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BIOGAS YIELD OF MAIZE STRAW

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Abstract. The paper presents the results of laboratory research of the effectiveness of biogas production from silage of maize straw with addition of the fermentation inoculum, which was post-fermentation pulp from agricultural biogas plant. Maize straw was ensiled naturally and with the use of artificial additives, the task of which was to ensure correct fermentation process. Two preparations were used for ensilage: Silomax (bacteria of lactic fermentation) and Labacsil Acid (the set of organic acids and potassium sorbate). The experiment was conducted in a multi-chamber biofermentator, monitoring biogas production and the minimum level of methane. It was found out that silage from maize straw without the ensiling preparations was characterised with the highest biogas yield. Whereas, with regard to methane production, maize straw silage with Labacsil Acid preparations was the most efficient.

Key words: maize straw, substrate, biogas, methane

Introduction

On the national market, there is an insufficient supply of cheap biomass, which will remain a renewable energy source, which brings the best effects with regard to production costsfor several years. It results from the limited resources of the national water power industry, average conditions for the development of wind energy and photovoltaics, which is low-efficient in the Polish conditions.

It may also be assumed that the demand for biomass will rise in the near future. Pursuant to obligations written down in the Directive of the European Parliament 2009/28/EC on promoting the use of energy from renewable sources in 2020, Poland must achieve 15% participation of original energy from RES in the total use of energy, in total in heavy current engineering, heat engineering and refrigeration and transport (Directive, 2009). Moreover, there are additional objectives related to the development of renewable energy sources in the resolution of the Council of Ministers on energy policy of Poland to 2030, which lead to inter alia: achieving in 2020 10% participation of biofuels int he market of transport fuels, increasing the use of 2nd generation biofuels and creating conditions for the development of dispersed power industry, based on the locally available raw materials (Polityka, 2009; Prognoza, 2009).

In order to implement directive 2009/28/ EC governments of the European countries were obliged to prepare National Action Plans (NAP, 2010) for renewable energy sources.

Presently, approx. 92% of energy generated in Poland from RES constitutes heat, produced in majority of biomass, electric energy constitutes 5% and transport fuels 3%. In the scenario for 2020 according to the NAP, heat participation in the production of energy of RES is going to constitute only 55%, of electric energy 26% and transport fuels 19%. However, as much as 78% of thermal energy and 32% of electric energy is going to be produced of solid biomass (Prognoza, 2009)

Straw is the basic source of biomass. On account of quickly increasing demand for straw by producers of briquettes, mushroom base, users of straw boilers, municipal waste composting plant, agricultural distilleries, which compost stillage on biological deposits and other subjects, on one side there is a deficiency of this raw material; on the other hand in conditions of unsatisfied demand, a price increase of the grain straw took place. Therefore, attention has been paid to the biomass source unused so far, that is maize straw and after-harvest remains after harvesting maize for seeds.

The content of dry mass in the maize straw is approx. 50% (Niedziółka et al. 2007) and may be subject to some oscillations on account of the time limit of harvesting, weather conditions and the type of the hybrid. Therefore, after-harvest remains of maize in a fresh state may not be managed with the methods used at the harvest of the grains straw. On account of the above, in order to ensure biogas production, permanent supply in raw material, straw should be preserved after harvesting. Ensilaging of the fragmented straw seems to be the most appropriate method of preservation. On account of the lack of scientific works concerning the technology of biogas production from maize straw stored in anaerobic conditions, laboratory conditions concerning different methods of ensilaging straw and their impact on biogas and methane yield were took up.

The objective of the paper

The objective of the paper was to assess the possibility of using the side crop in maize production for seeds, that is maize straw as a substrate for biogas production after previous preservation through ensilaging also with the use of ensilaging additives.

Material and research methods

Maize straw (after-harvest remains) after harvest of maize for seeds cultivar LG3612 number FAO 250 was used for research. Research material was obtained from Seed and Agricultural Farm in Chodów in Wielkopolskie voivodeship. Maize was cultivated on the soil class IIIa of low content K_2O and MgO and average content of P_2O_5. Plantation stock before harvest was 88.1 thousand of plants·ha^{-1}. Harvest of seeds of 31% moisture was 12 Mg·ha^{-1}. The structure of the maize harvest referred to dry matter was as follows: cobs 54%, stalks 26%, leaves 11% and covering leaves of cobs 9%. Mass relation of dry mass of the seeds yield to dry mass of the post-harvest remains was 1:1,3. The content of dry substance in ensiled post-harvest remains was 66.13% and the content of mineral substance was 6%. Maize seeds harvesting was carried out with the combine harvester Claas Lexion 580 equipped with 8-row adapter Geringhoff Mais Star Horizon 800/B placing a ground straw in a roller. Harvesting of maize straw and the remaining post-harvest remains was carried out with self-propelled chaff-cutter Class Jaguar 860 with a pick-up assembly.

Ensilaging the maize straw was carried out in a natural way and with the use of additives for ensilaging, which limit development of undesired bacteria, cause fast decrease of pH reaction and increase stability of silage after opening the silo. Two preparations were used for ensilage: Silomax including bacteria of lactic acid and Labacsil Acid which includes the set of organic acids and potassium sorbate. Bacteria in Silomax formula causes high production of lactic acid in silage, whereas acids included in Labacsil Acid limit the growth and activity of undesired bacteria, mould and yeast (Sano, 2010).

Post-harvest remains were ensiled in tightly closed mini-silos of 4 dm^3 volume in three repeats. After 160 days of ensiling, physical and chemical analysis from silages was carried out, and then tests on their biogas performance were carried out. The physical and chemical analysis of silages was carried out in the Laboratory of the Department of Feeding Animals and Fodder Management of the University of Natural Sciences in Poznań. The analysis included determination of dry mass, total protein, pH, gross energy and volatile fatty acids.

Laboratory research of biogas yield of the ensiled maize straw was carried out in the Laboraotry of Ecotechnology of the Institute of Biosystems Engineering of the University of Natural Sciences in Poznań according to the norm DIN 38 414 S8: 1985 based on *eudometric measurement* of the biogas yield. Biofermentators were located in the water jacket, enabling fixed temperature in the chamber that is approx. 38ºC proper for mesophile fermentation (fig. 1).

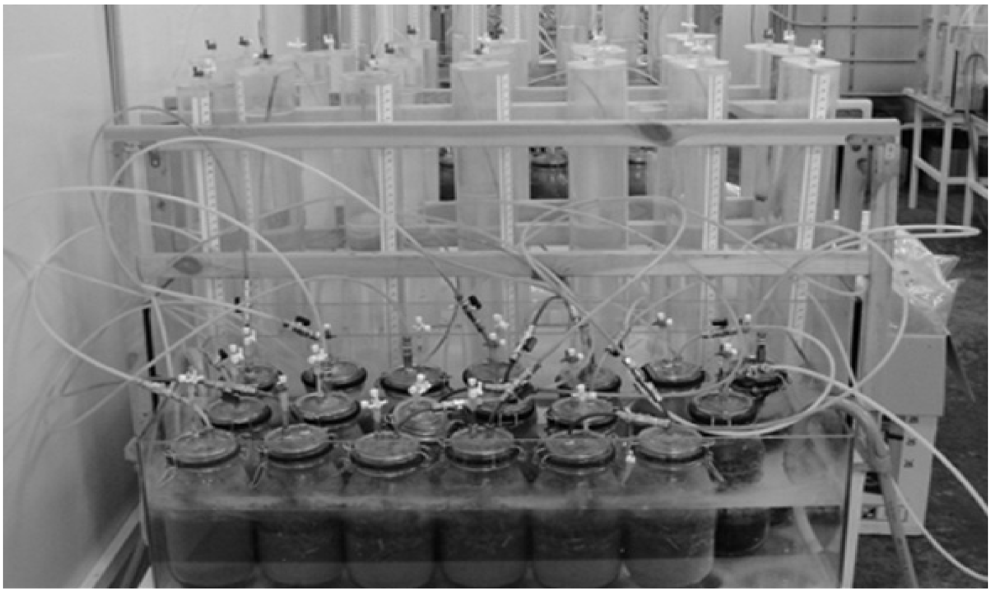

Figure 1. Biofermentator for testing efficiency of the methane fermentation process

Readouts of the produced biogas were carried out with daily frequency. Analysis of emission of biogas composing gases (CH_4, CO_2, O_2, NH_3, H_2S) was carried out with Microprocessor Monitoring-Recording System MSMR-4 by Alter company.

Before testing the biogas performance of maize straw inoculum parameters were determined, that is dry mass (measurement with drying method PN-75 C-04616/01), pH (measurement with electrometric method PN-90 C-04540/01), conductivity (PN-EN 27888: 1999), organic matter and ash (through combustion according to PN-Z-15011-3). Parameters of inoculum were as follows: pH 7.25, conductivity 4.76 mS, dry mass 1.33% and dry organic mass 72.9%.

Research results and their analysis

Quality of maize straw silage. Based on the analysis of the chemical composition, comparison of the quality of maize straw silage produced with ensilaging additives with the naturally prepared silage was carried out (tab. 1). Naturally produced silage included the highest number of protein that is 3.03% and was characterised with the highest gross energy, which was 2800 $Kcal \cdot kg^{-1}$ and the highest content of dry mass – 64.40%. In the silage with Silomax preparation, lower content of dry mass of silage was reported that is 61.19%, protein content decrease by 0.5%, gross energy by 81 $Kcal \cdot kg^{-1}$ and decrease of pH reaction to the level of 4.46. Also in silage with Labacsil Acid preparation in comparison to naturally prepared silage, decrease of the dry mass content by 2.24%, lower protein value by 0.3% and lower value of gross energy by 48 $Kcal \cdot kg^{-1}$ and 0.04% higher pH reaction were determined. According to Flieg-Zimmer scale, based on the content of volatile fatty acids, produced silages may be classified as good.

Table 1
Physical and chemical analysis of the tested silage

Silage	Dry mass (%)	Organic dry mass (%)	Total protein (%)	pH reaction (-)	Gross energy ($Kcal \cdot kg^{-1}$)	Lactic acid (%)	Acetic acid (%)	Butyric acid (%)
Maize straw naturally ensilaged	64.40	95.31	3.03	4.56	2,800	1.60	0.77	no
Maize straw ensilaged with Labacsil Acid preparation	62.16	94.18	2.70	4.60	2,752	1.35	0.87	0.21
Maize straw ensilaged with Silomax preparation	61.19	95.18	2.53	4.46	2,719	1.27	0.52	0.13

Results of the above analysis coincide with data in the scientific literature. According to Wróbel (2012) the use of microbiological preparations influences decrease of the dry mass content in silage. Whereas Bodarski et al. (2005) indicate that the additive of organic preparation to the maize silage influences decrease of the total protein content. Kowalik and Michalski (2009) state that the silage energy increases along with the dry mass content, which is confirmed by the tests, which were carried out.

Biogas yield of maize straw. Results of the experiment, which was carried out, proved that maize straw silage is useful for effective methane fermentation. The highest amount of biogas that is 433.78 $m^3 \cdot t^{-1}$ of dry organic mass was obtained from the maize straw naturally ensiled. Silages with ensilaging additives were characterised with lower biogas efficiency than 1.0-2.8%. Addition of Labacsil Acid preparation caused decrease of the biogas efficiency of silage by 4.19 $m^3 \cdot t^{-1}$ of dry organic mass and by 11.97 $m^3 \cdot t^{-1}$ of dry organic mass of Silomax preparation. (fig. 2).

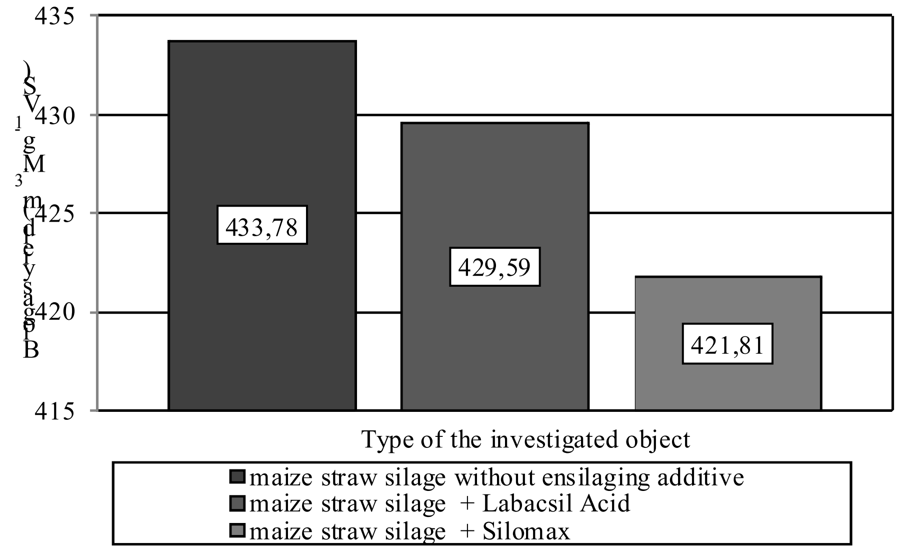

Figure 2. Biogas yield of maize straw silage without and with ensiling preparation

Biogas is a flammable gas mixture, the main component of which is methane (Janowicz, 2008). The highest methane flow rate amounting to 228.58 $m^3 \cdot t^{-1}$ of dry organic mass was obtained from maize straw ensilaged with additive of Labacsil Acid preparation. From the maize straw ensiled with additive of Silomax preparation 217.73 $m^3 \cdot t^{-1}$ of dry organic mass was obtained and 219.24 $m^3 \cdot t^{-1}$ of dry organic mass from silage without ensilaging additives. fig. 3).

The analysis of the biogas composition shows that the higher participation of methane took place in the biogas obtained from silage withensilaging additives. The highest participation of methane, amounting to 53.2% was reported in biogas from silage with Labacsil Acid preparation. In the biogas from maize straw ensilaged with addition of Silomas preparation, methane constituted 51.6% of the biogas volume. Whereas, biogas of lower methane content, amounting to 50.5% was obtained from maize straw naturally ensilaged. However, total methane participation in biogas from the tested silages was low, since, biogas contains from 55 to 80% of methane (Głaszczka, 2010; Jędrczak, 2008).

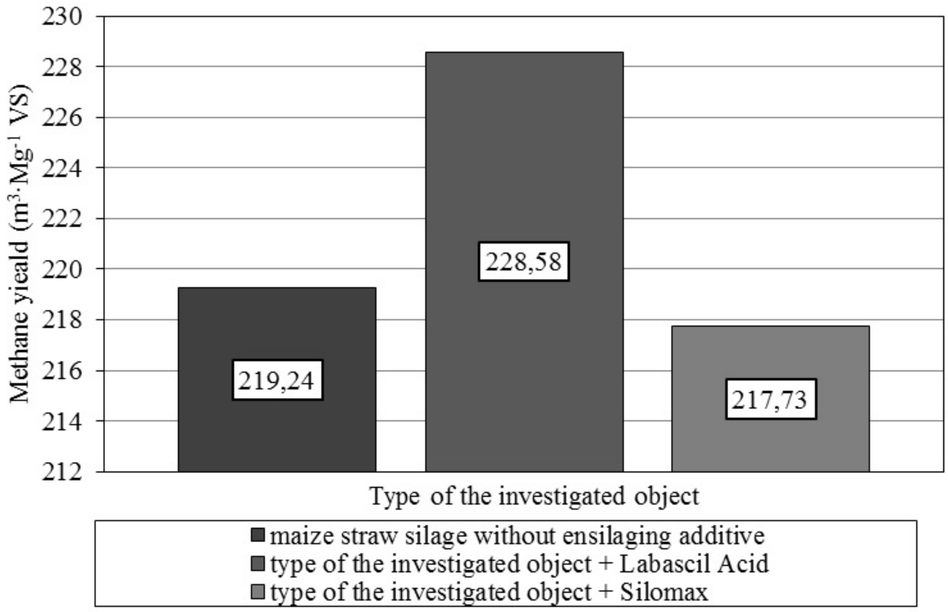

Figure 3. Methane yield of silage from maize straw without and with ensiling preparation

The obtained results indicate therefore that the use of ensilaging additive to maize straw in the form of Labascil Acid increases the flow rate of biomethane. The use of inoculants, which direct biochemical changes during ensilaging for limiting the formation of lactic acid and on the increase of the amount of acetic acid are recommended by Podkówka et al. (2010). Results of chemical analysis of the silage composition indicate that the activity occurred in case of silage with addition of Labascil Acid preparation (tab. 1).

Assessment of the possibility of use of maize straw as a substrate for biogas production requires referring the biogas efficiency to biomethane yield from all maize plants. According to Fugol et al. (2011) relative to the degree of maize fragmentation, biogas yield is from 544 to 635 $m^3 \cdot t^{-1}$ of dry organic mass and the methane participation is 82% that is from 446 to 520 $m^3 \cdot t^{-1}$ of dry organic mass According to Podkówka et al. (2010) relative to the content of dry mass, the amount of the obtained methane from whole maize plants is from 323 to 380 $m^3 \cdot t^{-1}$ of dry organic mass. In the tests carried out by Bauer et al. (2010) methane yield was 345 $m^3 \cdot t^{-1}$ of dry organic mass and according to Schittenhalm (2010), methane yield from maize silage was from 291 to 309 $m^3 \cdot t^{-1}$ of dry organic mass.

Referring to the above data, results of the own tests of ensilaged maize straw, which show that the methane yield was from 217.73 to 228.58 $m^3 \cdot t^{-1}$ of dry organic mass, one may state that methane efficiency of silage from whole maize plants is higher by approx. 35%. This result is similar to the one given by Amon et al. (2007a), who stated, during investigation of the biogas efficiency of maize that the biogas yield from plants devoid of cobs is by approx. 30% lower than from whole plants.

The other publication of this Austrian team (Amon et al. 2007b) says that the biogas production potential from 1 ha of maize amounting to 7,500-10,200 m^3 is 2-2.5 times higher that potential of grains (3200-4500 m^3), sunflower (2600-4550 m^3) and almost 3 times higher than grasses (3200-3500 m^3). Based on the obtained results one may state that maize straw devoid of cobs, having even 30% lower potential of producing from biogas in comparison to the material of whole plants, has as much as almost 2 times higher yield from one hectare of grains, sunflower or grass. Therefore, maize straw collected as substrate for biogas production may replace, to high degree, more expensive silage from maize.

Conclusions

Based on the research results and analysis carried out, the following conclusions have been formulated:

1. Maize straw silage is useful for effective methane fermentation.
2. Higher participation of methane took place in the biogas obtained from silage withensilaging additives.
3. Out of two investigated inoculants, on account of methane participation in biogas, Labacsil Acid preparation was more advantageous. It directs biochemical changes during ensilaging to limitation of lactic acid formation and to increase the amount of acetic acid.
4. Maize straw devoid of cobs, having approximately 30% lower potential of biogas production in comparison to material from whole plants, has almost 2-times higher efficiency from one hectare than grains, sunflower or grasses.

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WYDAJNOŚĆ BIOGAZOWA SŁOMY KUKURYDZIANEJ

Streszczenie. W pracy zaprezentowano wyniki laboratoryjnych badań efektywności produkcji biogazu z kiszonki ze słomy kukurydzianej z dodatkiem zaszczepki fermentacyjnej, którą była pulpa pofermentacyjna z biogazowni rolniczej. Słomę kukurydzianą zakiszono w sposób naturalny i z zastosowaniem sztucznych dodatków, których zadaniem było zapewnienie prawidłowego procesu fermentacji. Zastosowano dwa preparaty do zakiszania: Silomax (bakterie fermentacji mlekowej) oraz Labacsil Acid (zestaw kwasów organicznych i sorbinian potasu). Doświadczenie przeprowadzono w wielokomorowym biofermentorze, monitorując produkcję biogazu i minimalny poziom metanu. Stwierdzono, że największą wydajnością biogazową charakteryzowała się kiszonka ze słomy kukurydzianej bez preparatu zakiszającego. Natomiast w odniesieniu do produkcji metanu najbardziej wydajna była kiszonka słomy kukurydzianej z preparatem Labacsil Acid.

Słowa kluczowe: słoma kukurydziana, substrat, biogaz, metan

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