TEKA Kom. Mot. Energ. Roln., 2006, 6, 94–101

AN ESTIMATION OF ENERGY INPUT IN THE PROCESS OF SWEET CORN KERNELS HARVESTING AND CUTTING

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Summary. The research aimed at a description of labour and energy inputs during combine harvesting of cobs and their post-harvest treatment. Additionally, the cut kernels mass was determined for variable angular speeds of the cutter's knife head. The highest work input for a surface unit (11.3 $h \cdot ha^{-1}$) and the material's mass (0.7 $h \cdot t^{-1}$) was recorded for kernels cutting. The energy input, however, was the highest for cob harvesting (about 51% of the total input). An increase of the angular speed of the cutter's knife head in the range from 167.5 to 301.2 $rad \cdot s^{-1}$ at the cob feeder's linear speed 0.31 $m \cdot s^{-1}$ resulted in the cut mass increase by about 28%.

Key words: sweet corn, cob harvesting, kernels cutting, energy input

INTRODUCTION

Sweet corn is a vegetable harvested for consumption before its kernel is fully ripe. Extensive possibilities of sweet corn kernel's use have resulted in the growth of its cultivation area in Poland. It is now 3.5 thousand ha, 40% of which is being used for direct consumption and deep freezing and the remaining part for processing [Waligóra 2004]. This growth is, among others , due to an appearance of new cultivars yielding good crops in our climactic and soil conditions. Cob crops together with covering leaves range from 12 to 18 $t \cdot ha^{-1}$, at the water content in kernel 72-76%, and the cobs number can reach from 40 to 60 thousands per ha. On the market there are over 40 corn cultivars, which can be successfully grown in our country [Warzecha 2003].

Sweet corn home consumption per head reaches about 0.5 kg per head yearly, whereas in West Europe and the United States it exceeds 12 kg per head [Marr and Tisserat 1995, Waligóra *et al.* 1998]. Sweet corn for processing is harvested at the late-milk ripeness phase. A basic condition for sweet corn cobs production growth is using modern technologies for their harvesting and mechanical post-harvest treatment. A low content of sweet corn kernel dry mass, resulting in its high susceptibility to mechanical damage, as well as a lack of tradition of corn growing and high cost of mechanization cause the prevalence of manual cobs harvesting in the so far used technologies. This method guarantees a high quality of the collected material but is highly work-consuming and recommended mainly for small plantations. According to Wize [1998], four people can collect about 2 tons of cobs in 3 hours. It is only in the last years that both trailer and automotive combines have appeared for sweet corn cobs harvesting. Kernel production, from cob harvesting through the covering leaves removal to kernels cutting involves relatively high mass and nutritional losses. Sweet corn cobs are characterized by a high percentage of waste parts consisting of covering leaves and piths with kernel remainders. They reach 40 to 60% [Love 1990, World Bank 1998, Higgins 2002].

Among the requirements as to the cut kernel quality there should be mentioned: equal length of the cut kernels, smooth cutting surface, no mechanical damage and low mass and nutrients losses. The requirements depend on the physical properties of cobs, kernels moisture, their size and mechanical endurance, as well as on the parameters of the cutting process i.e. knives' geometry, cob feeder's linear speed and the angular speed of the head with knives [Niedziółka and Szymanek 2002, Niedziółka *et al.* 2003].

Our research aimed at the determination of the work and energy consumption involved in a combine cobs harvesting and their post-harvest treatment as well as an influence of the speed of the cutter's knife head on the quantity of the cut kernels.

MATERIALS AND METHODS

Tests on work and energy input during harvest and post-harvest processing of sweet corn cobs cultivar Jubilee were carried out in Leszno near Błonie. A scheme of technological activities involved with cobs harvesting and their processing is presented in Fig. 1.

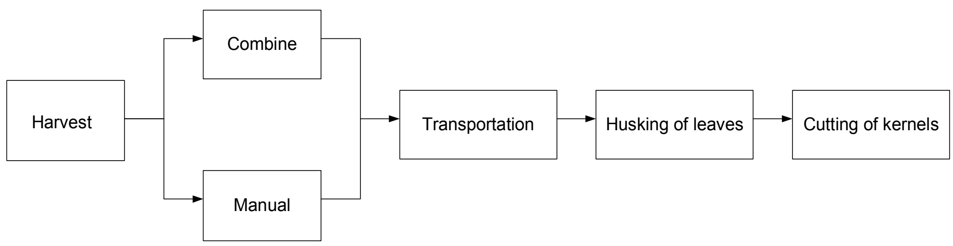

Fig. 1. The scheme of technology of sweet corn cobs harvesting and processing

The cobs harvesting was carried out by a self-propelled cob picker Bourgoin 410 A with the engine power 166 kW. The collected cobs were loaded onto a trailer and transported with an Ursus 1204 tractor (with the power of 85 kW) to the processing factory about 1 km away, were the covering leaves were removed and the kernels cut. The covering leaves husker was driven by an electric engine with 7 kW power and the knife head as well as the cob feeder by engines with 1.1 and 0.65 kW power. Tests on the cutter were carried out at changeable angular speeds of the knife head ranging from 167.5 to 301.2 rad·s^{-1} and at the constant cob feeder's speed – 0.31. The knife head's angular speed was changed with a frequency converter Telemecanique AtV 18V-18Hz.

The amount of the cut kernels was determined from the cob mass difference before and after the cutting process. The energy input for the cutting process was determined with an electric converter Lumel PP83. The energy consumption during sweet corn kernels cutting was determined from the difference of the total energy used in the cutting process and the energy of the cutter's idle run. The unitary cutting energy was calculated according to the formula:

$$E_o = E_c - E_j, \quad \text{kWh/cob} \tag{1}$$

where:

E_c – total energy used during the cutter's work, kWh,
E_j – energy of the cutter's idle run, kWh

To calculate work input N_r at the cobs harvesting and processing, the following formula was used:

$$N_r = \frac{\sum_{i=1}^{n} L_i}{F}, \ \text{h·ha}^{-1} \tag{2}$$

The mechanical and electric energy input N_e for the particular cobs harvesting and processing activities were calculated according to the formula:

$$N_e = \frac{\sum_{i=1}^{n} P_i \cdot K \cdot L_i}{Q}, \ \text{kWh·t}^{-1} \tag{3}$$

where:

n – the number of technological activities,
F – sweet corn growing area, ha,
Q – cobs and kernels mass, t,
K – coefficient of tractor's or electric engine's power consumption, K = 0.6-0.9,
L_i – number of working hours for a given activity, h,
P_i – combustion or electric engine's power, kW.

In order to reach the attempted result the following measurements were taken:

– time of the cobs harvesting, their unloading from the combine, loading, transport, unloading from the trailer, leaves removal and kernels cutting, exact to 1 min;
– mass of cobs with and without leaves as well as mass of piths, exact to 1 g;
– fuel consumption by the harvesting combine and agricultural tractor, exact to 0.1 l;
– electric energy input during the leaves removal and kernels cutting, exact to 0.01 kWh.

The corn kernels relative humidity was calculated according to the following formula:

$$W = \frac{(m_0 - m_1)}{m_o} \cdot 100 \ \ \% \tag{4}$$

where:

m_0 – the sample's mass before drying, g
m_1 - the sample's mass after drying, g

The fuel consumption was determined by the full tank method according to the formula:

$$Q_h = \frac{G_v}{(T_k - T_p) - T_o} \ , \ \mathrm{l \cdot h^{-1}} \tag{5}$$

where:

G_v – amount of fuel, l'
T_k – finishing time of an engine's work, h,
T_p – starting time of an engine's work, h,
T_o – engine stoppages longer than 3 minutes, h.

The necessary measurements number was determined on the basis of the initial measurements number n according to the dependency given by Telejko [1999]:

$$N \geq \frac{t^2_{n,\alpha} \cdot S^2_x}{\delta^2} \tag{6}$$

where:

$t_{n,\alpha}$ – the critical value of the Student's distribution t, read for n measurements and the significance level $\alpha = 0.05$,
S_x – standard deviation,
δ – the required accuracy.

The evaluation of the obtained research results was carried out using the mono-factor variance analysis method. Where significant differences were found between objects on the basis of the significance test F, quantitative concluding was carried out on the basis of the Tukey's trust intervals for the significance level $\alpha = 0.05$. The accuracy of the particular measurements results was determined by adding the standard deviation values for the arithmetic mean.

TESTS RESULTS AND ANALYSIS

Table 1 presents the results of tests on the selected physical properties of sweet corn cobs and kernel, whereas Table 2 presents the results of exploitation tests on machines for cobs harvesting and processing.

Table 1. The results of tests on sweet corn cobs cultivar Jubilee

Specification	Measurement unit	Tests results	
		Mean value	Standard deviation
Cobs crop	$t \cdot ha^{-1}$	16.83	0.7
Cutting kernels crop	$t \cdot ha^{-1}$	3.46	1.83
Length of corn cobs	cm	21.4	4.5
Diameter of corn cobs	mm	50.4	1.2
Number of kernel rows	szt.	16.2	2.1
Number of kernels in a row	szt.	30.3	4.6
Mass of cobs without the leaves	g	320.5	23.6
Bulk density of kernels	$g \cdot dm^{-3}$	617.3	32.5
Kernel content in a corn cob	%	72.2	4.2
Corn kernels moisture	%	72.6	2.4

Table 2. The results of tests on cobs harvesting and processing

Specification	Measurement unit	Tests results	
		Mean value	Standard deviation
Exploitation efficiency of a combine	$ha \cdot h^{-1}$	1.35	0.12
Exploitation efficiency of a leaves husker	$t \cdot h^{-1}$	9.11	0.27
Exploitation efficiency of a kernels cutter	$t \cdot h^{-1}$	1.49	0.12
Transportation efficiency	$t \cdot h^{-1}$	17.31	1.69
Transportation time	min	12.0	2.82
Loading time	min	12.0	2.12
Unloading time	min	8.0	1.41
Fuel consumption:			
– combine [1)]	$l \cdot ha^{-1}$	22.7	3.60
– transportation [2)]	$l \cdot mth^{-1}$	1.4	0.07
Electric energy input:			
– husker	$kWh \cdot t^{-1}$	7.02	1.36
– cutter	$kWh \cdot t^{-1}$	0.87	0.04

[1)] during harvesting and unloading
[2)] during transportation and unloading

Table 3 presents the values of labour and energy input during cobs harvesting and processing. The highest unitary labour input per surface unit (11.3 $h \cdot ha^{-1}$) and raw material's mass (0.7 $h \cdot t^{-1}$) was required during kernels cutting. This was due to the cutter's efficiency and also to the fact, that the cobs had to be manually fed, with their narrower end upfront, by the workers to the cutter's staff. It was found out, that the least labour-consuming activity (1.7 $h \cdot ha^{-1}$ and 0.1 $h \cdot t^{-1}$) was the process of cobs harvesting. It resulted mainly from the relatively high efficiency of the covering leaves removal, app. 9.1 $t \cdot h^{-1}$.

Table 3. Labour and energy input during the harvest and processing of cobs

Specification	Input values for:				Input structure %
	1 ha of the plantation		1 t of cobs		
	mean value	stand. dev.	mean value	stand. dev.	
Labour input, h, including:	17.77	0.36	1.05	0.03	100.0
– cobs harvesting	1.75	0.06	0.10	0.01	9.84
– cobs transportation	3.05	0.18	0.18	0.02	17.16
– leaves of cobs husking	1.68	0.14	0.10	0.01	9.45
– kernels cutting	11.29	0.08	0.67	0.6	63.53
Energy input, kWh, including:	484.61	38.57	28.79	3.32	100.0
– cobs harvesting	246.41	8.44	14.64	1.41	50.84
– cobs transportation	212.97	30.02	12.65	0.97	43.94
– leaves of cobs husking	9.43	0.01	0.56	0.79	1.94
– kernels cutting	15.80	0.10	0.94	0.15	3.26

On the other hand, energy input was the highest for cobs harvesting (app. 51% of the total input). It was due to the small distance of transport and to the cobs loading and unloading time. The lowest energy input (app. 2% of the total input) was needed for the covering leaves removal from cobs. It was due to the relatively high leaves remover's efficiency and also to the fact that, unlike the cutting process, the leaves removal process was fully automated.

Figure 2 presents the changeability of the cut kernels mass and Figure 3 the changeability of electric energy input during the cutting process in the function of the cutter's knife head angular speed. An analysis of variance and Tukey test showed that the differences between the mean measurement values are statistically significant.

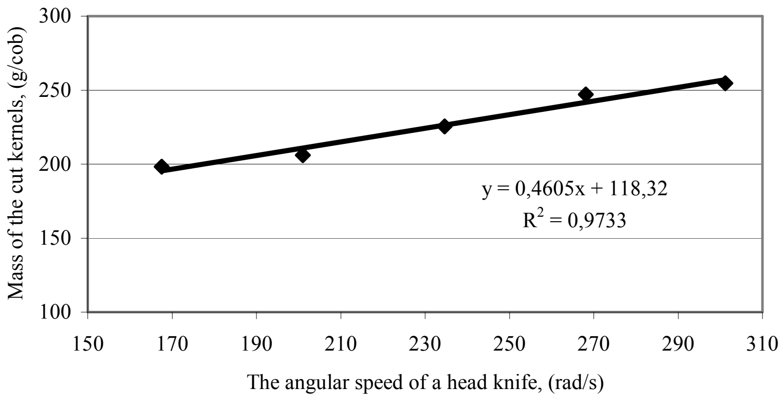

Fig. 2. The dependency of the cut kernels mass on the angular speed of a knife head

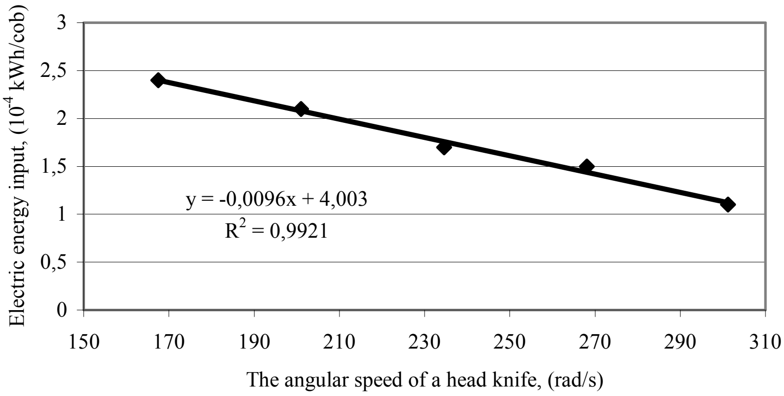

Fig. 3. The dependency of energy input on the angular speed of a knife head

The increase of knife head's speed in the range from 167.5 to 301.2 rad·s^{-1}, at a constant cob feeder's speed (0.31 m·s^{-1}) caused an increase of the cut kernels mass by about 28% (Fig. 2) and a decrease of electric energy input by about 46% (Fig. 3).

CONCLUSIONS

The article presents results of research on combine cobs harvesting and their post-harvest processing, considering only the process of leaves removal and kernels cutting. The investigations did not involve activities connected with transport of waste (the covering leaves and piths) or the further kernels processing (rinsing, cleaning, sorting, blanching, tinning). Moreover, water consumption was not taken into consideration, and water is used both at leaves removal and kernels cutting.

The value of labour input at kernels cutting constitutes nearly 64% of the total input in the process of kernel production i.e. 11.3 h·ha^{-1} and 0.7 h·t^{-1}. The value of this input results, among others, from the quality of the raw material, which not only should be collected in the optimum ripeness phase, but also should be characterized by a regular, straight-linear shape. The highest energy input for corn kernels production concerned cobs harvesting and amounted to 246.4 kWh·ha^{-1} and 14.6 kWh·t^{-1}, which constituted about 51% of the total input.

On the basis of the obtained research results it was found out that a change in the knife head's speed caused a drop in electric energy input during the kernels cutting process by about 46% and an increase in the cut off corn kernels mass by about 28%. These dependencies can be explained by a greater plastic deformation of the kernels with high humidity, which at lower knife head's speeds undergo a greater deformation during cutting, and by lower kernels cutting resistance values as well as by shorter lasting time of the process. Cultivars and morphological properties of sweet corn cobs also significantly affect the quantity and quality of the cut off kernels mass.

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