^{-1} the grain damage exceeded the permissible limit by 3.8 times. When the drum peripheral velocity was increased their impact on the ears was stronger and the cores were more crumbled (Fig. 5).

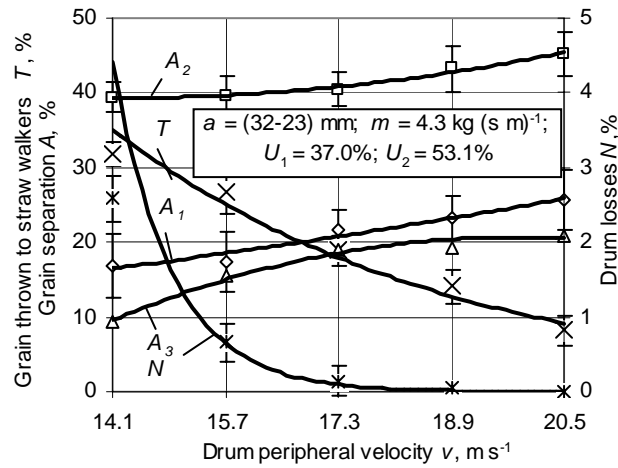


Fig. 4. Influence of drum peripheral velocity (v) to the grain ‘G12’ separation (A), grain thrown to straw walkers (T) and grain losses (N):

A_1 – grain separation through the additional part of the concave; A_2 – grain separation through the first part of the main concave; A_3 – grain separation through the second part of the main concave; T – grain amount on the straw walkers; N – drum losses

$$N = 1.2 \cdot 10^8 e^{-1.21v}; \quad R^2 = 0,91$$

$$T = 695 e^{-0.211v}; \quad R^2 = 0,96;$$

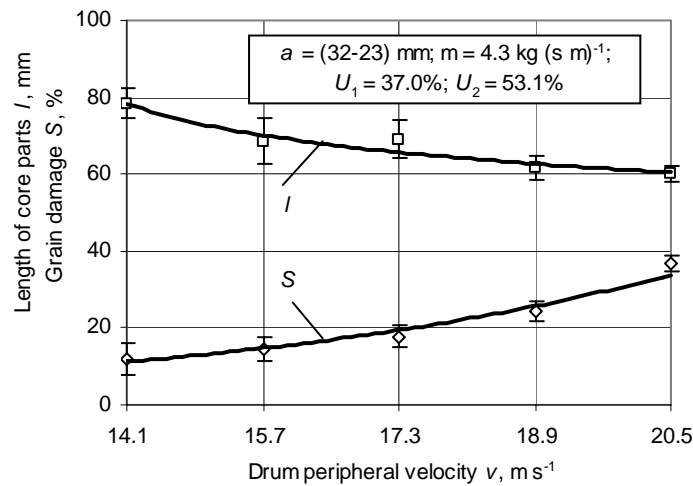


Fig. 5. Influence of drum peripheral velocity (v) to the maize ‘G12’ length of core pieces (l) and grain damage (S)

$$l = 499 v^{0.696}, \quad R^2 = 0,93;$$

$$S = 0.99 e^{0.174v}, \quad R^2 = 0,94$$

Clearance between the drum and the concave. The grain damage could be reduced by increasing the flow of the ears fed into the threshing apparatus and the clearance between the drum and the concave (Figs 6 and 7). But by increasing the clearance between the drum and the concave (the grain humidity 34.7%) the grain separation at the beginning of the concave (A_1) decreased because fewer grains were threshed and therefore grain losses (N) increased. When the gap between the drum rasp bars and the concave was about (35–35) mm the grain losses exceeded the permissible limit.

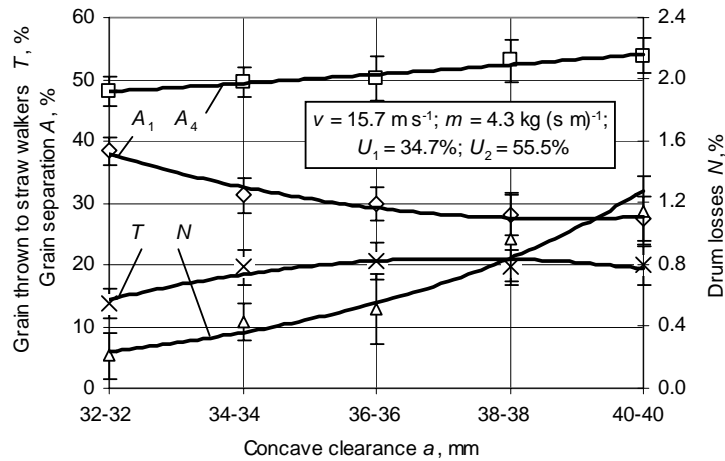


Fig. 6. Influence of concave clearance (a) to the grain ‘G12’ separation (A), grain thrown to straw walkers (T) and grain losses (N): A_1 – grain separation through the additional part of the concave; A_4 – grain separation through the main concave; T – grain amount on the straw walkers, N – drum losses;

$$N = 0.00028 e^{0.211a}; \quad R^2 = 0,96;$$

$$T = -0.237 a^2 + 17.7 a - 308; \quad R^2 = 0,89$$

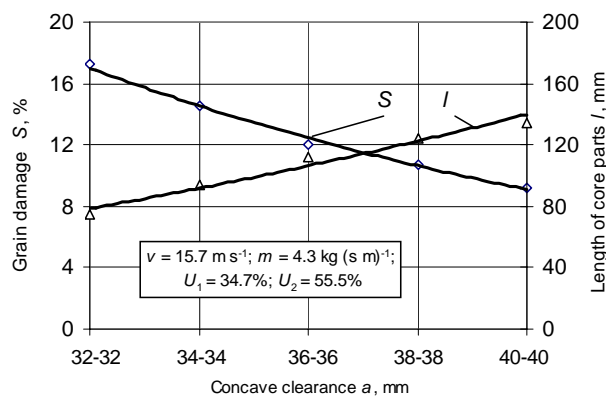


Fig. 7. Influence of the concave clearance (a) to the maize variety ‘G12’ length of core pieces (l) and grain damage (S)

$$l = 0.0098 a^{2.6}, \quad R^2 = 0,97;$$

$$S = 207 e^{-0.0781a}, \quad R^2 = 0,98$$

When the clearance between the drum and the concave was increased (Fig. 7) the ear deformation decreased because the core length increased and the grain damage decreased. When the threshing apparatus has the concave for the crop threshing, the wet maize ears could be not threshed for the drum losses not to exceed the permissible limit and the grain damage would be less than 5%. Thus wet maize grains should be immediately preserved.

After the estimation of biometrical indices of maize ears and the threshing results of the ear flow the conclusion could be made that 32 mm clearance should be set between the drum and the concave at the concave front, i.e., the clearance should be 10 mm smaller than the average diameter of the ear, the clearance at the concave end should be 23 mm, i.e., equal to the core diameter. During the threshing process the ear diameter, ear moisture content and flow rate often change. Thus at the end of the concave the clearance between the drum rasp bars and the concave transverse bar must be controlled by the computer because the ears of different diameter and different moisture content are fed into the threshing apparatus.

CONCLUSIONS

The threshing process of maize ears is mostly related with biometrical indices, grain humidity and their relationship with the core. The average diameter of the ears of maize variety 'G12' varied from 39.4 ± 1.7 mm to 42.3 ± 0.5 mm, and the core diameter was from 21.9 ± 0.42 mm to 24.1 ± 0.4 mm. The difference between the average diameter of the ear and core was about 18 mm, and the difference between the grain humidity at the beginning and the end of the ear was about 10%.

When the ear flow fed on the one meter length of threshing drum rasp bar is up to $0.82 \text{ kg (s m)}^{-1}$ the grain damage decreased, separation through the concave and drum losses increased but did not exceed the permissible 0.5% limit.

When wet ears were threshed (grain humidity about 35%) the clearance between the drum and the concave at the beginning of the concave should be 32 mm, i.e. about 10 mm smaller than the ear average diameter, and the clearance at the concave end should be 23 mm, i.e., equal to the core diameter. At the end of the concave the clearance between the drum rasp bars and the concave transverse bar should be controlled by the computer because the ears of different diameter and different moisture content are fed into the threshing apparatus.

The speed of rasp bars of threshing apparatus is related with ear humidity because wet grains are more strongly connected with the core. When the clearance between the drum and the concave is (32–32) mm the speed of the drum rasp bars should be 10 m s^{-1} (grain humidity about 37%). When the ears of greater moisture content are threshed the clearance between the drum and the concave should be reduced at the concave end.

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