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EVALUATION OF THE OPERATING PARAMETERS OF SELF-PROPELLED FORAGE HARVESTERS DURING MAIZE SILAGE HARVEST

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ABSTRACT

This study aims to determine and evaluate the operating parameters of three modern self-propelled forage harvesters during maize silage harvest. The machines were equipped with operator assistance systems. Field tests were conducted for three self-propelled forage harvesters: Claas Jaguar 870, Claas Jaguar 950, KroneBiG X 650. The tests were conducted in large-scale farms located in Wielkopolskie and Pomorskie voivodeships. Maize was harvested at the beginning of the full-grain maturity stage. A complete time study covering four control shifts in accordance with BN-76/9195-01 was performed to determine operating ratios and indicators. Fuel consumption was determined using the full tank method. The Claas Jaguar 950 forage harvester had the highest effective mass performance: 141.3 $Mg \cdot h^{-1}$. The same machine also achieved the lowest fuel consumption per tonne of fresh matter (FM) harvested: 0.51 $kg \cdot Mg^{-1}$. Labour expenditure for the self-propelled forage harvesters tested during the total time of change ranged from 0.38 to 0.62 labour hour per hectare. The tested machines also had very high technical and technological reliability.

Introduction

Maize silage is a primary roughage source for dairy cattle and fat livestock due to its low production costs, high energy content and high yield exceeding 20 tonnes of dry matter (DM) per hectare (Brzóska, 2001; Kruczyńska et al., 2001; Dewhurst, 2013; Janiak and Piecuch, 2018). Maize silage is also widely used as a substrate for biogas production (Szlachta and Tupieka, 2013; Szymańska et al., 2015; Pilarski et al., 2016; Golubić et al., 2019). In the whole process of maize silage production, the harvesting process is the biggest problem in terms of expenses (costs and labour) and energy demand (Gach and Kowalski, 2009, 2010; Gorzelany et al., 2011). Strict adherence to specific agrotechnical deadlines is also a very important factor when harvesting maize for silage. Performing all harvesting and maintenance operations at optimum periods requires the use of efficient technical means of production and the creation of organisational forms that favour the use of highly efficient machines equipped with technical means of data recording and transmission (Banasiak et al., 2002). Fineness of raw material crushing is one of the main factors that determine the ensiling process, especially of crops with thick stems and those with a high dry matter content. Obtaining silage with a very good food value requires harvesting to be performed when the dry matter content of maize crops is between 30-35% (Mueller et al., 1991; Roth and Heinrichs, 2001; Podkówka, 2004; Kowalik and Michalski, 2009). When the whole-crop dry matter content exceeds 30%, the maize harvesting process requires the use of modern fine chop forage harvesters, equipped with devices for active crushing of hard grains and stems, further increasing their energy demand (Kowalik et al., 2003; Gach and Kowalski, 2009). Due to the high harvest costs, it is also important to correctly select a high-capacity self-propelled forage harvester for the conditions and needs of use in a specific environment so that the work can be conducted at relatively low operating costs (Banasiak et al., 2002; Grześ and Kowalik, 2005; Muzalewski, 2010).

Manufacturers of agricultural technical means launch machines with increasingly sophisticated technical solutions. The status of technical equipment used in agriculture is determined by its structural and technological factors, with the technical equipment produced today including vehicles that are very sophisticated in terms of solutions in both these areas (Juściński and Piekarski, 2010; Staszak et al., 2018). Such technical equipment also includes self-propelled forage harvesters which can be equipped with various operator assistance systems and different operating modes of engines to increase their capacity. The operating parameters of self-propelled forage harvesters equipped with operator assistance systems can be assessed reliably when tests have been conducted and compared with the results of the machines used previously. Therefore, it can be expected that the application of new technical solutions to self-propelled forage harvesters will result in an increase in their performance and technical and technological reliability.

This study aims to determine and evaluate the operating parameters of three self-propelled forage harvesters equipped with operator assistance systems during maize silage harvest.

Materials and Methods

The study focused on three self-propelled forage harvesters: Claas Jaguar 870 with RU600 row-independent attachment, Claas Jaguar 950 with Orbis 600 row-independent attachment and Krone BiG X 650 with Easy Collect 7500 row-independent attachment. Table 1 shows basic characteristics of the self-propelled forage harvesters. The study was conducted on three large-scale farms in Wielkopolska and Pomorskie voivodeships in the following locations:

- Claas Jaguar 870, district of Szamotuły, village of Wilczyna (52°28′56.0″N, 16°25′56.9″E),
- Claas Jaguar 950, district of Poznań, village of Uzarzewo (52°27′09″N, 17°07′33″E),
- Krone BiG X 650, district of Człuchów, village of Przechlewo (53°48′01″N, 17°15′11″E).

Shifts were defined in accordance with BN-76/9195-01 and the operating ratios and indicators were determined in accordance with the field test methodology described in BN-77/9195-02. A complete time study covering four working shifts was performed for each self-propelled forage harvester. Fuel consumption was determined using the full tank method.

The maize development stage was determined, and maize was ground in accordance with PN-91/R-55025. The maturity stage at harvest was determined by the maturity of the grain taken from four randomly selected locations. Ten cobs were taken from each location and ten grains were shelled from the edge and central parts of each cob. This provided 400 grains, which were divided into fractions according to maturity. The crop maturity stage was assumed according to the most abundant grain fraction. The dry matter content of maize chaff was determined using the gravimetric method. For this purpose, primary samples were taken from four randomly selected transport sets during each working shift. The primary samples were then pooled to obtain an aggregate sample. The aggregate sample was then mixed, and four average samples were taken. Laboratory samples were taken from the average samples for the determination of moisture content in maize chaff.

Table 1.
Technical characteristics of the self-propelled forage harvesters

Specification	Unit	Machine manufacturer and model		
		Claas Jaguar 870	Claas Jaguar 950	Krone BiG X 650
Harvesting unit	symbol	RU 600	Orbis 600	Easy Collect 7500
Harvesting unit width	m	6	6	7.5
Number of rows to be harvested	pieces	8	8	10
Knife drum diameter	mm	630	630	660
Knife drum width	mm	750	750	800
Number of knives	pieces	24	24	28
Theoretical cutting length	mm	8	10	6
Grain crusher	type	Intensive cracker M Φ 196	Multi crop cracker M Φ 196	Corn Conditioner Φ 250
Engine power	kW	430	440	478

Field tests of each forage harvester were conducted during maize harvest at the beginning of full-grain maturity. All the tested self-propelled forage harvesters were equipped with the following operator assistance systems: an automatic guidance system along crop rows, an automatic harvesting unit levelling system and an automatic knife sharpening and shear bar sliding system. The machines were also equipped as standard with devices to protect the crushing units from metal objects and with row-independent harvesting attachments. Equipping the harvesting attachments with systems that control their distance from the field area ensured a uniform maize cutting height during each test run. After driving into the cornfield, the attachment automatically reached the set distance from the field area and the defined working position was automatically maintained during operation. The attachments were also equipped with an automatic levelling system to achieve better lateral alignment on uneven fields. The tested machines used systems for automatic guidance along crop rows using copying sensors in the form of two bales of maize. The system used on the tested machines functioned correctly and facilitated the work of the operator who was able to focus their attention more on the correct filling of transport vehicles. Only when there were no crops in the row for more than 3.0 metres,an uncontrolled slide of the machine to the left or right occur, which then required the operator to quickly correct the direction of travel. That occurred several times during the test runs and was due to the damage caused by wild animals in the form of dens. The self-propelled forage harvesters were also equipped with a system for automatic sharpening of knives and sliding the shear bar to the knife drum. During operation, the on-board computer informed the operator of the need to sharpen the knives through an audible signal and a text message displayed on the monitor. During the tests, the operator launched the automatic sharpening procedure two times during each working shift. The knives were sharpened each time when there was a break in operation due to waiting for a transport vehicle to arrive. Once knife sharpening was complete, the shear bar slid to the knife drum automatically using knock sensors mounted on the shear bar support.

Results

A crop stand in maize plantations ranged from 8 to 12 crops m^{-2} and a yield of green matter ranged from 32.0 to 40.0 Mg·ha^{-1} (Table 2). The dry matter content of the silage raw material ranged from 33.0% to 42.5% (Table 2). The high dry matter content was due to the prolonged drought that occurred in the pre-harvest period. The height of the harvested crops ranged from 147 to 221 cm, and the cob height was between 59 and 81 cm.

Table 2.
Characteristics of harvested crops and harvest parameters

Specification	Unit	Machine manufacturer and model		
		Claas Jaguar 870	Claas Jaguar 950	KroneBiG X 650
Grain maturity stage at harvest	-	beginning of full maturity	beginning of full maturity	beginning of full maturity
Crop stand	(plants·m^{-2})	12	9	8
Variety	-	LG 32.20	Barula	LG 30.240
FAO	-	230	230	230
Inter-row width	(cm)	75	75	75
Stubble field height	(cm)	25	20	30
Crop yields	(Mg·ha^{-1})	34	40	32
Dry matter content	(%)	42.5	35.0	33.0
Chaff length	(mm)	8.5	10.2	5.8
Height of crops	(cm)	147	221	198
Height of cob embedment	(cm)	59	81	76

In the tested machines, the time taken to automatically sharpen the knives of the knife drum and slide the shear bar ranged from 2 minutes 35 seconds to 3 minutes 15 seconds.

The working shift duration was determined by the time the machine was in operation on the farm. The average general shift time for the tested forage harvesters was Claas Jaguar 870: 607 minutes, Claas Jaguar 950: 556 minutes, Krone BiG X 650: 703 minutes. The average chaff length into which the maize crops were cut varied and was 8.5 mm for Claas Jaguar 870 forage harvester, 10.2 mm for Claas Jaguar 870 forage harvester and 5.8 mm for KroneBiG X 650 forage harvester (Table 2). Based on the results obtained from the time study measurements and fuel consumption measurements, the operating ratios and indicators of the tested forage harvesters were determined. The average values from all control shifts are summarised in Tables 3 and 4.

Table 3.
Area and mass performance of the self-propelled forage harvesters (averages of four working shifts)

Specification	Unit	Main machine		
		Claas Jaguar 870	Claas Jaguar 950	Krone BiG X 650
Effective performance W_1	$(ha \cdot h^{-1})$	2.55	3.53	3.76
	$(Mg \cdot h^{-1})$	86.6	141.3	120.7
Operating performance W_{02}	$(ha \cdot h^{-1})$	2.35	3.24	3.46
	$(Mg \cdot h^{-1})$	79.8	129.7	111.2
Performance in the working time W_{04}	$(ha \cdot h^{-1})$	2.06	2.73	3.10
	$(Mg \cdot h^{-1})$	70.0	109.2	99.7
Exploitation performance W_{07}	$(ha \cdot h^{-1})$	1.80	2.48	2.75
	$(Mg \cdot h^{-1})$	61.2	99.3	88.5
Performance in total time of change W_{08}	$(ha \cdot h^{-1})$	1.60	2.19	2.62
	$(Mg \cdot h^{-1})$	54.5	87.5	84.1

Table 4.
Exploitation indicators of the self-propelled forage harvesters (averages of four working shifts)

Specification	Unit	Main machine		
		Claas Jaguar 870	Claas Jaguar 950	Krone BiG X 650
Operation time use ratio K_{02}	-	0.92	0.92	0.92
Working time use ratio K_{04}	-	0.81	0.77	0.83
Exploitation time use ratio K_{07}	-	0.71	0.70	0.73
Total time of change ratio K_{08}	-	0.63	0.62	0.70
Daily service ratio K_{31}	-	0.90	0.87	0.91
Technological certitide ratio K_{41}	-	0.99	0.98	0.99
Technical certitide ratio K_{42}	-	1.00	1.00	1.00
Fuel consumption	$(kg \cdot h^{-1})$	31.05	45.01	51.16
	$(kg \cdot h^{-1})$	19.37	20.59	19.56
	$(kg \cdot Mg \cdot FM^{-1})^*$	0.57	0.51	0.60
Labor outlays in in the working time T_{04}	$(h \cdot ha^{-1})$	0.49	0.37	0.32
Labor outlays in total time of change T_{08}	$(h \cdot ha^{-1})$	0.62	0.46	0.38

*FM – fresh matter

The self-propelled forage harvesters were equipped with engines of varying power. Compared to the engine of the Jaguar 870 machine, the engine power of the Jaguar 950 forage harvester was 2.3% higher and that of the BIG X forage harvester was 11.2% higher. When harvesting maize for silage at the beginning of full-grain maturity, the effective performance of the forage harvesters ranged from 2.55 to 3.76 $ha \cdot h^{-1}$ while the effective mass performance ranged from 86.6 to 141.3 $Mg \cdot FM \cdot h^{-1}$. The highest field performance was achieved by Krone BiG X 650 self-propelled forage harvester, while the highest mass performance was obtained by Claas Jaguar 950 self-propelled forage harvester, harvesting of fresh matter in one hour. The same machine also had the lowest fuel consumption of 0.51 kg per 1 Mg of FM harvested. Krone BiG X 650 forage harvester achieved the lowest labour expenditure in the total time of change, which was 0.38 labour $hour \cdot ha^{-1}$, and the lowest effective mass performance per 100 kW of engine power, which was 8.33 Mg $DM \cdot h^{-1}$ (Fig. 1). This was due to factors such as the low yield of whole crops per hectare and the lowest average chaff length into which the harvested crops were cut. All the tested forage harvesters operated with active roller grain crushers during harvest with a standard speed difference between the rollers: 30% for Claas Jaguar 870 and 950 forage harvesters and 20% for Krone BiG X 650 forage harvester.

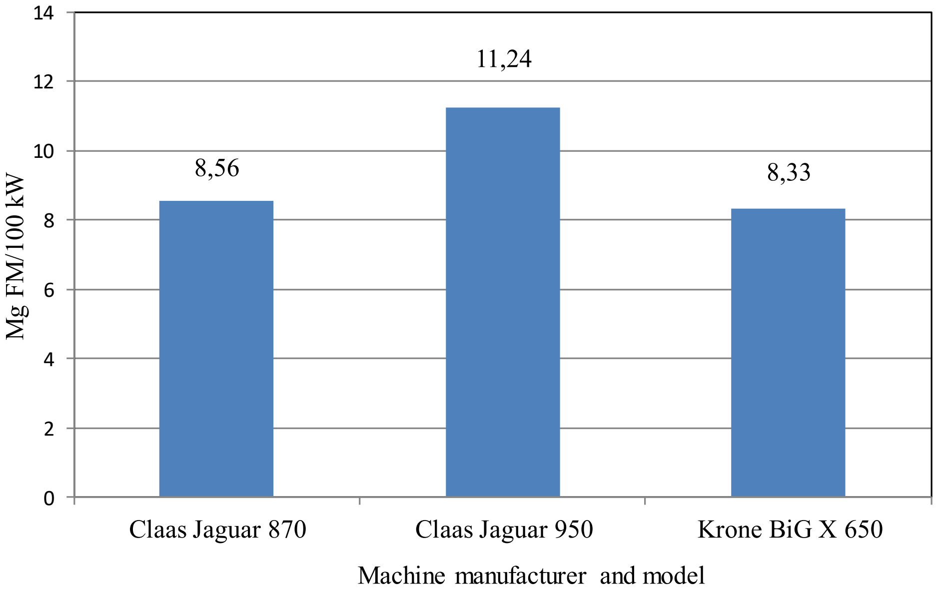

Figure 1. Effective mass performance of the self-propelled forage harvesters per 100 kW of engine power

Discussion

Self-propelled forage harvesters are one of the most expensive machines among all the technical means used in forage harvesting technologies. As a result, service companies or agricultural producers are making increasing technical and performance demands and paying attention to new technological solutions when purchasing new machines (Banasiak et al., 2002). In addition to the steadily increasing functional requirements, one of the most important parameters considered by users of technical means is always the performance of these machines (Grześ and Kowalik, 2005; Banasiak, 2008). In this study, the self-propelled forage harvesters achieved performance in the total time of change, ranging from 1.6 to 2.6 $ha \cdot h^{-1}$. In terms of mass performance, expressed in harvested tonnes of fresh matter of whole maize crops, effective mass performance ranged from 86.6 to 141.3 $Mg \cdot h^{-1}$, and from 54.5 to 87.5 $Mg \cdot h^{-1}$ in the total time of change. Such large differences between field effective performance and performance in the total time of change were mainly due to time losses for organisational reasons related to the lack of transport vehicles to collect the silage raw material. That was caused, among other things, by transport distances of more than 2 km and the poor condition of the mid-field roads, directly forcing transport speeds to be reduced. Therefore, one of the important conditions for a better use of technical progress is the existence of good infrastructure in rural areas, which provides optimal conditions for the use of machines (Banasiak et al., 2002). In a previous study by Kowalik et al. (2003), the field effective performance of the tested self-propelled forage harvesters was lower, ranging from 1.35 to 2.45 $ha \cdot h^{-1}$, and performance in the total time of change ranged from 0.84 to 1.67 ha h^{-1}, which was mainly due to the lower engine power with which the machines were equipped. Effective mass performance ranged from 51.6 to 98.0 Mg FM h^{-1} and from 32.0 to 69.7 $Mg \cdot FM \cdot h^{-1}$ in the total time of change and were also lower. In the study by Barwicki et al. (2011), John Deere 7500 self-propelled forage harvesters with a Kemper Champion 4500 adapter and Claas Jaguar 690 SL self-propelled forage harvesters with an RU 450 adapter achieved the effective performance of 0.91 and 0.69 $ha \cdot h^{-1}$ respectively. In the study by Marinich et al. (2012), however, self-propelled forage harvesters harvesting maize for silage achieved lower mass performance. Claas Jaguar 870 forage harvester achieved an average mass performance of 39.0 Mg FM h^{-1} in the total time of change, Claas Jaguar 850 33.0 $Mg \cdot FM \cdot h^{-1}$, and KBK-800 forage harvester only 23.0 $Mg \cdot FM \cdot h^{-1}$. The engine power of these machines was 440, 335 and 330 kW respectively.

An important operating indicator by which self-propelled forage harvesters are described is the unit fuel consumption (Agricultural Machinery System 1988). The tested forage harvesters differed in terms of their fuel consumption per hour (Table 4). Investigating technologies for harvesting maize for silage, Barwicki et al. (2011) found higher fuel consumption by Claas Jaguar 690 SL and John Deere 7500 self-propelled forage harvesters that consumed 0.95 and 1.02 dm^3 of fuel per 1 Mg of the harvested raw material, respectively, translating into 0.80 and 0.86 kg per 1 Mg of fresh matter. During tests of six self-propelled forage harvesters, which were conducted by Kowalik et al. (2003), fuel consumption was lower, ranging from 0.37 to 0.57 kg per 1 Mg of fresh matter; however, the harvest was done at wax grain maturity. Marsh (2013) compared the performance of John Deere 7950, Claas Jaguar 980, Krone Big X 800 and New Holland FR 9090 self-propelled forage harvesters and the fuel consumption when harvesting maize for silage at a moisture content of 64.9-67.6%. In their study, they showed that fuel consumption varied both between the years of the study and between the machines. Marsh (2013) determined the fuel consumption for the machines tested by specifying the weight of crushed maize crops in relation to 1 litre of fuel, which was 1.47-2.07 Mg·dm^{-3} for Claas Jaguar 980 forage harvester, 1.29-1.66 Mg·dm^{-3} for John Deere 7950, 1.25-1.87 Mg·dm^{-3} for Krone Big X 800 and 1.15-1.63 Mg·dm^{-3} for New Holland FR 9090. When comparing the fuel consumption results of the forage harvesters in this study with those of other authors, it can be concluded that there are some differences; however, the different ranges of data overlap and complement one another. It should also be noted that individual tests were conducted under different field conditions and the plant material varied in terms of dry matter content and was also cut to different lengths.

When deciding on the purchase of a machine, especially one of high value, entrepreneurs from service companies or agricultural producers pay a lot of attention to the criteria of failure rate, availability of spare parts and the cost of factory servicing. This user approach is confirmed in the study by Jasiulewicz-Kaczmarek et al. (2021), which addressed the validity of up to 24 different criteria in the assessment of critical machinery and equipment. When analysing the results, the researchers found that there were noticeable differences in terms of the importance of criteria between compared industries. In the case of the automotive industry, however, the criterion of the machine's failure rate per year was considered the most important. Moreover, the cost of repairs and the quality of machine work were also important criteria for automotive experts. In this study, all self-propelled forage harvesters had very high technical and technological reliability. All machines achieved the highest technical certitide ratio of K_{42}=1.00 and very high technological certitide ratio of $K_{41}$from 0.98 to 0.99, pointing to their high-quality design. Equipping self-propelled forage harvesters with operator assistance systems had a positive effect on the harvesting process. It can certainly be concluded that the machine monitoring systems relieved the operators of several attention-intensive tasks that are related to the day-to-day control of the height of the harvesting attachment or guiding the machine along crop rows. As a result, it was possible to improve direct supervision of the ongoing loading of transport vehicles travelling in parallel alongside the main machine. This allowed a better control of their correct filling without the risk of overloading, resulting in no loss of the silage raw material during loading.

Conclusions

Based on the tests and the results, the following conclusions can be drawn:

1. During the field tests, all tested self-propelled forage harvesters had very high technical and technological reliability. pointing to their high-quality design.
2. All three self-propelled forage harvesters had relatively low general shift time utilisation rates: 0.62 and 0.70, despite operating under large-scale farm conditions. The low rate was mainly influenced by numerous stoppages caused by the lack of transport vehicles to collect the silage raw material, which was due, among other things, to poor road infrastructure, meaning that the potential of the machines was not fully utilised.
3. The self-propelled forage harvesters, such as Claas Jaguar 870, Claas Jaguar 950 and Krone BiG X 650, had higher performance compared to other machines thanks to the higher power of their engines. Therefore, it can be concluded that the higher the power of the engine installed in the machine, the higher capacity potential.

4. The forage harvester that harvested maize with the highest dry matter content and the forage harvester crushing crops into the shortest chaff had a higher unit fuel consumption.
5. The highest effective mass performance per 100 kW of power of the engine installed in the machine was achieved by Claas Jaguar 950 forage harvester – 11.24 $Mg \cdot DM \cdot h^{-1}$, which harvested maize with the highest yield of 40 tonnes per hectare. The other machines, i.e., Claas Jaguar 870 and Krone BiG X 650, achieved similar theoretical material capacities – 8.56 and 8.33 $Mg \cdot DM \cdot h^{-1}$ respectively.
6. The lowest fuel consumption amounting to 0.51 $kg \cdot Mg^{-1}$ per tonne of fresh matter harvested was characteristic for the Claas Jaguar 950 forage harvester, which crushed maize crops into chaff with the greatest average length of 10.2 mm. Claas Jaguar 870 had a higher fuel consumption – 0.57 $kg \cdot Mg^{-1}$ of fresh matter. It harvested crops with the highest dry matter content of 42.5% and an average chaff length of 8.5 mm. KroneBiG X 650 forage harvester was characterised by the highest fuel consumption per tonne of fresh matter – 0.60 $kg \cdot Mg^{-1}$ of fresh matter. It crushed maize crops into the shortest chaff with an average length of 5.8 mm.

References

Agricultural Machinery System. (1988). Część 8 – produkcja pasz objętościowych. IBMER Warszawa – wydanie VII, pp. 62.

Banasiak, J., Bieniak, J., Detyna, J. (2002). Aktualne problemy użytkowania maszyn rolniczych. Eksploatacja i Niezawodność – Maintenance and Reliability, 14*(2),* 63-72.

Banasiak, J. (2008). Wydajnościowa analiza w procesach eksploatacji maszyn rolniczych. *Inżynieria Rolnicza,* 4*(102)*, 63-68.

Barwicki, J., Gach, S., Ivanovs, S. (2011). Input analyses of maize harvesting and ensilaging Technologies. *Agronomy Research,* 9*(1)*, 31-36.

BN-76/9195-01 Maszyny rolnicze. Podział czasu pracy.

BN-77/9195-02 Maszyny rolnicze. Metody badań eksploatacyjnych.

Brzóska, F. (2001). Wartość pokarmowa pasz z kukurydzy. *Biuletyn Informacyjny IŻ,* 1, 37-48.

Dewhurst, R. (2013). Milk production from silage: comparison of grass, legume and maize silages and their mixtures. *Agricultural and Food Science, 22,* 57-69.

Gach, S., Kowalski, P. (2009). Analiza nakładów ponoszonych w technologii zbioru i zakiszania kukurydzy z zastosowaniem różnych sieczkarni. *Zeszyty Problemowe Postępów Nauk Rolniczych, 543,* 69-77.

Gach, S., Kowalski, P. (2010). Nakłady materiałowe i koszty zbioru oraz zakiszania kukurydzy z zastosowaniem różnych technologii. *Problemy Inżynierii Rolniczej, 2,* 41-49.

Golubić, S., Voća, N., Pliestić, S. (2019). Multi criteria analysis of the energy potential of agricultural residues. *Spanish Journal of Agricultural Research, 17,* 1-14.

Gorzelany, J., Puchalski, C., Malach, M. (2011). Ocena kosztów i nakładów energetycznych w produkcji kukurydzy na ziarno i kiszonkę. *Inżynieria Rolnicza,* 8*(133),* 135-141.

Grześ, Z., Kowalik, I. (2005). Badania rocznego wykorzystania maszyn rolniczych. *Inżynieria Rolnicza,* 3*(64),* 189-195.

Janiak, W., Piecuch, K. (2018). Wyniki porejestrowych doświadczeń odmianowych. Kukurydza. COBORU Słupia Wielka, 39.

Jasiulewicz–Kaczmarek, M., Antosz, K., Żywica, P., Mazurkiewicz, D., Sun, B., Ren, Y. (2021). Framework of machine criticality assessment with criteria interactions. *Eksploatacja i Niezawodność – Maintenance and Reliability,* 23*(2),* 207-220.

Juściński, S., Piekarski, W. (2010). The farm vehicles operation in the aspect of the structure of demand for maintenance inspections. *Eksploatacja i Niezawodność – Maintenance and Reliability, 1,* 59-68.

Kowalik, I., Michalski, T. (2009). Zawartość suchej masy w surowcu jako szacunkowy wskaźnik wartości pokarmowej kiszonki z kukurydzy. *Nauka Przyroda Technologie,* 3*(2),* 1-10.

Kowalik, I., Przybył, J., Sęk, T. (2003). Exploitation comparative research into forage harvesters during harvest of maize for silage. *Scientific Papers of Agricultural University of Poznań. Agriculture, 4,* 31-38.

Kruczyńska, H., Darul, K., Nowak, W., Kowalik, I. (2001). The chemical composition and ruminal degradability of maize silages depending on the cultivar and mowing height at harvest. *Journal of Animal and Feed Sciences,* 10*(2),* 331-337.

Marinich, L.A., Lensky, A.V., Kudrevich, A.A. (2012). Srawnitielnyj analiz effektywnosti eksploatacji sama chodnych lormouborocznych kombajnow Jaguar 850/870 i KBK-800 pri zagatowkie kukuryzy i podborie traw. Viesci Nacyanalnaj Akademii Nauk Belarusi. *Serya Agrarnych Nauk, 3,* 94-102.

Marsh, B.H. (2013). A comparison of fuel usage and harvest capacity in self-propelled forage harvesters. *International Journal of Agricultural and Biosystems Engineering,* 7*(7),* 649-654.

Mueller, J.P., Green, J.T., Kjelgaard, W.L. (1991). *Corn silage harvest techniques*. National Corn Handbook, 49, Iowa State University.

Muzalewski, A. (2010). *Koszty eksploatacji maszyn*. Wydawnictwo ITP, Falenty – Warszawa, 47.

Pilarski, K., Pilarska, A.A., Witaszek, K., Dworecki, Z., Zelazinski, T., Ekielski, A., Makowska, A., Michniewicz, J. (2016). The impact of extrusion on the biogas and biomethane yield of plant substrates. *Journal of Ecological Engineering,* 17*(4),* 264-272.

PN-91/R-55025 Metody badań kombajnów zielonkawych.

Podkówka, W., Podkówka, Z. (2004). Technologia produkcji kiszonki z całych roślin kukurydzy i jej wykorzystanie w żywieniu zwierząt. In: Technologia produkcji kukurydzy; A. Dubas (ed). Warszawa, 82-91.

Roth, G., & Undersander, D. (1995). Corn silage production, management, and feeding. In *Corn silage production, management, and feeding* American Society of Agronomy/Crop Science Society of America/Soil Science Society of America, Madison, WI.

Staszak, Ż., Grześ, Z., Rybacki, P. (2018). A method of comparative studies on checkup sets to evaluate the technical condition of tractors. *Eksploatacja i Niezawodność – Maintenance and Reliability,* 20*(3),* 450-454.

Szlachta, J., Tupieka, M. (2013). Analiza opłacalności produkcji kukurydzy z przeznaczeniem na kiszonkę jako substratu do biogazowni. *Inżynieria Rolnicza,* 3*(145),* 375-386.

Szymańska, M., Sosulski, T., Szara, E., Pilarski, K. (2015). Technologie przetwarzania pofermentu z biogazowni oraz właściwości fizykochemiczne otrzymanych produktów. *Przemysł Chemiczny,* 94*, 8,* 1419-1423.

OCENA PARAMETRÓW OPERACYJNYCH SIECZKARNI SAMOJEZDNEJ PODCZAS ZBIORU KUKURYDZY PRZEZNACZONEJ NA KISZONKĘ

Streszczenie. Niniejsze badanie ma na celu określenie i ocenę parametrów operacyjnych trzech nowoczesnych samojezdnych sieczkarni podczas zbioru kukurydzy na kiszonkę. Maszyny były wyposażone w systemy wspomagania operatora. Badania polowe zostały przeprowadzone dla trzech samojezdnych sieczkarni: Claas Jaguar 870, Class Jaguar 950, Krone BiG X 650. Badania przeprowadzono w dużych gospodarstwach na terenie województwa Wielkopolskiego i Pomorskiego. Kukurydzę zbierano na początku etapu pełnej dojrzałości ziarna. Przeprowadzono pełne badania czasu w celu określenia wskaźników operacyjnych, które objęło cztery zmiany kontrolne zgodne z normą BN-76/9195-01. Zużycie paliwa określono przy użyciu metody pełnego zbiornika. Sieczkarnia Class Jaguar 950 miała najwyższą wydajność masy efektywnej: 141.3 $Mg \cdot h^{-1}$. Ta sama maszyna osiagnęła także najniższe zużycie paliwa na tonę świeżej zebranej masy 0.51 $kg \cdot Mg^{-1}$. Nakład pracy samojezdnych sieczkarni zbadanych podczas całego czasu zmiany wahał się między 0.38 do 0.62 roboczogodzin na hektar. Badane maszyny posiadały także wysoką niezawodność techniczną oraz technologiczną.

Słowa kluczowe: zużycie paliwa, wydajność zbioru, zbiór kukurydzy, działanie, sieczkarnia samojezdna