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The biogas potential of selected perennial grasses from genus bromus

Potencjał produkcji biogazu wybranych traw wieloletnich z rodzaju stokłosa

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The paper presents the results of the assessment of yield and laboratory tests of biogas parameters of two species of the genus Bromus, compared to the tetraploid perennial ryegrass. Silage was prepared from whole plants in the heading phase, using the laboratory method in plastic sleeves. Biogas yield was determined by the eudiometric method according to the accredited testing procedure of the implemented DIN 38 414-S8: 1985 standard. Along with the analysis of the results, the possibility of using the examined silage as alternative substrates for agricultural biogas plants was presented.

Key words: biogas, grass silage, *Lolium perenne, Bromus catharticus, Bromus inermis,* rescue grass, brome grass

W pracy zaprezentowano wyniki oceny plonowania oraz badań laboratoryjnych parametrów związanych z produkcją biogazu dwóch gatunków z rodzaju stokłosa (bezostna oraz obiedkowata) w porównaniu do tetraploidalnej odmiany życicy trwałej. Kiszonki przygotowano z całych roślin w fazie kłoszenia, w warunkach laboratoryjnych w rękawach foliowych. Biogazodochodowość oznaczano metodą eudiometryczną wg akredytowanej procedury badawczej implementowanej normy DIN 38 414-S8:1985. Wraz z analizą wyników przedstawiono możliwość wykorzystania badanych kiszonek jako alternatywnych substratów dla biogazowni rolniczych.

Słowa kluczowe: biogaz, kiszonka z traw, *Lolium perenne, Bromus catharticus, Bromus inermis,* stokłosa

Introduction

In order to promote green economic growth, the European Community has set the priorities of sustainable climate and energy policies of the Member States, including energy savings and the increased utilization of energy from renewable sources. According to Directive 2009/28/EC, biomass from agriculture can be the largest source of materials for decentralised energy production, especially in areas of low value for arable use (poor quality soils, degraded land in need for restoration, etc.), while limiting the import of biomass. New forms of grasses and other energy crops with a high yielding potential and suitable for silage production may improve the profitability of Polish agriculture, which altogether is of great economic and environmental importance. Biomass from plants, especially from grasses, can be the largest potential source of green energy in Poland, Europe and the world. The biogas industry is one of the most important sectors of renewable energy, which additionally provides environmental benefits and can increase farmers' income (Oslaj et al. 2010). An important aspect necessary for the development of a biogas plant is the constant supply of raw materials, especially of plant origin. Moreover, biogas plants provide energy in less urbanized areas. As stated in the Strategy for Responsible Development to 2020, investments in biogas production are aimed at improving the energy security of Poland. Following the implementation of the plan for the stabilization of food prices, popular energy crops such as maize, cereals or sugar beet will be in the coming years successively replaced with alternative biomass from plants characterised by high yield and high biogas potential, e.g. sorghum (Matyka, Księżak 2012).

Biomass can also be obtained from crops grown on wasteland or land of low suitability for agriculture by growing perennial grass species having specific traits and the ability to create biomass whose processing parameters will not require changes in the technology of operating biogas plants. Therefore, it is necessary to test various, including less popular, perennial grass species in order to obtain information about their

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potential suitability for biogas production.

Among the many species of perennial grasses that can be grown in Poland, there are those that meet the basic criteria of suitability for cultivation in areas with low value for agriculture. According to literature data, these are species that can grow successfully on land of low agricultural value, such as tall fescue (*Festuca arundinaca* Schreb.), reed canary grass (*Phalaris arundinacea* L.), tall wheatgrass (*Elymus elongatus* (Host) Runemark), smooth brome (*Bromus inermis* Leyss.) and rescue grass (*Bromus catharticus* Vahl.). The quality of biomass, both in terms of incineration and biogas production, has been documented for the first three species (Dickeduisberg et al. 2017; Mast et al. 2014; Lalak et al. 2016; Kulig et al. 2015; Martyniak et al. 2017; Żurek and Martyniak 2012; Przybysz et al. 2019), but the last two species have been much less investigated in this respect.

Smooth brome is a common species found in dry habitats, on roadsides, embankments, sunny slopes, on substrates rich in minerals and of a neutral or slightly alkaline reaction. This grass can be used for establishing meadows and pastures on moderately fertile sandy and periodically dry soil. Rescue grass is a less popular species, sometimes used for fodder. This species is characterized by good winter hardiness and relatively high resistance to periodic droughts. It has low requirements for soil. Therefore, rescue grass can be suitable for the production of biomass for energy. The available publications provide no information on the biogas potential of these grass species.

The aim of the study was to assess the yield of biogas and methane as well as the dynamics of the silage fermentation for two selected perennial species of *Bromus* grasses in order to identify alternative material for agricultural biogas plants.

Material and Methods

Two species from the genus *Bromus* were selected for experiments: rescue grass (*Bromus catharticus* Vahl.), breeding line 19, and smooth brome (*Bromus inermis* Leyss), breeding line 1-Lin. A tetraploid variety Flinston of perennial ryegrass (*Lolium perenne* L.) was used as a reference.

A field experiment was established in a random block design in 2011 at DANKO Hodowla Roślin sp. z o.o., Plant Breeding Farm, Branch in Szelejewo (Wielkopolskie province, Poland) on class IV medium-compact soil. This soil, defined as sandy loam, contained on average 68.5% of sand, 28.5% of dust and 3% of silt. Organic matter content was 1.1%, and pH=7.2. Macronutrient content, expressed in mg/l of soil, was as follows: total N: 25.8; P: 64.7; K: 95.3; Ca: 712.2 and Mg: 127.8.

Weather conditions in the years of the experiment were relatively favourable, especially considering high levels of rainfall in June, July and August (Tab. 1).

Necessary agrotechnical works and treatments were performed, including the preparation of fields, soil cultivation and application of mineral fertilizers before grass sowing at a dose of 150 kg/ha (Polifoska (6:20:30), as well as ammonium nitrate (34% N) at a dose of 30 kg of pure component per ha in spring and after each mowing.

Yields of biomass were assessed by mowing individual grass varieties at the full heading stage (first harvest) and 7-8 weeks later (second harvest), each time collecting the biomass from approx. 10 m^2, at 3–4 locations per replicate. Mowing was done with a bar mower with a working width of 90 cm to a height of approx. 10 cm. Yield was assessed in 2012 and 2013.

Tests were carried out at the Research Laboratory of Agricultural Technologies and Biosystems of the Institute of Technology and Life Sciences in Falenty, branch in Poznań, which was accredited by the Polish Centre for Accreditation (PCA) no. AB 116 for testing the content of dry matter, dry organic matter and biogas yield using the eudiometric method.

Silage was obtained from randomly selected freshly cut above-ground parts of whole plants in the heading stage. Silage was prepared by inoculation of grass with Labacsil® (Sano). Chopped grass, 2-3 cm long, was fogged with a mixture of Labacsil® Acid and Labacsil® Bacteria following the manufacturer's instructions in a relevant proportion for grass silage, i.e. 100 l of water: 10 kg of Labacsil® Acid: 100 g of freeze-dried bacteria: 100 t of chopped grass. Chopped biomass was packed in 5 litre vented plastic sleeves and compacted by tamping. Ensilage lasted 6 weeks at an incubation temperature of 32^{o}C, which simulated conditions inside the silage pile.

Chemical analyses were performed in 4 replicates according to PN-EN 12880, PN-EN 12879, and PN-EN 12176:2001 standards. Biogas yield and the characteristics of the biogas dynamics of the substrate samples were carried out using a validated and accredited testing procedure: PB-01/LBMPZ-2008/FM, method DIN 38 414-S8:1985. The tests were carried out in a thermostated eudiometric system with a 1000 ml fermentation bottle, in eudiometers with 600 ml of biogas. Static fermentation was carried out at 37 ± 0.1 ˚C, using 360 ±

Tabela 1
Table 1

Wartości średnich temperatur powietrza oraz miesięczne sumy opadów panujące w okresie realizacji doświadczenia na tle wartości z wielolecia.

Mean values of monthly air temperature and sum of monthly rainfalls during the vegetation season against the background of normal values.

Miesiąc / month	Rok / Year	Parametr:	
		temperatura / temperature [˚C]	opad / rainfall [mm]
Marzec / March	2011	6,0	47,2
	2012	5,2	38,1
	1981 - 2000	3,6	37,8
Kwiecień / April	2011	9,1	44,0
	2012	9,6	22,0
	1981 - 2000	8,8	31,3
Maj / May	2011	13,4	13,6
	2012	15,7	23,4
	1981 - 2000	14,0	49,5
Czerwiec / June	2011	16,6	50,2
	2012	16,7	79,8
	1981 - 2000	16,6	56,8
Lipiec /July	2011	20,1	59,4
	2012	19,8	85,6
	1981 - 2000	18,9	75,7
Sierpień / August	2011	22,8	68,8
	2012	19,2	73,6
	1981 - 2000	18,3	60,8
Wrzesień / September	2011	15,2	29,8
	2012	15,9	32,8
	1981 - 2000	13,7	41,7
Średnia - suma za okres wegetacyjny	2011	14,7	313,0
	2012	14,6	355,3
	1981 - 2000	13,4	353,6

0.5 g of standardized, starved inoculate of methane fermentation bacteria from continuous culture in a laboratory anaerostat, and 40 ± 0.5 g samples of undisintegrated grass silage. Tests were repeated 3 times for each silage type. The biochemical methane potential (net BMP) of the analysed samples was calculated using a 400 g reference sample of inoculate. Daily measurements of biogas volume were normalized for 0^{o}C and 1013 hPa. The concentrations of methane and impurities were tested directly from the eudiometers using the GA 2000 biogas analyzer from Geotechnical Instruments Ltd.

The significance of differences between the mean values of parameters was assessed with a probability of 95% based on statistical analyses carried out with the STATISTICA 12.0 package. LSD values were calculated using the Fisher test.

Results and Discussion

Biomass yield

Considering all analysed grass species, the highest yield was obtained from *Bromus catharticus*, with a mean of more than 14 Mg of dry matter per ha for 2 years (Tab. 2). The yield of this species was significantly influenced by the second harvest, which accounted for approx. 48% of the total yield. This is one of characteristic features of *Bromus catharticus* (Falkowski, 1982).

The second harvest accounted for 43% of

Tabela 2
Table 2

Wyniki oceny plonowania zielonej i suchej masy badanych gatunków traw (średnie z 2 lat pomiarów)

Results of green and dry matter yields estimation for tested grass species (means from two years)

Gatunek Species	Plony zielonej masy [Mg·ha-1] Green forage yields [Mg·ha-1] pokosy / cuts			Łączny plon suchej masy Total dry matter yield [Mg·ha-1]
	1	2	1 + 2	
Lolium perenne	22,3	12,0	34,3	6,07 ± 0,9
Bromus catharticus	33,9	31,2	65,1	14,2 ± 2,1
Bromus inermis	23,7	17,9	41,6	8,4 ± 1,4
NIR/LSD (P<95%)	5,4	5,1	10,2	4,2

the total yield for *Bromus inermis* and 35% for *Lolium perenne* (the lowest biomass yield). The yields obtained in this experiment were within the ranges reported, for example, by COBORU in post-registration tests for perennial grass species with morphology and biomass production potential similar to those analysed in our study. For example, in 2012 the mean dry matter yield was 13.5 $Mg \cdot ha^{-1}$ for 13 cultivars of *Dactylis glomerata*, and 12.9 Mg · ha^{-1} for 6 cultivars of *Festuca arundinacea*. In 2010-2012 the mean yield for 32 cultivars of *Lolium perenne* was 7.9 $Mg \cdot ha^{-1}$ (COBORU, 2013). Skrabek et al. (1979) reported similar yields of dry matter for 'Una' rescue grass (14 to 18 $Mg \cdot ha^{-1}$), depending on the dose of fertilizers. The same researchers also reported that the 'Brudzyńska' smooth brome tested in parallel produced approx. 28% lower yield compared to rescue grass. A similar relationship was recorded in our study, but the range of differences was greater.

Analysis of biogas potential for silage

The comparison of results from basic tests performed for the samples of green forage and silage (Tab. 3) revealed that the content of dry matter (d.m.) and dry organic matter (d.o.m.) were lowest for green and fermented tetraploid perennial ryegrass (4x) var. Flinston (17.7 ± 0.3% of d.m. and 83.83 ± 2.51% of d.o.m. for green forage and 14 ± 0.3% of d.m. and 79.52 ± 2.39% of d.o.m. for silage).

The calculated loss of organic matter during ensiling for the Flinston variety was 37–42 $g \cdot kg^{-1}$. All statistics in this case had the lowest standard deviation compared to other tested varieties. This may indicate the relatively greatest homogeneity of the tested material from the Flinston variety. Silage prepared from Flinston ryegrass had a relatively dense and slightly greasy texture, and was characterised by the largest loss in volume and the largest volume of silage leachate compared to other species.

Green forage from rescue grass was characterised by the highest content of dry matter (21.9±0.4%) and dry organic matter (89.54±2.7%). Silage from rescue grass contained 19.1±0.4% of d.m. and 87.38±2.62% of d.o.m. The relatively high standard deviation indicates a relatively greater heterogeneity of plant material. Silage from rescue grass was the loosest, and characterised by the lowest loss in volume and silage leachate, with the loss in organic matter in the range of 28.0–29.2 $g \cdot kg^{-1}$.

Intermediate results were found for *Bromus inermis*. Green forage from *Bromus inermis* contained 20.2 ± 0.4% of d.m. and 88.9 ± 2.7% of d.o.m., while silage was slightly compacted, easily disintegrating, with the mean volume loss and loss of organic matter in the range of 31.9 – 32.2 $g \cdot kg^{-1}$. Silage from *Bromus inermis* contained 17.0±0.3% of d.m. and 86.86 ±2.61% of d.o.m. This silage had the highest pH (6.29) after 6 weeks of fermentation and was slightly more acidic than the green forage (pH=6.48).

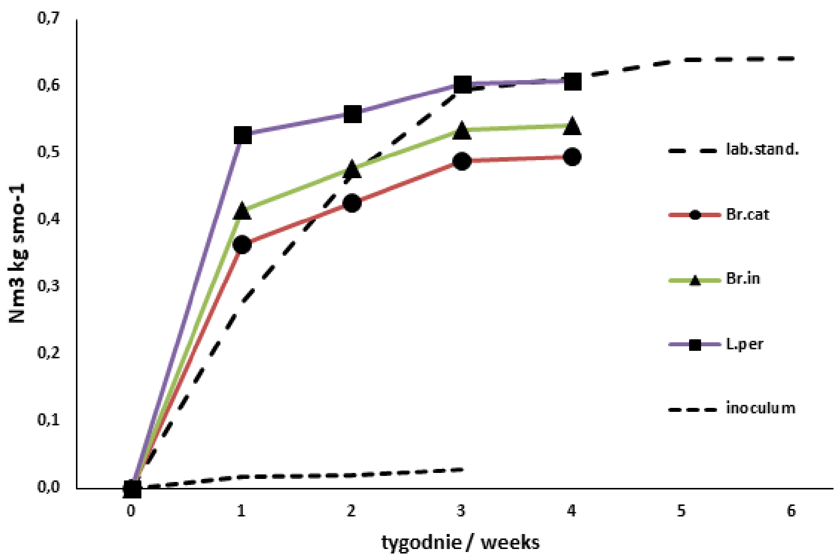
Tests for the biogas yield indicated a high biochemical methane potential of silage samples from the analysed grasses and a medium concentration of methane. Fermentation was carried out for 4 weeks and was very stable (Fig. 1).

The highest biogas yield calculated for the content of dry organic matter (0.6119 ± 0.0324 Nm^3 $kg \cdot d.o.m^{-1}$, with the mean concentration of methane 54.8%) was found for silage from *Lolium perenne*. Biomass from the two *Bromus* grasses had lower biogas yield, ranging from 0.4852 ± 0.0257 Nm^3 $kg \cdot dom^{-1}$ (*Bromus catharticus*) to 0.5183 ± 0.0275 Nm^3 $kg \cdot d.o.m^{-1}$ (*Bromus*

Tabela 3
Table 3
Wyniki analizy podstawowej próbek materiału organicznego zielonek oraz kiszonek badanych traw wieloletnich (średnie ± błąd standardowy).

Results of basic analysis of green crop and silage made form tested grass species (mean ± standard errors)

Gatunek/ Species	pH (H_2O)	w % / in %			
		sucha masa dry matter	wilgotność moisture	sucha masa org. org. dry matter	popiół ash
Zielonka / Green forage					
Lolium perenne	6,16 ± 0,02	17,7 ± 0,3	82,3 ± 1,6	83,8 ± 2,5	16,17 ± 0,5
Bromus carinathus	6,52 ± 0,02	21,9 ± 0,4	78,0 ± 1,6	89,5 ± 2,7	10,5 ± 0,3
Bromus inermis	6,48 ± 0,02	20,2 ± 0,4	79,7 ± 1,6	88,9 ± 2,7	11,1 ± 0,3
Kiszonka / Silage					
Lolium perenne	4,90 ± 0,02	14,0 ± 0,3	86,0 ± 1,7	79,5 ± 2,4	20,5 ± 0,6
Bromus carinathus	4,98 ± 0,02	19,1 ± 0,4	80,9 ± 1,6	87,4 ± 2,6	12,6 ± 0,4
Bromus inermis	6,29 ± 0,02	17,0 ± 0,3	83,0 ± 1,7	86,9 ± 2,6	13,3 ± 0,4
NIR/LSD (P<95%)	0,38	2,5	4,50	5,2	6,1



Legenda: lab.stand. – standard laboratoryjny, Br.cat. – Bromus catharticus, Br.in – Bromus inermis, L.per – Lolium perenne.

Ryc. 1. Przebieg fermentacji biogazowej badanych kiszonek z traw wieloletnich w porównaniu ze standardem laboratoryjnym - kiszonka z kukurydzy o wydajności 0,642 Nm^3 kg smo^{-1}.

Fig. 1. The course of methane fermentation of sileges made from tested grass species as compared to laboratory standard – maize silage (0.642 Nm^3 kg·dom^{-1}).

inermis), while the concentration of methane was lower and did not exceed 50.5%.

As shown in the fermentation profile (Fig. 1), the process was more dynamic and faster than that for the laboratory reference standard (maize silage), which was especially clear for *Lolium perenne*. Slower fermentation, but still ahead of the reference process, with a steady production of methane was observed for the silage from *Bromus inermis*.

The fermentation time for the analysed samples was shorter compared to that for the laboratory reference material. After 3 weeks of fermentation, more than 98% of the total biogas yield was generated from them vs 92.5% for the reference material. This fact may be important in the context of the cost-effective use of fermenting tanks. In practice, 3 weeks after the beginning of fermentation of the analysed perennial grass species, the tank can be filled with a new batch of plant material and another process of biogas production can be initiated. In contrast, silage from maize needs about 2 weeks more for complete gasification.

Tabela 4
Table 4
Średnie stężenia metanu i zanieczyszczeń biogazu w przebiegu fermentacji biogazowej próbek materiału organicznego badanych gatunków traw wieloletnich

Mean methane concentration and biogas impurities after fermentation of organic material samples of tested perennial grasses

Parametry jakościowe biogazu / Biogas quality parameters	*Lolium perenne*	*Bromus catharticus*	*Bromus inermis*	K0 - inoculat	NIR / LSD (P < 95%)
Uzysk biogazu [Nm^3/kg smo] / Biogas yield [Nm^3/kg odm]	0,612 ± 0,03	0,485 ± 0,026	0,518 ± 0,028	0,029 ± 0,001	68,2
CH_4 [%]	54,8	50,23	50,42	49,2	1,3
CO_2 [%]	36,1	38,33	41,18	43,82	2,5
O_2 [%]	0,43	0,13	2,38	2,38	1,1
H_2S [mg kg-1]]	272	280	298	36	15,1
N_2O [mg/m3]	8,4	6,25	7,6	0,45	1,25
NH_3 [mg/m3]	1,2	0,51	1,04	0,01*	0,91

The use of silage from the *Bromus* species described in this study increases the t*hroughput* of the fermentation tank, making it possible to obtain more biogas per time unit.

In newly built biogas plants, shorter gasification (retention) of biomass allows for the construction of fermentation tanks with a smaller total capacity, which offers substantial savings for investors. Therefore, before the decision on the size of the planned biogas plant's capacity is made, it is absolutely necessary to obtain information from a competent scientific and research institution as to the composition of biomass optimal for local soil from which biomass could be contracted, while taking into account the optimal gasification parameters (Łukaszek et al. 2011).

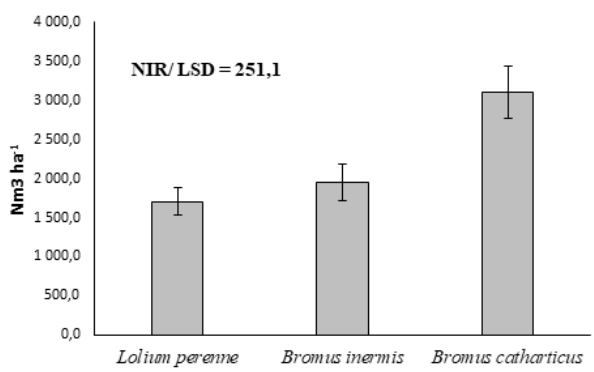
Taking into account the obtained biomass yield, the amount of biogas and its methane content, it was possible to assess the potential methane yield per unit of crop area (Fig. 2). The highest value of this parameter was found for *Bromus catharticus* (mean 3104.1 $Nm^3 \cdot ha^{-1}$ of methane). Lower values were obtained for other species, ranging from 1951.3 $Nm^3 \cdot ha^{-1}$ (*Bromus inermis)* to 1706 $Nm^3 \cdot ha^{-1}$ (*Lolium perenne)* (Fig. 2).

The results of our study indicate the decisive role of the biomass yield per unit area for the efficiency of methane generation. Similar results were reported, for example, by Ust`ak et al. (2013) for *Lolium perenne* (1974.0 $Nm^3 \cdot ha^{-1}$), when compared to *Dactylis glomerata* (2555 $Nm^3 \cdot ha^{-1}$) or *Festuca arundinacea* (2648 $Nm^3 \cdot ha^{-1}$). Biogas yield from the biomass of meadow grasses and other plants usually range from 0.460 to more than 0.600 Nm^3 $kg \cdot dom^{-1}$ (Matyka and Księżak 2012; Mast et al. 2014).

Relatively highest biogas yield is obtained from maize, but also plants that use C4 photosynthesis, such as sorghum and *Miscanthus* species (El Bassam, 2010; Purwin et al. 2014). Interestingly, *Bromus catharticus* is also regarded as a species with some metabolic features of C4 photosynthesis (Falkowski, 1982). In this species it results in stable yielding over the season. Moreover, *Bromus catharticus* contains a high level of reducing sugars during the summer and high levels of cellulose, haemicellulose and lignins (Falkowski, 1982). In our study this grass species was characterised by a relatively lowest biogas yield per unit of dry organic matter, and the obtained result associated with the highest methane yield per unit of crop area is the consequence of the highest biomass yield (Żak 2012; Mast et al. 2014).

Conclusions

1. The biogas yield for the two analysed *Bromus*



Ryc. 2. Plon metanu z jednostki powierzchni uprawy badanych gatunków traw.

Fig. 2. Methane hectare yield for tested grass species.

grasses is approx. 20% to 29% lower (0.518 Nm^3 kg·dom^{-1} for *Bromus inermis*, 0.458 Nm^3 kg·dom^{-1} for *Bromus catharticus)* compared to the laboratory reference material (silage from maize, 0.642 Nm^3 kg·dom^{-1}).

2. The highest methane yield per unit of crop area (3104.1 $Nm^3·ha^{-1}$ CH_4) was found for *Bromus catharticus*. Methane yield for other analysed grass species was much lower.
3. Methane yield per unit of crop area for the analysed *Bromus* grasses was determined by biomass yield.
4. Silage prepared from *Bromus inermis* was characterised by faster gasification compared to maize silage. This feature is very important in the context of shortening the fermentation process.
5. Perennial grasses, including the analysed *Bromus* species, are a valuable material for biogas plants and can be grown on soils with low value for agricultural production.

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