BIOGAS POTENTIAL FROM RESIDUES OF FOOD PROCESSING FACTORIES

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Abstract. To find out the biogas potential from potato crisps (PC) and salad beetroots (SB) a study was conducted using laboratory equipment. Sixteen bioreactors were filled with vegetable processing plant residues (SB) or PC factory wastes for anaerobic fermentation in batch mode for 43 days of fermentation at temperature of 38 ºC. Specific biogas volumes recovered were 1.611 $l \cdot g_{DOM}^{-1}$ and 1.095 $l \cdot g_{DOM}^{-1}$ from potato crisps and salad beetroots, respectively. Specific methane volumes were 0.960 lg_{DOM}^{-1} and 0.666 $l\ g_{DOM}^{-1}$ obtained from potato crisps and salad beetroots, respectively. The study showed that from the PC production plant and vegetable processing plant residues can be successfully utilised for biogas production.

Keywords: biogas, methane, biomass, anaerobic fermentation, digestate.

Introduction

The European Union Directive states that 20 % (40 % for Latvia) of the gross energy must be produced from alternative energy sources in 2020. Most of the energy were sourced from wood biomass in Latvia. However, it should taken into account that biomass per 1 ha agricultural land accumulates more energy compared to energy obtainable from 1 ha of forest wood biomass increment per year. Conversion of biomass into energy can be provided in biogas plants, and the most energy can be obtained from anaerobic fermentation of energy crops[1-2]. There were 56 biogas plants with summary power of 56.92 MW, including44 plants running on agricultural biomass in Latvia in 2015 [3]. Most of agricultural biogas plants utilise corn biomass in Latvia, as a large quantity of fresh corn or corn silage provide stable round year biogas plant running [4-5]. However, production of cornis expensive, therefore the local biomass residues and organic wastes should be utilised at first for biogas production. To assess the sustainability, the biogas plants should provide effective energy conversion, low life cycle greenhouse gas emissions and additional environmental effects, e.g., digestate production for substitution of mineral fertilizers [6]. Many projects implemented in Latvia use technologies and machinery designed in Germany, and mostly do not take in account the differences in climatic conditions or average yields, that are much lower in Latvia. For example, the insulation layer of Binowa bioreactor did not provide the optimum energy balance in winter needed for maintenance of stable temperature in the reactor. To achieve the nominal power output the increased quantity of raw material is necessary to feed in the reactor that compromises the stability of the anaerobic fermentation process often. It is considered that rapid hydrolysis is the key factor to provide maximal biodegradation rate of raw materials. The hydrolysis process is ongoing together with other anaerobic fermentation process stages in the single bioreactors installed in many biogas plants in Latvia. However, the breeding conditions for bacteria providing hydrolysis or for methane forming bacteria are different; therefore it may be useful to separate these processes in individual bioreactors. Such biogas plants, having two bioreactors, are running also in Latvia, and some of these plants utilise aerobic pre-fermentation by supplying of the air, that according to the authors [7] should enhance more rapid and complete decomposition of organic matter. In practice, however, the proposed rapid decomposition does not take place. Biogas output, which can be obtained from a variety of raw materials, is different and not a constant [8]. Various researchers working with similar raw materials have achieved different results. Biogas and methane production depends on the substrate itself, composition of microorganisms, anaerobic process conditions and other factors [9]. The most important factor that determines the potential of biogas production is the organic matter (OM) content and composition, in particular on the content of the three main OM groups: carbohydrates, proteins and lipids [10].

In several countries, particularly in Germany, the highest biogas output was derived from the so-called energy beets, especially bred to produce high biomass yields. For production of biogas also sugar beets and sugar beet leaves can be used, but especially the waste sugar beet residues from sugar and ethanol production factories. Sugar beet cultivation is quite limited in Latvia now, due to closure of the sugar production factories, but there are plans to renew sugar production in future. Imported sugar beet residues are available on the market for affordable price, and some biogas plants in Latvia are utilising this biomass in the biogas plants. Biogas outcomes from different biomass investigated by various authors are summarised in Table 1.

Table 1

The outcome of biogas from beets and sugar beets

Raw material	Methane $m^3 \cdot kg_{DOM}^{-1}$	Methane content, %	Biogas, $m^3 \cdot kg_{DOM}^{-1}$	Reference
Sugar beet	0.357	51	700	6
Beet leaves	0.297	54.0	550	6
Beets	0.349	51.0	684	6
Sugar beet	0.350	72.0	-	10
Beets	0.350	50.0	-	10
Sugar beet	0.444	-	-	5
Sugar beet	-	53-54	800-860	5
Beet leaves	-	54-55	550-600	8
Sugar beet	0.350	54	-	11
Sugar beet	-	51	700	6; 7
Fodder beet	-	51	683	6; 7

Biogas outcome of potato crisps and salad beetroothas not been studied in Latvia or foreign countries until now. The purpose of this study was to find out how much biogas and methanecan be obtained from damaged potato crisps and poor qualitysalad beetroots.

Materials and methods

The study deals with investigation of biogas and methane production from damaged potato crisps (PC) and vegetable processing factory residue salad beetroot (SB), which do not comply with the marketing standard. The method used for the investigation was similar to the methods described in literature [12].

The average samples were taken from waste biomass, and the chemical composition of every sample was investigated in the laboratory of the Latvia University of Agriculture using the methods in compliance to the standard ISO 6496:1999. Salad beetroots were chopped before fermentation. The average sample for each group of raw materials or inoculum was analysed for dry matter, ashes and organic dry matter content before filling into the bioreactor. All mixtures were prepared using the same inoculum obtained from continuously working bioreactor filled with cow manure. Biogas production has been investigated in 16 laboratory bioreactors with the volume of 0.75 l made from standard glass jars with sealed caps equipped with fitting for gas pipelines. 500 g inoculum (control) was filled into two bioreactors each and 20 g raw materials and 500 g inoculum were filled into eachother14 bioreactors. All bioreactors were placed in the universal oven Memmert at temperature 38 ± 0.2 ºC maintained automatically during the fermentation period. Each bioreactor was connected with the gas storage bag positioned outside the heated camera. All bioreactorswere slightly shaken occasionally to reduce the floating layer. A portable gas analyser was connected to the gas bag for gas composition measurements regularly. Analyses of the pH value, dry matter, ashes and organic dry matter content were provided for digestate from every bioreactor after finishing of the fermentation process.

Measuring accuracies were the following: ± 0.2 g for inoculum and substrate weight (scales Kern FKB 16KO2), ± 0.001 g for biomass samples for dry matter, organic matter and ashes weight analyses, ± 0.02 for pH value (accessory PP-50), ± 0.05 l for gas volumes, and ± 0.2 ºC for temperature inside the bioreactor. Dry matter was determined using a specialized unit Shimazy at temperature 105 ºC, and as hing was performed by the oven Nabertherm at temperature 550 ºC using the standard as hing cycle. Oxygen, carbon dioxide, methane and hydrogen sulphide content was measured using the gas analyser GA 2000.

Results and discussion

The analyses of substrates were provided, and the results of average values for the experimental groups of the bioreactors are presented in Table 2.

Table 2

The results of the analyses of the raw materials

Bioreactor	Raw material	pH	TS, %	TS, g	Ash, %	DOM, %	DOM, g	Weight, g
R1;R16	IN (control)	7.79	4.73	23.65	24.45	75.55	17.87	500
	CP20		27.6	5.52	5.0	95.0	5.244	20
R2-R8	CP20+IN500	7.71	5.61	29.17	20.76	79.24	23.114	520
	SB20		13.89	2.778	11.95	88.05	2.446	20
R9-R15	SB20+IN500	7.65	5.08	26.428	23.13	76.87	20.316	520

Abbreviations: TS – total solids; Ash – ashes; DOM – dry organic matter; R1-R16 – bioreactors; CP – potato crisps, SB – salad rootbeets;IN – inoculum.

As it can be seen from the table, the potato crisps have a high dry matter content and also high organic matter content. The salad beet roots have less organic dry matter content, but biomass is still suitable for biogas production purposes due to high sugar and juice contents.

The result of the analyses of finished digestate after 43 days fermentation from every bioreactor is provided in Table 3.

Table 3

The results of the analyses of the finished digestate

Bioreactor	Substrate	pH	TS, %	TS, g	Ash, %	DOM, %	DOM, g	Weight, g
R1	IN	7.51	4.58	22.58	24.86	75.14	16.97	493.0
R16	IN	7.43	4.60	22.69	28.41	71.59	16.24	493.2
Aver. R1;R16	**IN**	**7.470**	**4.590**	**22.635**	**26.635**	**73.365**	**16.605**	**493.1**
R2	CP+IN	7.53	4.15	21.16	28.36	71.64	15.16	509.8
R3	CP+IN	7.67	4.28	21.68	28.05	71.95	15.60	506.6
R4	CP+IN	7.56	4.46	22.75	28.50	71.50	16.27	510.2
R5	CP+IN	7.42	4.38	22.21	28.14	71.86	15.96	507.1
R6	CP+IN	7.47	4.43	22.52	26.83	73.17	16.48	508.4
R7	CP+IN	7.58	5.05	25.43	20.18	79.82	20.30	503.5
R8	CP+IN	7.80	4.50	22.59	27.52	72.48	16.37	502.0
Aver. R2-R8	**CP+IN**	**7.576**	**4.464**	**22.620**	**26.797**	**73.203**	**16.591**	**506.80**
R9	SB+IN	7.65	4.60	23.23	26.38	73.62	17.1	504.9
R10	SB+IN	7.42	4.38	22.35	27.41	72.59	16.22	510.2
R11	SB+IN	7.56	4.16	21.22	27.33	72.67	15.42	510.2
R12	SB+IN	7.50	4.28	21.82	28.11	71.89	15.69	509.8
R13	SB+IN	7.47	4.24	21.60	29.21	70.79	15.29	509.5
R14	SB+IN	7.44	4.41	22.27	27.11	72.89	16.23	505.0
R15	SB+IN	7.50	4.32	22.14	28.18	71.89	15.90	512.4
Aver. R9-R15	**SB+IN**	**7.506**	**4.341**	**22.090**	**27.676**	**72.334**	**15.979**	**508.60**

The difference between the average contents of the dry organic matter (DOM) in substrates with potato crisps (PC+IN) at the start (Table 2) and after anaerobic fermentation (Table 3) shows that organic matter of the mixture was biodegraded by 6.523 g. Calculation of percentage of biodegradation of the added total biomass in the anaerobic fermentation process was 28.22 %. Inoculum in the control bioreactors biodegraded 1.27 g. That means that organic matter of potato crisps (5.244 g) was degraded completely (by 100 %), but unspecific biodegradation of inoculum in the mixture calculated was 7.1 %.Unspecific biodegradation can be minimized in further experiments by usage of very finished inoculum (cow manure digestate) and by adding the second portion of biomass and providing the re-fermentation cycle until biodegradation reaches the second plateau phase [13].

Similar calculations provided according to salad beetroot substrate (SB+IN) show that percentage of biodegradation of total added biomass in the anaerobic fermentation process has 21.36 % (4.34 g). It may be assumed that unspecified biodegradation of inoculum occurred in salad beetroot and inoculum mixture more 0.62 g, as percentage of biodegradation SB was expressed 100 %.

Methane and biogas yields from potato crisps and salad beet roots are shown in Table 4.

Table 4

Biogas and methane yield from bioreactors

Reactors	Substrate	Biogas, l	Biogas, $l \cdot g_{DOM}^{-1}$	Methanea ver., %	Methane, l	Methane, $l \cdot g_{DOM}^{-1}$
R1	IN500	1.16	0.068	20,26	0.235	0.014
R16	IN500	0.8	0.049	21.75	0.174	0.011
R2	PC20+IN500	8.7	1.659	52.20	4.542	0.866
R3	PC20+IN500	7.7	1.468	57.77	4.45	0.848
R4	PC20+IN500	10.4	1.983	61.17	6.34	1.213
R5	PC20+IN500	6.9	1.316	62.01	4.281	0.816
R6	PC20+IN500	8.1	1.544	59.39	4.81	0.917
R7	PC20+IN500	10.9	2.078	62.99	6.66	1.309
R8	PC20+IN500	6.45	1.229	61.21	3.943	0.752
Aver. (R2-R8)	**PC20+IN500**	**8.45 ± 2.22**	**1.611 ± 0.397**	**59.53 ± 5.35**	**4.44 ± 1.38**	**0.960 ± 0.275**
R9	SB20+IN500	3.0	1.226	56.36	1.69	0.691
R10	SB20+IN500	2.6	1.063	58.04	1.51	0.617
R11	SB20+IN500	3.0	1.226	70.63	2.118	0.866
R12	SB20+IN500	3.0	0.919	62.31	1.42	0.581
R13	SB20+IN500	3.2	1.308	59.09	1.89	0.773
R14	SB20+IN500	2.3	0.934	61.22	1.4	0.572
R15	SB20+IN500	2.4	0.991	56.81	1.38	0.563
Aver. (R9-R15)	**SB20+IN500**	**2.79 ± 0.39**	**1.095 ± 0.18**	**60.64 ± 5.16**	**1.63 ± 0.42**	**0.666 ± 0.151**

Abbreviations: $l\ g_{DOM}^{-1}$ – litres per 1 gram of dry organic matter (of raw material basis).

Biogas and methane production from potato crisps is shown in Fig.1.The results are presented with average biogas and methane volumes from the control reactors already subtracted.

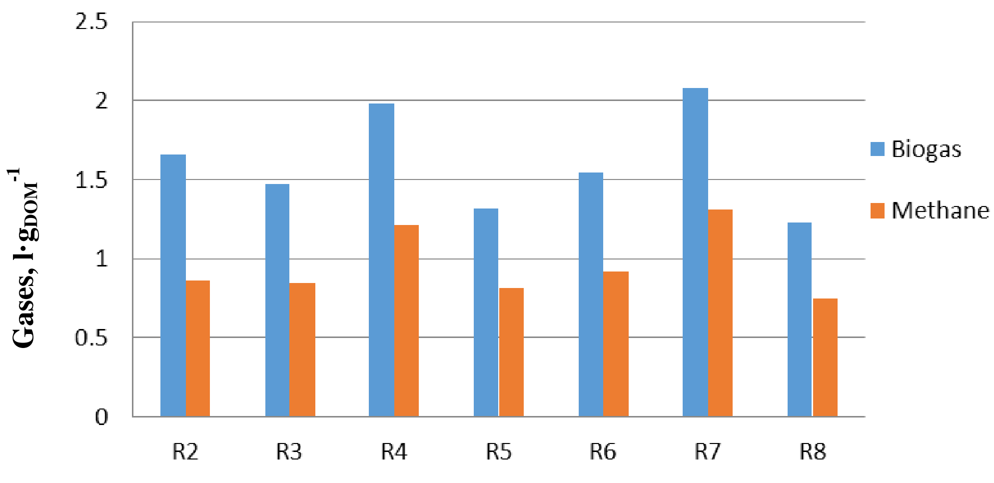

Fig. 1. **Specific biogas and methane production from potato crisps**

The exquisite results of specific biogas methane production in the reactors R2-R8 can be explained by the chemical composition of the raw mixture (CP+IN) containing mostly easy biodegradable potato starch, as well as by the minor co-digestion effect of the crisps-inoculum mixture.

Biogas and methane production from salad beet roots is shown in Fig. 2.

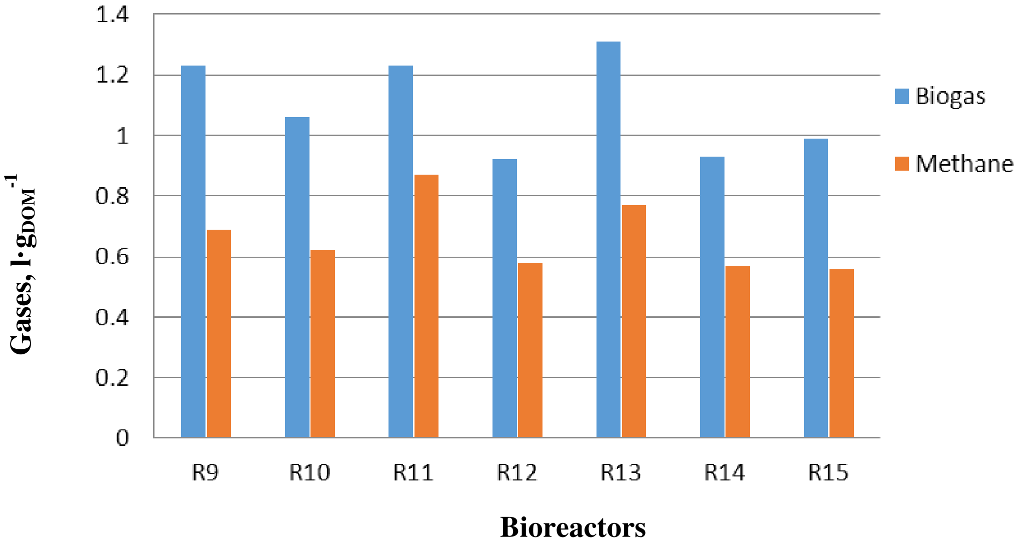

Fig. 2. **Specific biogas and methane production from salad beetroots**

Good results of specific biogas and methane production in thereactors R9-R15from fresh salad beetroots can be explained by sugars and the beet juice content in the raw mixture (SB+IN).

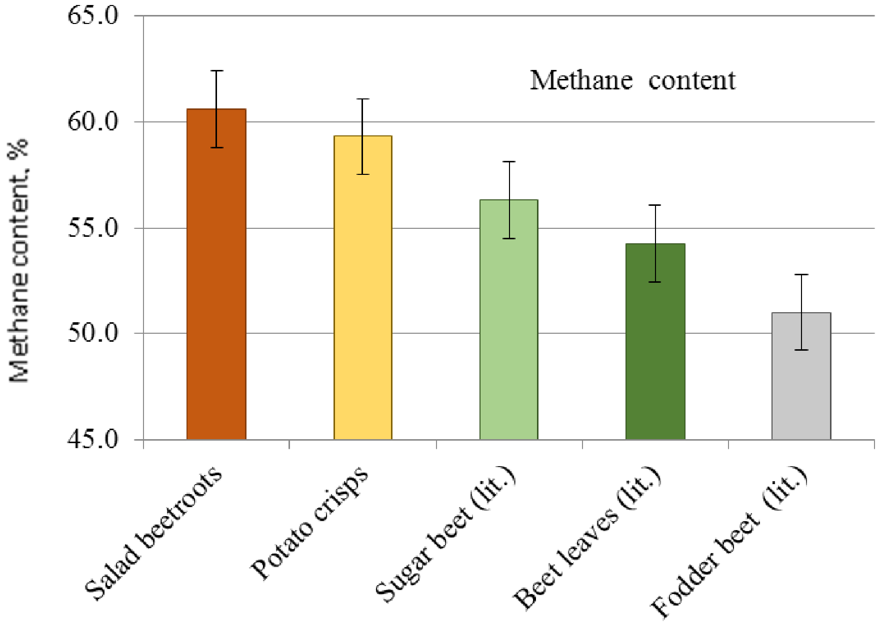

Fig. 3. **Methane content in biogas from vegetable wastes:** lit. – reference data from literature

The highest average methane content (60.6 %) is investigated in biogas from salad beetroots, and potato crisps also provide a good average methane content (59.3 %).

The methane content in biogas from salad beetroots or potato crisps is significantly higher compared to the literature data for methane content in sugar beets, beet leaves or fodder beets, see Fig. 3.

Conclusions and proposals

1. High specific methane volume (0.96 ± 0.21 $l \cdot g_{DOM}^{-1}$) can be obtained from defective potato crisps.
2. Good specific methane yield (0.666 ± 0.12 $l \cdot g_{DOM}^{-1}$) can be obtained from damaged salad beetroots.
3. The results show that food industry wastes, and especially, salad beet and potato crisp wastes are an excellent raw material for energy and fertiliser production.
4. The results show that potato crisps and salad beet roots in mixture with inoculum from cow manure can provide minor unspecific biodegradation. Unspecific biodegradation can be minimized in further experiments by usage of very finished inoculum (cow manure digestate).

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