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EFFECTIVENESS OF BIOGAS PRODUCTION FROM C3 (*Festuca arundinacea* Schreb.) AND C4 (*Spartina pectinata* L.) PERENNIAL GRASSES

Summary

The aim of the study was to evaluate of Festuca arundinacea Schreb. spec. Rahela (Tall fescue) and Spartina pectinata L. suitability for biogas production. Biomass of investigated C3 and C4 grasses was grown in Experimental Station of Warsaw University of Life Sciences in Skierniewice, harvested on the 30th of June 2014 and ensilaged. Methane fermentation of experimental silages was carried out under mesophilic conditions (39°C) for at least 21 days. Fresh biomass of spartina contained higher amount of volatile solids, crude fiber and higher ratio of C/N compared to fescue biomass. Both grasses were susceptible to ensiling. Obtained silages were in good quality, secondary fermentation process was not detected. Silages from spartina contained much higher amount of acetic acid than lactic acid. After methane fermentation of silages prepared from spartina and fescue 734,1 ± 34,33 $m^3 \cdot t^{-1}$dm and 722,7 ± 52,52 $m^3 \cdot t^{-1}$dm of biogas with 55% of methane content was obtained respectively and differences were not significant (p >0,05). Taking into account higher biomass yield of spartina than fescue, examined C4 grass seems to be more suitable alternative source for biomethane production.
Key words: *perennial grasses, biogas, silages*, *Festuca arundinacea* Schreb., *Spartina pectinata* L.

EFEKTYWNOŚĆ PRODUKCJI BIOGAZU Z TRAW WIELOLETNICH C3 (*Festuca arundinacea* Schreb.) I C4 (*Spartina pectinata* L.)

Streszczenie

Celem pracy była ocena przydatności wieloletnich traw o typie fotosyntezy C3 - kostrzewy trzcinowej (Festuca arundinacea Schreb.*, odmiana Rahela) i C4 - spartiny preriowej (Spartina pectinata* L.*) do produkcji biogazu. Biomasa traw zebrana została 30 czerwca 2014 roku z pola doświadczalnego w Skierniewicach, należącego do Katedry Fizjologii Roślin Wydziału Rolnictwa i Biologii Szkoły Głównej Gospodarstwa Wiejskiego w Warszawie. Po rozdrobnieniu biomasę zakiszono, a następnie poddano mezofilnej fermentacji metanowej (w temp. 39°C przez co najmniej 21 dni). Biomasa spartiny charakteryzowała się wyższym plonem suchej masy, wyższą zawartością suchej masy organicznej, włókna surowego oraz wyższym stosunkiem węgla do azotu w porównaniu do kostrzewy. Obie trawy były podatne na zakiszanie, uzyskane kiszonki były dobrej jakości bez oznak wtórnej fermentacji. Kiszonki ze spartiny charakteryzowały się znacznie większą zawartością kwasu octowego niż mlekowego. Z kiszonki ze spartiny otrzymano 734,1 ± 34,33 $m^3 \cdot t^{-1}$ sm, a z kiszonki z kostrzewy 722,7 ± 52,52 $m^3 \cdot t^{-1}$ sm biogazu o zawartości metanu średnio 55%. Różnice w uzysku biogazu z badanych traw nie były istotne statystycznie (p>0,05). Biorąc pod uwagę wyższy plon biomasy spartiny niż kostrzewy stwierdzono, że większą przydatność jako alternatywne źródło biometanu stanowi biomasa ze spartiny preriowej.*
Słowa kluczowe: *biogaz, trawy wieloletnie, kostrzewa trzcinowa, spartina preriowa, kiszonki*

1. Introduction

Poland is considered as a country of a large potential for biomass production for energy purposes [1]. It is estimated that by 2020 the demand for solid biomass energy will be around 10 million tones of dry matter whereof 5 million tones would be obtained from energy crops [7]. Amon et al. suggested that 1500 m tonnes of agricultural material is available for digestion in UE each year, half of which is crop material [1].

Anaerobic digestion is used as a method of gaseous fuel production from various agricultural residues and other biodegradable wastes. During this process methane and carbon dioxide rich biogas is produced [4]. While maize is a dominant crop in use, grass silage is used in over 50% of the biogas plants operating in Germany and Austria [12]. Grass is an excellence source of biomethane. It is a feedstock for anaerobic digestion with a high content of solids and it has a high specific methane capacity [10]. Nevertheless, it is widely accepted that biomass for energy applications should not be food and feed products. In this situation there is a need to investigate the suitability of various plant material for biogas production which could be harvested on non-crop areas.

To satisfy the growing demand for biomass, the introduction of the cultivation of high productive plant species will be required. In this context C4 photosynthetic plants seem to be the most valuable. They characterized by a high biomass yield thanks to their ability to efficient CO_2 absorption. This type of metabolism is often found in grasses coming from Asia and North America. The differences in the anatomical organs assimilation of C4 plants are the result of their adaptation to specific environmental conditions with limited humidity, high temperature and strong sunlight [8].

Another factor which influences the usefulness of a particular plant species for biogas production is their susceptibility for ensiling. It is important to preserve the biomass after harvesting. Ensiling is the cheapest and the most commonly used method for this purpose. During ensiling mono sugars are converted by lactic acid bacteria into lactic acid. Low pH makes that silage could be stored for a long time and used as a substrate for anaerobic digestion for at least a year. Ensiling process could be considered also as a biomass pretreatment method. Pretreatment is required to alter the structure of lignocellulosic biomass to make cellulose and hemicellulose more accessible to anaerobic digestion [9]. During ensiling a partial hydrolysis of structural polysaccharides occurs and volatile acids are produced which could be beneficial for biochemical reactions taking place during multi steps anaerobic digestion process [11].

The aim of this study was to evaluate the usefulness of C3 (*Festuca arundinacea* Schreb. spec. Rahela) and C4 (*Spartina pectinata* L.) perennial grasses for biogas production.

2. Materials and methods

2.1. Experimental design

In this work *Spartina pectinata* L. and *Festuca arundinacea* Schreb. spec. Rahela (Tall fescue) biomass was obtained from the collection of energy crops of Department of Agriculture and Biology of Warsaw University of Life Science, conducted at Experimental Station in Skierniewice (51° 57 'N, 20° 09' E) on soils of class IV a, good rye complex. Plants were harvested on the 30th of June 2014, cut into 2 cm pieces and ensiled in the amount of approx. 10 kg in barrels (in triplicate). After 12 weeks barrels were opened and samples of silages were collected for chemical analysis.

2.2. Analytical methods

The dry mass of the fresh biomass and silages was determined by gravimetric method according to PN-EN 12880 (drying the samples at 105°C to constant weight), volatile solids by gravimetric method according to PN-EN 12879 (burning dried samples at 550°C). The sward samples were dried, ground and then chemical components were analyzed (using the NIRS method with a NIRFlex N-500 using hay presets created by INGOT®). Nitrogen was determined by Kjeldahl method according to PN-EN 13342, content of total carbon by infrared detection method after combustion of samples on the platinum catalyst (aparat TOC 5000 A, Shimazu). pH of silages was determined by potentiometric method, content of organic acids by enzymatic assays using r-Biopharm UV tests. Chemical components of silages were determined by NIRS method with the NIRFlex N-500 spectrometer using silage presets created by INGOT®.

The Biochemical Methane Potential (BMP) test was used to assess the biogas production from investigated plants. To do so a BMP protocol [2] adapted for the use of the OxiTop® (WTW, Germany) pressure monitoring system was developed. Fermentation was carried out for at least 21 days at 39°C in glass reactors with a capacity of 1300 ml, closed by measuring OxiTop® heads. To the side tubes of reactors gas analyzer (COMBIMASS®GA-m) was connected in order to analyze the biogas composition. As inoculum (the source of methanogen bacteria) the content of secondary digester was used, obtained from agricultural biogas plant in Konopnica (Central Poland). During methane fermentation increasing pressure of produced biogas was measured every day. Value of the gas pressure was then converted into the amount of biogas (in moles) using the ideal gas equation:

$$pV = nRT \tag{1}$$

p – pressure [Pa]; V – reactor capacity [m^3]; T – temperature [K]; R – universal gas constant 8,31 [J (mol K)$^{-1}$]; n – number of moles.

The amount of biogas was then converted into the volume of biogas expressed in cubic meters and referring to the pressure 1013.25 hPa and temperature 0°C.

2.3. Statistical methods

In order to examine the significance of differences in the average biogas production from the tested grasses Student test was performed at a significance level of 0.05.

3. Results and discussion

3.1. The chemical components of fresh and ensilaged biomass

The higher fresh biomass yield was obtained from spartina than fescue. Spartina biomass was characterized by by higher content of dry mass and volatile solids compared to fescue biomass (Table 1).

Tab. 1. Yield and chemical composition of fresh biomass of *Spartina pectinata* L. and *Festuca arundinacea* Schreb.

Species	Biomass yield [t · h^{-1}]	Dry mass [%]	Volatile solids [% dm]	C/N	Crude fibre [% dm]
spartina	32,5	32,9	96,2	35,5	39,8
fescue	25,0	29,6	89,3	22,9	29,7

dm – dry mass

Source: own work

Total solid yield was 10,7 t · h^{-1} from spartina and 7,4 t · h^{-1} from fescue. Volatile solids yield was 10,3 and 6,6 t · h^{-1} from spartina and fescue respectively.

Lower content of organic matter in fescue compared to spartina could be due to silicon content which also reduces palatability and intake of fescue grass by animals [5]. Festuca compared to spartina was characterized by lower C/N ratio and crude fibre content – parameters which influence biogas productivity. Theoretically all biodegradable organic compounds may be fermented during methane fermentation. However, in practice, those compounds are more valuable which are more accessible to the anaerobic digestion. The higher content of structural polysaccharides which are the part of crude fibre, the longer hydrolysis takes place, which is the first step of methane fermentation [3].

C/N ratio is also one of the factors that influences the methane fermentation process. The optimal C/N ratio in biomass should be ranged from 10 to 30 [14]. Ratio over 30 was observed for spartina and it means that there is a shortage of nitrogen which may adversely affect the development of microflora involved in anaerobic digestion.

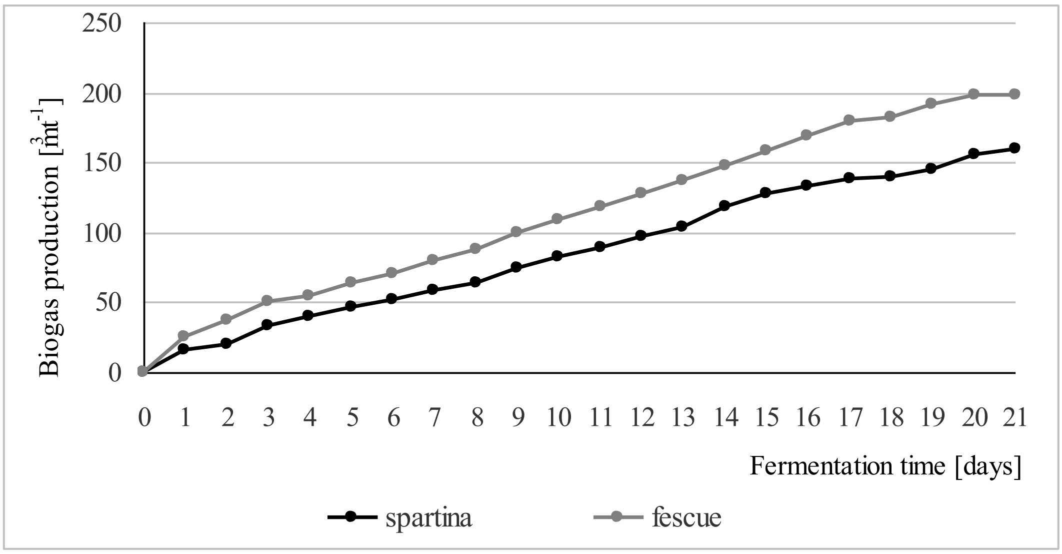
Chemical composition of fresh biomass affects the quality of prepared silages. Silages obtained from investigated grasses were characterized by similar parameters related to pH, protein, crude fat and mono sugars content (Table 2).

Tab. 2. Chemical composition of silages from *Spartina pectinata* L. and *Festuca arundinacea* Schreb.

Species	pH	Ash[1] [% dm]	Dry mass [%]	Protein [% dm]	Crude fat [% dm]	Mono sugars [% dm]	Cellulose[2] [% dm]	Hemi-cellulose[3] [% dm]	Lignine[4] [% dm]	Digestibility[5] [%]
spartina	5,2	4,7	26,7	8,8	1,9	5,8	33,2	6,6	3,8	60,6
fescue	5,2	11,7	21,4	10,0	2,2	5,5	30,4	5,7	3,0	62,9

Source: own work

[1] calculated as difference between 100 and the content of volatile solids
[2] calculated as difference between the content of ADF and ADL fibres
[3] calculated as difference between the content of NDF and ADF fibres
[4] as the content of ADL fibres
[5] calculated from the formula 88,9-0,779 x ADF



Source: own work

Fig. 1. Biogas production from spartina and fescue silages

Spartina silages were characterized by higher content of cellulose, hemicellulose and lignin so that digestibility of these silages was lower compared to fescue silages. It is accepted that silages for biogas production should exhibit quality and digestibility similar to silages intended for feeding [6].

In silages from spartina much higher content of acetic acid than lactic acid was detected (Table 3).

Tab. 3. Organic acids contents in the experimental silages

Species	Organic acids [g·kg^{-1} dm]		
	lactic	acetic	butyric
spartina	0,5	17,3	n.d.*
fescue	89,7	2,3	n.d.*

*n.d. - not detected (below the limit of quantification)

Source: own work

Higher content of acetic acid than lactic acid indicates that in spartina silages heterolactic fermentation prevailed. Acetic acid is a substrate from which methane is synthesized by methanogen bacteria [4]. For that reason high concentration of acetic acid in silages intended for biogas production is claimed to be a positive effect of ensiling process, while it might even enhance methane formation [11]. Acetic acid is also a fungistatic compound and it increases the oxygen durability of the silages, which has an impact on quality of ensilaged material. In all experimental silages butyric acid was not detected which is a sign that spoilage processes caused by *Clostridium* bacteria did not occur during ensiling. Quality of plant substratum intended for biogas production has to be very high in order to ensure good efficiency of methane. Spoiled silages, affected by moulds and contaminated with mycotoxin have an effect on decreasing the biogas production [6].

3.2. Biogas production

The biogas production curve for spartina and fescue silages was found to be similar. The maximum biogas yield was measured after 21 days of incubation (Fig. 1). Taking into account the content of dry mass in silages 734,1±34,33 m^3 of biogas from spartina and 722,7±52,52 m^3 of biogas from fescue per tone of dry mass were obtained and differences were not significant ($p > 0,05$). The average content of methane in biogas from both grasses was 55%.

4. Conclusion

The suitability of a given species to biogas production depends not only on biogas production from unit weight but also on dry matter yield that can be achieved per year and susceptibility to preservation. Taking into account high biomass yield of *Spartina pectinata*, investigated C4 grass seems to be more suitable alternative source of biomethane production than *Festuca arundinacea* C3 grass.

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