Agronomy Research **12**(1), 33–40, 2014

Technical and economical analysis of harvesting and ensilaging of corn grain

J. Barwicki[1], S. Gach[2], K. Koprysz[2], S. Ivanovs[3,*], A. Adamovics[3] and O. Valainis[3]

[1]Institute of Technology and Life Sciences in Falenty, Warsaw Branch, Warsaw, Poland
[2]Department of Production Engineering, Warsaw Agricultural University – SGGW, Warsaw, Poland
[3]Latvia University of Agriculture, Research Institute of Agricultural Machinery, Ulbroka, Latvia; [*]Correspondence: semjons@apollo.lv

Abstract. Elaborated test results concerning two technologies of corn grain harvesting using grain harvesters. One technology called ZKP was using a mill crusher unit with direct filling system of a plastic bag and the other one was using a mill crusher connected to a silo press and was called ZKG. Provided research and calculations enabled evaluation of the values of critical coefficients, which were the following: unitary fuel consumption and unitary labour cost requirement. Because of different corn grain yields, these values referred to a unitary area of crop and also unitary mass of corn grain. It has been proved that the total costs of harvesting and conservation of corn grain with the technology ZKP equalled 321.83 € ha^{-1}, but the same costs with the technology ZKG equalled 245.69 € ha^{-1}. However, when taking into consideration the unitary mass of harvested grain, lower costs appeared with the technology ZKP at the value 21.89 € t^{-1} compared to the 31.02 € t^{-1} for the technology ZKG.

Key words: maize, harvesting technology, grain ensilaging, plastic bag, costs, labor, harvesting, transportation, fuel consumption.

INTRODUCTION

Increasing demand for maize, but especially for corn grain, designated for feed as well as for other goals, such as the needs of distillery industry and energy production, leads to dynamic growth of the cultivated area of this grain (Sokhansanij et al., 2002; Kowalczyk & Rzepiński, 2003). However, usage of corn as high energetic feed for all animal groups is of the highest importance (Gach & Kowalski, 2010; Gach et al., 2011).

Maize can be grown for silage as whole plants, for silage using corn cobs only (LKS – corn cobs with leafs or CCM) as well as for grain itself only (Niedziółka, 1999; Podkówka & Michalski, 2003; Bulghakov et al., 2006).

Making silage using chaff from whole maize plants is quite rational, because it utilizes all food components and can be used as a fundamental base for feeding of ruminant animals. (Podkówka & Michalski, 2003; Ustinovs & Ivanovs, 2003; Weinberg & Ashbell, 2003; Gach & Kowalski, 2010; Kowalski, 2010).

Growing maize for corn grain also holds an important position, but requires quite a high energy input for the drying process. The moisture content of the corn grain for storage must be lower (Eckl, 2003). Because of the high energy prices, the costly drying is replaced by grain ensiling using special conservation additives (Płonka, 2002; Chlebowski et al., 2008).

Ensiling of maize for feeding purposes is effective from the perspective of small losses of food components and silage can be stored for several month, so it can solve the problems of feeding animals. Grain silage contains less non-nitrogen extraction compounds, but it contains more protein and is characterized by higher digestibility of food compounds by animals compared to dried grain (Podkówka & Michalski, 2003). Total utilization of the components contained in feed is possible by using proper methods of harvesting and ensiling (Niedemaier, 1998; Gach et al., 2011).

Harvesting is usually done by using properly adapted grain harvesters (Szymanek et al., 2008), however, before storage, grain is crushed by using special mill crushers, the operation of which is known as the so-called Mursk method (Plonka, 2002). It is possible to use different variations of the technology, such as utilization of mill crushers in a separate operation and then filling the crushed grain into a plastic bag using a silo press or utilization of an aggregate performing both of these operations together (Gach et al., 2011). There are not many research results published in literature concerning harvesting and ensiling of corn grain in a plastic bag (Csermley et al., 2000).

It shows that evaluation of the exploitation parameters concerning preparation of crushed corn grain silage is very important as a research task. Fuel consumption, labor input, the costs involved according to the elementary area of maize designated to ensiling, or taking into account the dry matter involved can be good parameters to compare when evaluating different technologies. It can also be utilized for verification of elaborated models of similar processes, during simulation for better knowledge and for development and modelling the technology for ensiling of whole maze plants (Zaliwski & Hołaj, 2006; Kowalski & Gach, 2009).

The goal of this elaboration was evaluation of exploitation parameters, as well as to discover the material and cost inputs during harvesting and ensiling of corn grain using field test results taken directly from the production activity in a farm.

MATERIAL AND METHODS

The research work and evaluation of the whole process were provided for two technologies of maize harvesting for corn grain named ZKP and ZKG. A scheme of these technologies is presented on Fig. 1.

The tests for the technology ZKP were performed during 2009 in the Agricultural Experiment Research Station of the Warsaw Agricultural University (SGGW) in Obory near Warsaw. Corn grain harvesting was carried out using an adapted grain harvester Claas MEGA 360. The harvesting assembly was replaced by a six row adapter Conspeed 6-75FC for corn cobs separation from maize plants. After separation of corn cobs, maize stalks were shredded and left on the field, where the process of decomposition of the green mass could begin easily. This situation helped to prepare the field for after-harvest growing of other cultures.

During corn grain harvesting using high capacity harvesters, it is essential to prepare a proper amount of means of transport for delivering the corn grain. In the case of the present technology, the corn grain from the harvester was transported to the reloading area using a trailer PP14 Metaltech Mirosławiec Co. with the capacity of

14 tons, which transported the corn grain to the main truck SCANIA 114L with the capacity of 29 m^3. Reloading of the trailer was provided by using a screw conveyor located on the trailer. Then, the corn grain was transported to the place of storage and ensiling located 16 km from the field. Unloading of the corn grain from the truck was performed by tripping of the carrying body.

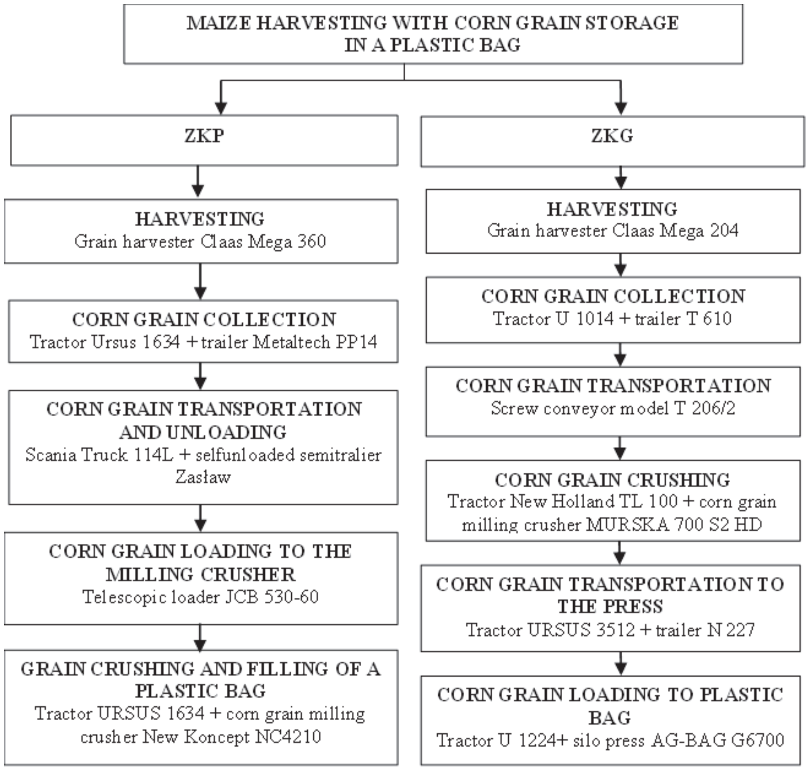

Figure 1. Scheme of the technology for corn grain ensilaging in a plastic bag.

Transportation and loading of corn grain to the mill crusher were performed by using a telescope loader JCB 530-60 equipped with a bucket for loose materials. For corn grain crushing, a roller mill crusher NC4210 New Concept Co. driven from a tractor Ursus 1634 using the PTO system were utilized. Crushed corn grain was compressed into a plastic bag. The size of the plastic bag was: 60 m long and 2.4 m in diameter.

The technology ZGK was presented as follows:

Corn grain harvesting and corn cubs separation were performed directly on the field using an adapted grain harvester CLAAS Dominator 204 Mega. The grain harvester was adapted by replacing the header unit with a 5-row adapter, which separates corn cobs from plants. Further, some changes were made to the harvester shredding and cleaning units.

Utilization of stalk rotation shredders working in vertical position and placing them under corn cobs separation unit. All chaff left after separation and shredding were spread on the ground behind the harvester and made good material for developing organic fertilizer.

The obtained corn grain was loaded on type T 610 trailers and transported with U 902 tractors to the shredding and ensilaging area, where it was filled into a plastic bag.

Unloading of the corn grain was performed directly on the entry table of the milling crusher MURSKA, equipped with a magnetic and rock separator. The mill crusher had two rollers 70 cm long each. The distance between the rollers was set on 0.3 mm. The mill crusher was powered by the PTO unit of a New Holland tractor. The crushed grain was charged through an unloaded pipe on the transporter, which directed it into a press. The transportation process was performed by using two sets of tractors C-360 and trailers type N227. Unloading of the trailer was performed using a flour conveyor powered by the PTO system of a tractor.

The corn grain from the charging hopper was fed into a plastic bag type B 820 by a silo press type AG-BAG, which was powered by a tractor Zetor 1211. The size of the plastic bag equalled 2.4 m width and 60 m length and had the capacity from 180 to 220 ton depending on the grain moisture content.

The exploitation tests of the machinery utilized in this technology were performed according to the requirements of the relevant standards and methodology developed at the Warsaw Institute of Technology and Life Sciences (ITP) (Barwicki et al., 2011).

On the basis of tests results described above, the yield per ton of corn grain was calculated. Moreover, the cost structures of the presented technologies were calculated taking into account: fuel costs, material costs, labor input and machinery costs.

RESULTS AND DISCUSSION

The main parameters of the provided experiments are presented in Table 1. As we can see, plants were harvested at a proper moisture content and the corn grain yield was quite high compared to the average yields on a country scale.

The values of exploitation and economical parameters were evaluated on the basis of typical standards and methodology, taking into account the actual prices of farm machinery (Barwicki et al., 2011).

Table 1. Characteristics of test conditions

Description of parameters	Units	Value	
Tested material	-	Corn grain	
Technology	-	ZKP	ZKG
Variety	-	PIONEER – PR39D23	PIONEER – PR39D81
Yield	t ha^{-1}	14.70	7.92
Moisture content	%	36	31.4
Row spacing	m	0.75	0.75
Number of plants on m^2	Piece m^{-2}	8.2	6.02
Average height of plants	m	2.91	2.43
Average height of corn cobs location	m	1.23	1.08

The yield of different technologies of the utilized machinery and aggregates were different, and are presented in table 2.

Table 2. Values of performance indicators

Description of parameters	Technology	
	ZKP	ZKG
	Yield [t h^{-1}]	Yield [t h^{-1}]
Harvester Claas Mega 360	13.50	7.56
Tractor U1634 + trailer Metaltech PP14	13.5	-
Truck Scania 114L + selfunloaded semitrailer Zasław	10.9	-
Telescopic loader JCB 530-60	8.9	-
Trailer U1634 + milling crusher NC4210	8.9	-
Tractor New Holland TL 100 + milling crusher MURSKA 700 S2 HD	-	8.0
Tractor U 1224+ silo press AG-BAG -G 6700	-	8.39

The calculated values refer to a specific area and also to a specific mass, because the yields for both technologies were considerably different. Fuel consumption is characterized in connection with a specific area or a specific yield and is presented in table 3. Taking into account the higher yield for the first technology when looking for a mass of the harvested corn grain, lower fuel consumption was present in the case of the technology ZKP – 3.42 dm^3 t^{-1} – compared to the technology ZKG – 4.10 dm^3 t^{-1}.

Table 3. Fuel consumption during harvesting and ensilaging of corn grain using different technologies

Description of parameters	Technology	
	ZKP	ZKG
	dm^3 t^{-1}	dm^3 t^{-1}
Harvesting	1.55	2.24
Loading and transportation	0.78	0.38
Loading of corn grain to milling crusher	0.35	-
Grain crushing and filling of plastic bag	0.74	-
Grain crushing	-	0.36
Transportation and loading to silo press	-	0.18
Plastic bag filling using silo press	-	0.94
Total	3.42	4.10

In the case of both technologies, fuel consumption was highest during harvesting with the following results: technology ZKP – 1.55 dm^3 t^{-1}, technology ZKG 2.24 dm^3 t^{-1}.

In the case of the technology ZKP, the lowest fuel consumption was related to loading of the corn grain to the milling crusher – 0.35 dm^3 t^{-1} –, but in the case of the technology ZKG, transportation and loading of the corn grain to the silo press – 0.18 dm^3 t^{-1}.

The total labour input values concerning specific areas in both technologies were quite close and were as follows: ZKP – 6.66 rbh t^{-1}, ZKG – 6.89 rbh t^{-1}. However, concerning the specific mass of corn grain, for the technology ZKP, it equalled 0.45 rbh t^{-1} and 0.87 rbh t^{-1}, which is almost twice higher because of different yields as shown Table 4. The highest labour consumptions during operations were those related to loading-unloading and transportation, the lowest one, however, was related to harvesting as a very efficient operation.

Table 4. Labour input for harvesting and ensilaging using different technologies

Description of parameters	Technology	
	ZKP	ZKG
	rbh t^{-1}	rbh t^{-1}
Harvesting	0.07	0.13
Loading and transportation	0.16	0.26
Loading of corn grain to milling crusher	0.11	-
Grain crushing and filling of plastic bag	0.11	-
Grain crushing	-	0.12
Transportation and loading to silo press	-	0.12
Plastic bag filling using silo press	-	0.24
Total	0.45	0.87

When taking into account the specific mass of collected grain, lower costs were obtained with the technology ZKP at the value of 21.89 € t^{-1} compared to the technology ZKG with the value of 31.02 € t^{-1}, as presented in Table 5.

In the cost structures of the tested technologies, in the case of the technology ZKP, corn grain harvesting had the highest impact on final expenditure– 7.50 € t^{-1} – but for the technology ZKG, the result equals 15.18 € t^{-1}.

Besides that, a considerable share of the costs is related to grain crushing and filling of the plastic bag: ZKP – 7.36 € t^{-1}; there is a similar situation in the case of the technology ZKG, where filling of the plastic bag using a silo press consumes 9.37 € t^{-1}. The costs related to transportation and loading-unloading operations are considerably lower.

Table 5. Specific costs of harvesting and ensilaging of corn grain in different technologies

Description of parameters	Technology	
	ZKP	ZKG
	€ t^{-1}	€ t^{-1}
Harvesting	7.50	15.18
Loading and transportation	5.08	2.07
Loading of corn grain to milling crusher	1.95	-
Grain crushing and filling of plastic bag	7.36	-
Grain crushing	-	3.30
Transportation and loading to silo press	-	1.10
Plastic bag filling using silo press	-	9.37
Total	21.89	31.02

In addition to the above, the costs of some other analysis were provided, taking into account the following costs: machinery, fuel consumption, labour consumption, additional materials. All this is presented in Table 6.

In the second place was fuel consumption with the following values for each technology: ZKP – 3.30 € t^{-1} – and the technology ZKG – 4.0 € t^{-1}. The costs of additional materials such as the plastic foil used for the plastic bag and the conservation agent supporting better development of the ensilaging process were equal: ZKP – 3.15 € t^{-1} – and for the technology ZKG – 2.17 € t^{-1}. The lowest values were the costs of labour input, which equalled: ZKP – 1.23 € t^{-1} – and the technology ZKG – 1.81 € t^{-1}.

Table 6. Comparison of specific costs involved in harvesting and ensilaging of corn grain in a plastic bag

Description of parameters	Technology ZKP	Technology ZKG
	€ t^{-1}	€ t^{-1}
Machinery	14.21	23.04
Fuel	3.30	4.0
Labour	1.23	1.81
Other materials – plastic foil	3.15	2.17
Total	21.89	31.02

The described experiment can be very helpful in determining values and structural inputs of harvesting and ensiling of corn grain. This area of research is very important and should be continued in the future, because we should consider the improvement of efficiency of each step of harvesting and ensilaging process described in this research work. The knowledge presented in this paper can be utilized for developing new technologies, but also for verifying elaborated models of old technologies for harvesting and ensiling of corn grain (Zaliwski & Hołaj, 2006, Kowalski & Gach, 2009).

CONCLUSIONS

On the basis of the provided research and analysis, the following conclusions can be made:

1. When taking into account the specific mass of the collected corn grain, lower fuel consumption took place in the technology ZKP – 3.42 dm^3 t^{-1} – than in the technology ZKG – 4.10 dm^3 t^{-1} –, because of the higher yield in the first technology compared to the second one. The highest fuel consumption was present during harvesting, but the lowest occurred during loading of the corn grain to the milling crusher in the case of the technology ZKP and during transportation and loading of the corn grain to the silo press in the case of the technology ZKG.

2. However, when taking into account the mass of corn grain in the technology ZKP, the labor input was twice lower than in the technology ZKG, because of the considerably higher yield of the first technology. The highest labor input occurred during grain loading, unloading and transportation.

3. When taking into account the specific mass of the collected corn grain, lower costs were achieved with the technology ZKP – 21.89 € t^{-1} – compared to the technology ZKG – 31.02 € t^{-1}.

4. In the structure of all costs for both technologies, the costs were highest for harvesting and the results were as follows: for the technology ZKP – 7.50 € t^{-1} – and for the technology ZKG – 15.18 € t^{-1}. Further, the costs related to corn grain crushing and filling of the plastic bag had a considerable influence: ZKG – 7.36 € t^{-1} – and also for the technology ZKG using silo press – 9.37 € t^{-1}.

5. In the cost structure related to the machinery, fuel consumption, labour requirement and additional materials, machinery costs had the highest share with the

following values: for the technology ZKP – 14.21 € t^{-1} – and for the technology ZKG – 23.04 € t^{-1}. Fuel consumption costs had the following values: for the technology ZKP – 3.30 € t^{-1} – and for the technology ZKG – 4.0 € t^{-1}.

REFERENCES

Barwicki, J., Gach, S. & Ivanovs, S. 2011. Inputs analyses of maize harvesting and ensilaging technologies. *Agronomy Research* **9**, 31–36.

Bulgakov, V., Shpokas, L. & Petkavicius, S. 2006. Issledowanije uborki kukuruzy na zerno. Motorization and powerindustry in agriculture. ISSN 1730 – 8568. Lublin, Vol. 8, 58–68. (in Russian).

Chlebowski, J., Gach, S., Gozdalik, I. & Kowalski, P. 2008: Analiza nakładów ponoszonych na zbiór i zakiszanie ziarna kukurydzy. *Inżynieria Rolnicza* 1, 71–76 (in Polish).

Csermely, J., Bellus, Z., Herdovics, M., Komka, Gy., Schmidt, J. & Sipöcz, J. 2000. Fodder preservation by fermentation in plastic bags. Hung. *Agricult. Eng.* **13**, 32–35.

Eckl, J. 2003. Wenn trocken zu teuer ist. *DLZ-Agrarmagazin*. Jg 54 nr 9, 80–82 (in German).

Gach, S. & Kowalski, P. 2010. Technologiczne i techniczne aspekty zbioru kukurydzy na kiszonkę. *Postępy Nauk Rolniczych* **1**, 91–99 (in Polish).

Gach, S., Korpysz, K. & Polańczyk, M. 2011. Nakłady ponoszone na zbiór i zakiszanie ziarna kukurydzy w worku foliowym. *Journal of research and applications in agricultural engineering*, **56**(2), 44–48 (in Polish).

Kowalczyk E. & Rzepiński, W. 2003: Kiszenie ziarna kukurydzy jako metoda poprawy efektywności ekonomicznej produkcji pasz lub etanolu. [w:] Kierunki wykorzystania wysokoenergetycznych odmian kukurydzy do produkcji biopaliw. Instytut Biotechnologii Przemysłu Rolno-Spożywczego. Monografie. Warszawa: 20–31. (In Polish)

Kowalski, P. & Gach, S. 2009. Model matematyczny zbioru i zakiszania kukurydzy. Zeszyty Probl. Post. Nauk Roln., 543, 167–180 (in Polish).

Niedemaier, H. 1998. Mais- Gaskorn silage – eine alternative zu CCM? *Top Agrar* **6**, 12–16 (in German).

Niedziółka, I. 1999. Analiza energetyczno-ekonomiczna technologii produkcji ziarna kukurydzy. *Inżynieria Rolnicza*, R. 3, **4**(10), 89–95 (in Polish).

Niedziółka, I. & Szymanek M. 2003. Przemysłowe i energetyczne wykorzystanie ziarna kukurydzy. *Motoryzacja i Energetyka Rolnictwa* **5** (in Polish).

Płonka, S. 2002. Zabezpieczenie bazy paszowej w gospodarstwie. Kiszenie ziarna o wysokiej zawartości wilgoci. [w:] Wdrażanie nowych proekologicznych technologii w zakresie roślin uprawnych. Puławy, pp. 441–448 (in Polish).

Podkówka, W. & Michalski, T. 2003. Technologie zbioru i użytkowania kukurydzy ziarnowej. Kukurydza rośliną przyszłości. Agro Serwis, pp. 41–45 (in Polish).

Sokhansanj, S., Turhollow, A., Cushman, J. & Cundif, J. 2002. Engineering aspects of collecting corn stover for bioenergy. *Biomass Bioenergy* **23**(5), 347–355.

Szymanek, M., Tanaś, W., Zagajski, P. & Dreszer, K.A. 2008. Możliwości wykorzystania kombajnów zbożowych do zbioru kukurydzy. *Technika Rolnicza Ogrodnicza Leśna* **3**, 21–24 (in Polish).

Zaliwski, A. & Hołaj, J. 2006. Modelowanie technologii produkcji kukurydzy na ziarno w aspekcie efektywności ekonomicznej. *Inżynieria Rolnicza*r **6**, 407–413 (in Polish).

Ustinovs, V., Ivanovs, S., 2003. Improvements in the technologies and technical means of growing maize for silage. Engineering. Lithuanian University of Agriculture. Research papers 6(1). Akademija, pp. 97–101.

Weinberg, Z.G & Ashbell, G. 2003. Engineering aspects of ensiling. *Biochemical Engineering Journal*, **13**, 181–188.