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Use of Polish-bred maize hybrids for biogas production

Wykorzystanie mieszańców kukurydzy polskiej hodowli do produkcji biogazu

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Abstract

The suitability for biogas production of silages from selected Polish-bred maize hybrids was investigated. Biogas and methane yield of silages was 513 – 703 and 339 – 443 Ndm^3•kg^{-1} ODM. Hybrids were characterized by a high methane content in biogas (over 63%). Differences were found in biogas and methane production from different maize varieties. The highest-yielding hybrids were SMH 1785 and KBK 11149.

Keywords: biogas, biomass, maize silage, methane

Streszczenie

Przeprowadzono badania na średnio wczesnych (SMH 1785, SMH 1796, KBK 11149) i średnio późnych (SMH 1742, SMH 1793, Kadryl, SMKOC 1101) mieszańcach kukurydzy. Na podstawie badań biogazodochodowości i analizy składu podstawowego określono przydatność kiszonek sporządzonych z całych roślin wybranych mieszańców do produkcji biogazu. Odmiana SMH 1785 wykazywała najwyższą wydajność biomasy (768 dt•ha^{-1}). Uzysk biogazu i metanu z kiszonek wyniósł odpowiednio 513 – 703 i 339 – 443 Ndm^3•kg^{-1} SMO, najwyższe wartości odnotowano dla mieszańca KBK 11149. Oceniane mieszańce odznaczały się wysoką zawartością metanu w biogazie (powyżej 63%). Dla odmian SMH 1785 i KBK 11149 stwierdzono powyżej 8 000 Nm^3 metanu z 1 ha uprawy. Wykazano różnice w produkcji biogazu i metanu z kiszonek różnych odmian kukurydzy.

Słowa kluczowe: biogaz, biomasa, kiszonka z kukurydzy, metan

Streszczenie szczegółowe

Szczególnie przydatnym substratem biogazowym jest kiszonka z kukurydzy. Kukurydza wykazuje duży plon biomasy, ma dobrą przydatność do zakiszania oraz daje duży uzysk biogazu i metanu w procesie fermentacji beztlenowej na ustabilizowanym poziomie. Do uprawy trafiają specjalne odmiany kukurydzy z przeznaczeniem na biogaz. Również polscy hodowcy kukurydzy pracują nad stworzeniem nowych, typowo biogazowych odmian.

Celem badań było określenie przydatności do produkcji biogazu kiszonek wybranych mieszańców kukurydzy polskiej hodowli.

Badania przeprowadzono na siedmiu niezarejestrowanych odmianach kukurydzy polskiej hodowli. Mieszańce pochodziły z Hodowli Roślin Smolice Spółka z o.o. Grupa IHAR -: SMH 1785 i SMH 1796 (średnio wczesne) i SMH 1742 i SMH 1793 (średnio późne) oraz z Małopolskiej Hodowli Roślin Spółka z o.o.: Kadryl (średnio późny) i KBK 11149 (średnio wczesny). Mieszaniec SMKOC 1101 (średnio późny) został wyhodowany wspólnie przez obie te firmy.

Kukurydza uprawiana była na glebie klasy IIIa. Jesienią 2010 roku wykonano orkę zimową, a wiosną przeprowadzono włókowanie i uprawę przedsiewną. Kukurydzę wysiano 27 kwietnia 2011. W połowie maja wykonano oprysk środkiem chwastobójczym, w połowie czerwca zastosowano dokarmianie dolistne, zaś w połowie lipca wykonano oprysk środkiem owadobójczym.

Zielonkę zebrano w połowie września 2011 roku w fazie dojrzałości woskowej ziarna i zakiszono w mikrosilosach z polietylenu (Ø15 cm, wys. 49 cm). Po upływie sześciu tygodni kiszonki poddano badaniom biogazodochodowości (Biogaz Zeneris Tech Spółka z o.o. w Poznaniu) oraz przeprowadzono analizę składu podstawowego (AOAC, 1990). Badania biogazodochodowości przeprowadzono wykorzystując beztlenową fermentację kiszonki z kukurydzy. Dobrano początkowe obciążenie fermentora, tak aby wynosiło 4,95 kg suchej masy organicznej (SMO)•m^{-3}. Odczytu poziom gazu w kolektorze dokonywano co 24 h. Okresowo analizowano skład biogazu. Fermentacje prowadzono 42 dni. Skład biogazu oznaczono za pomocą analizatora Geotechnical Instruments – typ GA 2000 Plus. Wyniki analiz laboratoryjnych składu chemicznego wykorzystano do szacowania ilości uzyskiwanego biogazu, z wykorzystaniem wzoru (Amon i wsp., 2007a). Uzyskane wyniki opracowano statystycznie za pomocą pakietu statystycznego SAS (1995) z wykorzystaniem analizy wariancji. Istotności różnic między grupami oceniano testem Tukey’a.

Zawartość suchej masy w badanych kiszonkach wahała się od 29,20% (SMH 1742) do 31,49% (SMH 1796). Sucha masa organiczna (w % w suchej masie) stanowiła od 94,45% (SMH 1785) do 95,69% (SMKOC 1101). Spośród wszystkich ocenianych odmian najwięcej białka ogólnego zawierał mieszaniec KBK 11149, tłuszczu surowego mieszaniec SMH 1785, włókna surowego mieszaniec Kadryl, zaś związków bezazotowych wyciągowych mieszaniec SMH 1796. Różnice w składzie chemicznym pomiędzy badanymi odmianami nie były statystycznie istotne.

Uzysk biogazu z kiszonek wyprodukowanych z badanych odmian kukurydzy wyniósł średnio 597 Ndm^3•kg SMO^{-1}, a różnice pomiędzy mieszańcami były statystycznie

istotne. Uzysk metanu natomiast wyniósł średnio 389 Ndm•kg SMO^{-1}. Najwyższy uzysk biogazu i metanu otrzymano z odmiany KBK 11149 (703 i 443 Ndm•kg SMO^{-1}), a najniższy z odmiany SMH 1742 (odpowiednio 513 i 339 Ndm•kg SMO^{-1}).

Mieszańce wykorzystane w badaniach odznaczały się wysoką zawartością metanu w biogazie (powyżej 63%).

Średni plon biomasy z 1 ha uprawy kukurydzy wyniósł 674 dt. Najwyższą wydajność (768 dt•ha^{-1}) stwierdzono dla odmiany SMH 1785.

Z 1 hektara uprawy można było wyprodukować średnio 7 665 Nm^3 metanu. Najwyższą wydajność metanu z 1 ha uzyskano dla odmiany SMH 1785.

Porównano wyniki wydajności metanu oznaczone metodą laboratoryjną i wyniki uzysku metanu obliczone za pomocą równania regresji. Różnice pomiędzy metodami wyniosły średnio 5,1%. Do celów praktycznych w celu określania wydajności metanu można z powodzeniem stosować równanie podawane przez Amona i wsp. (2007a), wykorzystujące zawartość podstawowych składników w kiszonkach.

Badania wykazały różnice w produkcji biogazu i metanu z kiszonek sporządzonych z różnych odmian kukurydzy. Najwydajniejszymi w przeprowadzonych badaniach okazały się mieszance SMH 1785 (HR Smolice) i KBK 11149 (Małopolska HR).

Introduction

The Climate and Energy Package, known as the 20-20-20 package, was adopted in March 2007 by the European Council and the heads of European Union member states. It obliges the member states to reduce emissions of greenhouse gases in 2020 by at least 20% from a base year of 1990. In addition, it is planned to increase the share of energy from renewable sources in final consumption of energy to 20% until 2020, and to increase energy efficiency use by 20% compared to prognosis on fuel and energy demand, also until 2020. In January 2014, the European Commission proposed a policy framework for climate and energy in the European Union. The objectives for 2030 are a 40% cut in CO2 emissions (compared to 1990 levels) and a 27% share of renewable energy sources (RES) in the energy mix. Most EU countries expect these ambitious climate goals to be quickly approved.

The official documents and independent forecasts predict that during the next decade agricultural biogas production will develop at a rate of several dozen per cent a year. Much evidence shows that over the next few years agricultural biogas will gain in importance in the energy market (Przewodnik dla inwestorów, 2011). In 2010, the Polish Ministry of Economy published the document “Directions of development for agricultural biogas plants in Poland between 2010 and 2020” (Kierunki rozwoju biogazowni, 2010). The objective is to create optimal conditions for the development of agricultural biogas installations. Theoretical feedstock production potential is estimated to be 5 billion m3 of biogas. It is assumed that use will be made of byproducts from agricultural production, animal urine and faeces, as well as by-products and residues of the agri-food industry. At the same time, along with the use of this feedstock, it is expected that crops will be produced mainly as a substrate for biogas plants. Ultimately this may cover the area of 700,000 ha, which will meet

100% of domestic food demand while acquiring additional feedstock for biofuel and agricultural biogas production (Kierunki rozwoju biogazowni, 2010).

Maize silage is a particularly useful biogas substrate. The advantages of this component as digester input include high yield of green matter per unit area, good ensilability, and high biogas and methane yield during anaerobic fermentation.

Compared to other substrates, maize silage has the advantage of ensuring stable biogas and methane production during the operation of agricultural biogas plants; this facilitates controlling substrate feeding into the digester and ensures stable operation of the cogeneration unit (Szachta and Tupieka, 2013). According Weiland (2010) of one tone of SSO whole plant maize silage obtained 560 - 650 m^3 of biogas.

Special maize varieties bred for biogas production are being brought into cultivation (Herrmann and Rath, 2012; Koutný et al., 2012). Also Polish maize breeders are working to develop special maize varieties for biogas production.

The aim of the study was to determine suitability of silages from seven Polish-bred maize hybrids for biogas production.

Materials and Methods

The study was conducted with seven unregistered Polish-bred maize hybrids originating from Smolice Plant Breeding Ltd of the Plant Breeding and Acclimatization Institute (hybrids SMH 1742, SMH 1785, SMH 1793 and SMH 1796) and Małopolska Plant Breeders Ltd (hybrids Kadryl and KBK 11149). Hybrid SMKOC 1101, developed jointly by these two companies, was also used. The characteristics of the different hybrids are shown in Table 1.

Maize was cultivated on soil class IIIa. Before winter (in 2010) was plowed field. Trawls were conducted in spring and used seedbed cultivation... Maize seeded on April 27th 2011. In the middle of May herbicide spraying was performed, in mid-June foliar fertilization applied, while in mid-July were performed aerial spraying insecticide.

Table 1. The characteristics of the experimental hybrids

Tabela 1. Charakterystyka mieszańców użytych w doświadczeniu

Hybrid	Earliness of group	Type of hybrid	Type of grain
SMH 1742	medium-late	single cross	dent
SMH 1785	medium-early	three-way cross	semident
SMH 1793	medium-late	three-way cross	dent
SMH 1796	medium-early	three-way cross	dent
SMKOC 1101	medium-late	three-way cross	dent
KADRYL	medium-late	three-way cross	dent
KBK 11149	medium-early	three-way cross	dent

Forage for ensilage was harvested in mid-September 2011 at the wax ripeness stage. After chopping into 1-cm pieces, it was ensiled in polyethylene micro-silos (15 cm in diameter, 49 cm in height). After thoroughly compacting forage, the micro-silos were sealed with rubber stoppers equipped with fermentation tubes. The tubes were filled with glycerol to allow fermentation gases to escape.

Silos were opened after six weeks. Part of silage from each micro-silo was submitted for the analysis of biogas profitability and the remainder was analyzed for basic composition.

The silages were analyzed at the laboratory of the Department of Animal Nutrition and Feed Management, the University of Technology and Life Sciences in Bydgoszcz. Silage samples were prepared in accordance with standards (PN-ISO 6498:2001) and ground to pass through the 1-mm screen of a cutting mill (Retsch SM100 Comfort). The so prepared material was analyzed for dry matter (DM), crude ash (CA), crude protein (CP), crude fat (CFa) and crude fibre (CFi) according to standard procedures (AOAC, 1990). N-free extractives (NFE) were calculated by subtracting the sum of CA, CP, CFa and CFi from DM (Praca zbiorowa, 2013).

Biogas profitability was determined in the laboratory of Biogaz Zeneris Tech Ltd. in Poznań. The analyses were performed using anaerobic fermentation of maize silage, with three replications for each hybrid. Prior to the analysis, the raw material was ground through a 2 – 4 mm plate (Uniscale Meat Mincer, Model Inoxxi MM S22). Based on the results of raw material analysis, the initial fermenter load was set at 4.95 kg of organic dry matter (ODM)•m^{-3}. Next, a weighed quantity of the substrate with inoculum was placed in a tightly sealed fermentation vessel with a working volume of 500 ml. Fermenters were immersed in a water bath at 37°C. The generated biogas was transferred to a cylindrical, calibrated gas collector filled with acidulated water. Gas level in the collector was read every 24 h. Biogas composition was analyzed periodically. Fermentations were carried out for 42 days. Starved and well-adapted anaerobic sludge, obtained at the laboratory of Biogaz Zeneris Tech Ltd, was used for the analysis. Biogas composition was determined using a GA 2000 Plus analyzer (Geotechnical Instruments). The amount of biogas and methane produced was converted to normalized conditions (273 K and 1013.25 mbar).

The laboratory analyses of the chemical composition were used to estimate the amount of biogas produced, based on a formula provided by Amon et al. (2007a):

$$ME = 15.27 \times CP + 28.38 \times CFa + 4.54 \times CFi + 1.12 \times NFE$$

where:

ME – methane yield (Ndm^3•kg ODM^{-1})

CP – crude protein (% DM)

CFa – crude fat (% DM)

CFi – crude fibre (% DM)

NFE – N-free extractives (% DM)

The results were statistically analysed with SAS package (SAS/STAT, 1995) using analysis of variance. Significant differences between the groups were analyzed with Tukey’s test.

Results

Meteorological conditions during the vegetation are presented in Figure 1. In May saw high rainfall. By contrast, in June was characterized by high temperatures and low rainfall. For the other months was observed favorable conditions for the development of maize plants.

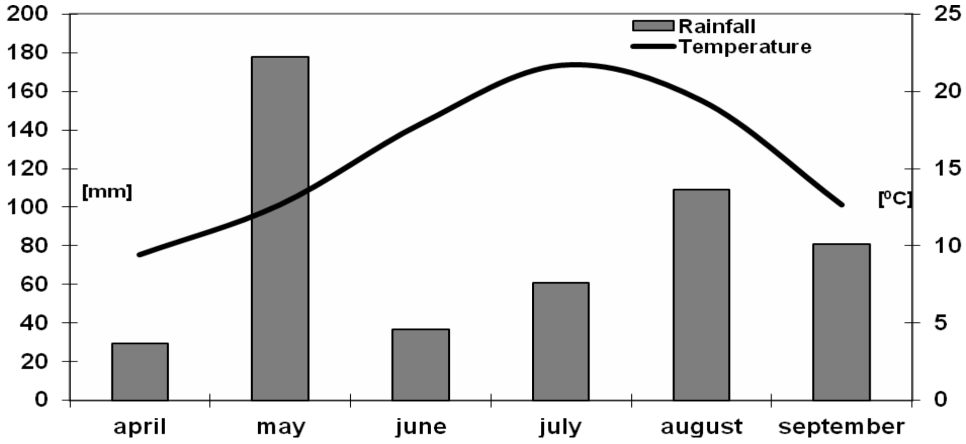

Figure 1. Temperature and rainfall during the experience

Rysunek 1. Temperatura i opady podczas trwania doswiadczenia

Table 2 presents chemical composition of the maize silages. Dry matter content of the silages ranged from 29.20% (SMH 1742) to 31.49% (SMH 1796). Organic dry matter (in % DM) accounted for 94.45% (SMH 1785) to 95.69% (SMKOC 1101). Out of all the varieties, crude protein were the highest in hybrid KBK 11149, crude fat in SMH 1785, crude fibre in Kadryl, and N-free extractives in SMH 1796. Differences in chemical composition between the varieties were not significant.

Table 2. The chemical composition of the experimental silages

Tabela 2. Skład chemiczny badanych kiszonek

Hybrid	Dry matter (%)	Organic matter (% DM)	Crude protein (% DM)	Crude fat (% DM)	Crude fibre (% DM)	NFE (% DM)
SMH 1742	29.20	95.26	7.66	3.20	21.97	62.43
SMH 1785	30.98	94.45	8.37	3.80	20.65	61.63
SMH 1793	29.98	94.56	7.89	3.30	21.99	61.38
SMH 1796	31.49	95.67	7.43	3.14	21.50	63.59
SMKOC 1101	29.44	95.69	8.15	3.41	21.89	62.24
KADRYL	29.31	95.66	7.86	3.07	22.58	62.15
KBK 11149	30.30	95.24	8.53	3.12	22.56	61.12
Mean	30.10	95.22	7.98	3.29	21.88	62.08

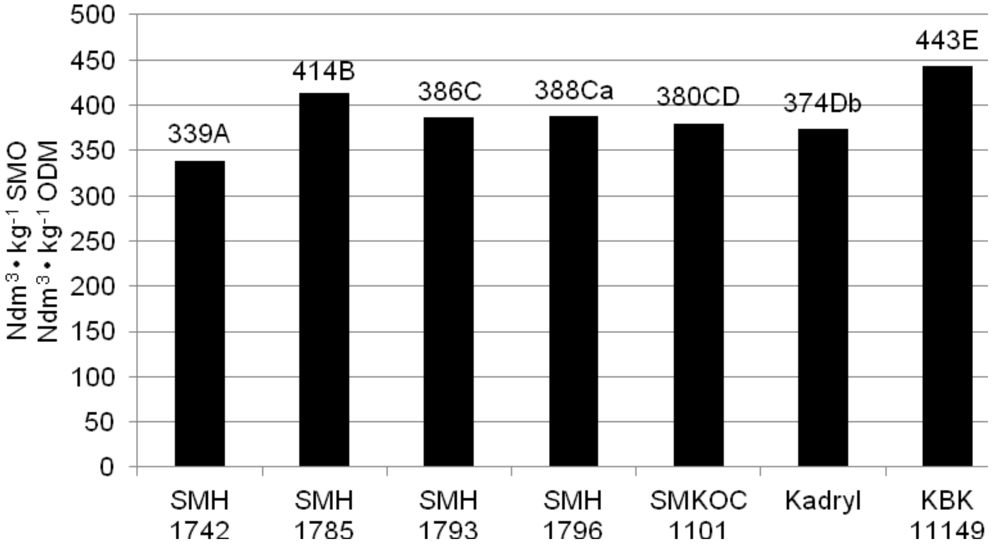

Figure 2. Methane yield from the experimental silages

Rysunek 2. Uzysk metanu z badanych kiszonek

A, B - P≤0.01; a, b - P≤0.05

Table 3. shows statistically significant differences in biogas yield from silages between the studied varieties, which averaged 597 Ndm^3•kg ODM^{-1}. Methane yield is presented in Figure 2.

Table 3. Yield and productivity of biogas

Tabela 3. Uzysk i wydajność biogazu

Hybrid	Biogas yield (Ndm^3•kg ODM^{-1})	Biomethane content in biogas (%)	Biogas productivity (Nm^3•ha^{-1})
SMH 1742	513^A	66	10 032
SMH 1785	642^B	65	13 747
SMH 1793	597^C	65	11 356
SMH 1796	590^{Ca}	66	11 971
SMKOC 1101	576^{CD}	66	11 526
KADRYL	557^{D}b	67	10 931
KBK 11149	703^E	63	12 780
Mean	597	65	11 763

Legend: ODM – organic dry matter
AB – significant differences at p ≤0.01
ab – significant differences at p ≤0.05

Legenda: SMO – sucha masa organiczna
AB – statystycznie istotne różnice przy p ≤0,01
ab – statystycznie istotne różnice przy p ≤0,05

The average methane production in the studied silages was 389 Ndm^3•kg ODM^{-1}. Differences in methane yield between the studied hybrids were statistically significant. The greatest amounts of biogas and methane were obtained from KBK 11149, but this variety had the lowest methane content in biogas. The lowest biogas and methane yield was characteristic of SMH 1742 variety. The methane content in biogas produced from the studied maize silages (Table 3) ranged from 63% for KBK 11149 to 67% for Kadryl.

Average biomass yield from 1 ha of maize crop was 674 dt. It showed large variation but the differences were not significant. The highest green matter yield was found for SMH 1785 and the lowest for KBK 11149 variety, with a difference in the yield amounting to 168 dt•ha^{-1} (Figure 3).

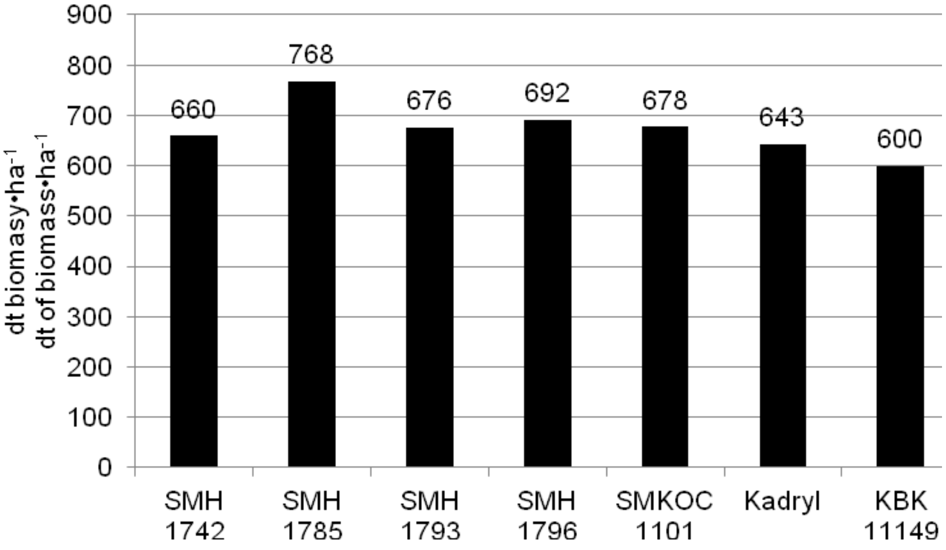

Figure 3. The experimental maize biomass yields

Rysunek 3. Plony biomasy badanych odmian kukurydzy

The production of methane per hectare of maize crop averaged 7 665 Nm^3. Figure 4 presents the amounts of methane obtained from different hybrids.

Despite the highest yield of methane from KBK 11149, this variety failed to achieve the highest methane productivity due to the lowest biomass yield. The highest methane productivity was obtained for SMH 1785 variety, which was characterized by the highest green matter yield. Large differences were found in methane productivity between the studied hybrids. The difference between the extreme methane productivity values obtained in the experiment was 2 242 Nm^3•ha$^-$1.

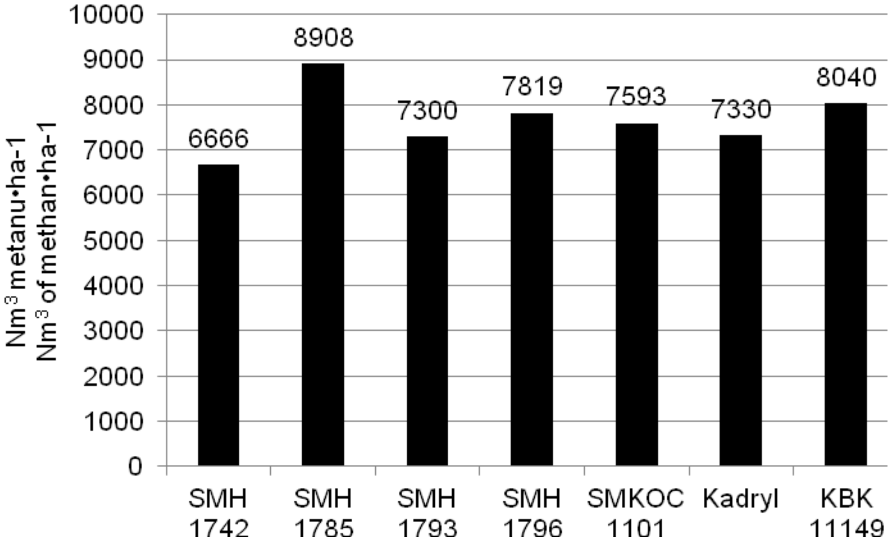

Figure 4. Methane yield of the silages

Rysunek 4. Wydajność metanu z kiszonek

Table 4 shows methane productivity values determined by the laboratory method and methane yield values calculated using with the regression equation.

Table 4. Comparison of methane productivity (Ndm^3•kg ODM^{-1}) as determined in the laboratory and calculated from the regression equation

Tabela 4. Porównanie wydajności metanu (Ndm^3•kg SMO^{-1}) oznaczonej w laboratorium i obliczonej z równania regresji

Hybrid	Biomethane productivity (Ndm^3•kg ODM^{-1})		Difference between the determined and calculated amounts	
	determined	calculated	Ndm^3	%
SMH 1742	339	377	38	11
SMH 1785	414	398	-16	-4
SMH 1793	386	383	-3	-1
SMH 1796	388	371	-17	-4
SMKOC 1101	380	390	10	3
KADRYL	374	379	5	1
KBK 11149	443	390	-53	12

The difference in methane productivity between the methods ranged from 3 to 53 Ndm^3•kg ODM^{-1}. The largest differences were noted for the extreme methane productivity values obtained in the laboratory. The difference was 11% for the lowest productivity and 12% for the highest productivity, with the mean difference of 5.1%.

Discussion

Maize silage made for biogas production should contain from 28 to 35% dry matter (Herrmann and Rath, 2012; Podkówka, 2012). The dry matter content of silages from the experimental varieties fell within this range.

In the biogas plant digester, anaerobic organisms degrade organic matter under anaerobic conditions. Płatek (2007) reports that the level of organic dry matter (ODM) in maize silage should be 95%. In the experimental silages, ODM was higher for five varieties and lower for two varieties when compared to the above level.

The methane produced by fermentation is generated from organic components (crude protein, crude fat, crude fibre, N-free extractives), which are decomposed by methane bacteria (Amon et al., 2007a). Chemical composition of silages has an essential effect on the amount of methane obtained from maize (Amon et al., 2007b; Oslaj et al., 2010; Zsubori et al., 2013). The content of basic components in the experimental silages was no different from the typical values reported in the literature for this type of feedstock (Kolver et al., 2001; Podkówka and Podkówka, 2004; Podkówka and Podkówka, 2011).

Myczko and Kołodziejczyk (2011) report that 1 kilogram of the organic dry matter (ODM) of maize silage yields from 450 to 700 Ndm^3 of biogas. One of the experimental varieties (KBK 11149) generated a slightly higher yield of biogas. For the other varieties, biogas productivity ranged from 513 to 642 Ndm^3 per kg of ODM.

From a kilogram of the organic dry matter of maize silage, Amon et al. (2007b) obtained between 268 and 366 Ndm^3 of methane. In our study we had a higher methane output for all samples except one (SMH 1742). This could be due to the higher CP and CFa content of the silages compared to the silages analysed by the authors cited above. As reported by Amon et al. (2007a) and Herrmann and Rath (2012), these two components (crude protein and crude fat) have a decisive influence on the amount of methane produced.

Good quality biogas contains more than 60% of methane (Zsubori et al., 2013). Silages from all the experimental varieties showed a higher methane content of biogas.

Biomass yield depends on maize hybrid (Amon et al., 2007a), which was reflected in our study. According to the data of the Central Statistical Office (GUS, 2012), maize biomass yield in Poland in 2012 was 499 dt•ha^{-1}. All the hybrids evaluated in our experiment gave higher dry matter yields.

According to Amon et al. (2007b), methane productivity per ha of maize crop depends on both biomass yield and methane yield per kilogram of silage organic dry matter. This is supported by our study: the highest productivity was characteristic of the hybrids SMH 1785 (highest biomass yield) and KBK 11149 (highest methane yield). In this context, Schittenhelm (2008) and Herrmann and Rath (2012) state that breeders of new maize varieties, grown specifically for biogas production, should strive to maximize biomass yields.

Regression equations are used to determine methane yield from maize silage (Herrmann and Rath, 2012; Amon et al., 2007a). In the study by Amon et al. (2007a), the difference in methane yield between the amount determined in the laboratory and the amount calculated from the equation was 0.7%. In our study, this difference was higher (5.1%). The equation provided by Amon et al. (2007a) can be successfully used for practical purposes.

Amon et al. (2007a) and Bruni et al. (2010) found no differences in the amount of methane produced from different maize varieties. Studies by other authors (Oslaj et al., 2010; Vindis et al., 2010) and our experiment found variety to have an effect on the amount of methane produced.

Conclusions

Using standard methods of cultivation of maize. Weather conditions in 2011 conducive the cultivation of this plant.

Biogas yield from maize silages made from the experimental maize varieties ranged from 513 to 703 Ndm^3 per kilogram of organic dry matter. The highest biogas production was found for KBK 11149 variety.

The experimental hybrids were characterized by a high methane content of biogas (over 63%) and a high methane yield. The highest methane yield (443 Ndm^3•kg ODM^{-1}) was observed for KBK 11149 variety.

The analyzed hybrids were characterized by high biomass yields. The highest green matter yield (768 dt•ha) was obtained for SMH 1785 variety.

The present experiment demonstrated differences in biogas and methane production from the silages made from different Polish-bred maize hybrids. Hybrids SMH 1785 and KBK 11149 gave the highest yields in our study.

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