ANAEROBIC FERMENTATION OF KITCHEN WASTE

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Abstract. Global warming is leading to an increase in the production of renewable energy and the prevention of harmful emissions into the atmosphere worldwide. Many countries around the world are developing special programs to get more green energy. There are currently fifty-two biogas plants in Latvia. Forty-eight of them use agricultural waste. The kitchens of households and catering companies also generate a lot of organic waste. If they are not recycled, methane and carbon dioxide are released into the atmosphere during decomposition in landfills during anaerobic fermentation. Organic kitchen waste should be used as a raw material for biogas production. Biogas could be used to generate heat, electricity or as a fuel for vehicles. Energy prices have risen sharply in Latvia and Europe. Therefore, biogas producers are intensively looking for cheaper raw materials. They need to know how much methane can be extracted from each feedstock. In this study, we found out how much methane can be obtained from four food waste that is often thrown away in food waste bins. We fermented banana peel, orange mandarin peel, onion residues and peel, as well as kiwi peel in fourteen bioreactors at 38 ºC. In order to find out how much gas could still be obtained from the inoculum, it was fermented in two bioreactors. The process took 30 days. Most methane was obtained from onion residues and peel 0.523 $L \cdot g^{-1}_{DOM}$. 0.325 $L \cdot g^{-1}_{DOM}$ obtained was of banana peel, 0.487 $L \cdot g^{-1}_{DOM}$ of mandarin orange peel and 0.462 $L \cdot g^{-1}_{DOM}$ of methane from kiwi peel. Research shows that this kitchen waste is a very good raw material for methane production.

Key words: anaerobic fermentation; methane; kitchen waste.

Introduction

The new environmental policies of the European Union focused on two main points: (1) the need to strengthen the separate collection of wastes and (2) the encouraging the pyramidal hierarchy for waste valorisation. Kitchens also generate a lot of organic waste. In the specific case of organic wastes, they can be also exploited for the production of biofuels and bioenergy [1].

Anaerobic digestion (AD) of waste has been broadly acknowledged as a sustainable treatment technique that generates a high-value gaseous product.

The fruit-processing industry generates daily several tons of wastes, of which the major share comes from banana farms. This study [2] examines the effect of organic loading (OL) and cow manure (CM) addition on AD performance whsen treating banana peel waste (BPW). The maximum daily biogas production rates of banana peels (BPs) with a cattle manure (CM) content of 10%, 20%, and 30% at 18 and 22 g of volatile solids (g_{VS}) per liter were 50.20, 48.66, and 62.78 $mL \cdot (g_{VS} \cdot d)^{-1}$ and 40.49, 29.57, and 46.54 $mL \cdot (g_{VS} \cdot d)^{-1}$, respectively. The biogas yields of BP at 10 $g_{VS} \cdot L^{-1}$ with CM content of 10%, 20%, and 30% were 514.87, 496.95, and 426.43 $mL \cdot g^{-1}_{VS}$, respectively.

As only a few studies have examined the bioenergy potential of BP [2-4], a deeper investigation is necessary in order to address the energy demand and enormous amount of organic waste in banana processing.

The production of biogas from orange peel has been studied by many researchers [5-8]. The study [6] found the final values of the specific methane production, which were 356 $NL_{CH4} \cdot kg^{-1}_{TVS}$ and 366 $NL_{CH4} \cdot kg^{-1}_{TVS}$ for the OPs without and with limonene extraction, respectively [7].

Researchers from the University of Boras removed limonene from their orange peel and then obtained a much higher yield 0.217 m^3 methane per kg_{VS} [6].

A study of researchers from Argentina is focused to find a viable alternative for sustainable onion residues treatment and recycling, by anaerobic digestion with biogas generation and bio-fertilizer reuse [9]. The tested onion peels exhibited biogas yields similar to cellulose 0.32 $L \cdot g^{-1}_{VS}$. Onion bulbs did not produce at least two times in comparison with peels.

Another study showed better results. The anaerobic digestion of onion residual from an onion processing plant was studied under batch-fed and continuously-fed mesophilic (35 ± 2 ºC) conditions in an Anaerobic Phased Solids (APS) Digester. The batch digestion tests were performed at an initial loading of 2.8 $g_{VS} \cdot L^{-1}$ and retention time of 14 days. The biogas and methane yields, and volatile solids reduction from the onion residual were determined to be 0.69 ± 0.06 $L \cdot g_{VS}^{-1}$, 0.38 ± 0.05 $L_{CH4} \cdot g_{VS}^{-1}$, and 64 ± 17%, respectively [10].

There are also studies on the production of biogas from kiwi peel [11]. Thus, the energy valuation of the agro-industrial residues of kiwi production was evaluated by anaerobic digestion, aiming at optimizing the biogas production and its quality. Ten assays were carried out in a batch reactor (500 mL) under mesophilic conditions and varying a number of operational factors: different substrate/inoculum ratios; four distinct values for C: N ratio; inoculum from different digesters; and inoculum collected at different times of the year. The best result was obtained with 20 g of substrate and 380 mL of inoculum from the anaerobic digester sludge of WWTP of Ave (with addition 600 mg of sodium bicarbonate), presenting a value of 85% of CH_4, with a production of 464 L biogas per kg VS.

Materials and methods

The methodology similar as described by other researchers was used for the study [12-14].

The fresh ripened BP and other raw materials were washed thoroughly with water to remove physically adsorbed contamination and then cut into pieces of approximately 0.5 cm × 0.5 cm in size. The inoculum, taken from a continuously operating 110 L bioreactor, in each bioreactor was filled with 500 g in 16 bioreactors volume 0.75 L. Bioreactors R2-R5 were filled with 20 g of chopped banana peel. Bioreactors R6-R9 were filled with 20 g of chopped mandarin orange peel. Bioreactors R10-R12 were filled with 20 g of chopped onion peel and residues. Bioreactors R13-R15 were filled with 20 g of chopped kiwi peel. Bioreactors R1 and R16 were for control filled only with inoculum. The contents of the bioreactors were then mixed thoroughly, the bioreactors sealed and weighed together with the gas collection bags (Tedlar) attached to the lids.

Then all bioreactors were placed in a SNOL incubator, and the operating temperature was set at 38 ± 1 ºC. The composition of the emitted gas was measured with a GA 2000 gas analyzer. All raw materials were analyzed prior to loading into the bioreactors by help of the equipment Shimazu and Nabertherm. The analyzer PP-50 was used to determine the pH. After 26 days, the anaerobic fermentation process was stopped, the bioreactors were removed from the incubator and weighed together with the gas bags. The bioreactors were then opened. The digestate from each the bioreactor was then sampled and analyzed.

The daily biogas volume was normalized (T = 0 ºC, P = 1 bar (1 bar = 10^5 Pa)) according to Eq. (1):

$$V_N = \frac{V \times 273(760 - p_w)}{(273 + T) \times 760}, \tag{1}$$

where V_N – volume of the dry biogas under standard conditions, mL;
V – volume of the biogas, mL;
p_w – water vapour pressure as a function of ambient temperature. mm Hg (1 mm Hg ≈ 133.322 Pa);
T – ambient temperature, °C.

Results and discussion

Analyses of raw material samples and raw material samples mixed with inoculum are shown in Table 1.

Onion residues contain the largest amount of DOM (95.2%), but kiwi peels less (77.37%). All raw materials contain enough dry organic matter to produce methane. Inoculum has a fairly high TS, but the ash content of the TS is not high. Table 2 shows the specific biogas and methane yields obtained from each bioreactor. The average results obtained from the inoculum have already been subtracted.

Although ODM in inoculum was still high, the bacteria produced little biogas and methane. This can be explained by the fact that the 110 L bioreactor operated with cow manure and very little organic load. Average methane yield from BP was a little better as obtained by other researchers 319.27 $L \cdot kg^{-1}_{DOM}$ [2], average methane yield from MP was better – 366.46 $L \cdot kg^{-1}_{DOM}$ [8], average methane yield from OR was better – 380.38 $L \cdot kg^{-1}_{DOM}$ [9], but average methane yield from KP was a little less as obtained by other researchers – 464.56 $L \cdot kg^{-1}_{DOM}$ [11]. However, these results are not exactly comparable due to differences in research methodologies.

Table 1

Analyses of raw material samples and mixed with inoculum before anaerobic digestion

Bioreactor	pH	TS, %	TS, g	Ash, %	DOM, %	DOM, g	Weight, g
R1, R16 In	7.87	4.6	23.0	25.48	74.52	17.14	500
R2-R5 BP		10.11	2.022	20.55	79.45	1.606	20
R2-R5 BP + In	7.86	4.81	25.022	25.08	74.92	18.746	520
R6-R9 MP		32.23	6.446	8.30	91.70	5.911	20
R6-R9 MP + In	7.86	5.66	29.446	21.72	78.28	23.651	520
R10-R12 OR		12.47	2.494	4.80	95.20	2.374	20
R10-R12 OR + In	7.85	4.90	25.494	23.46	76.54	19.514	520
R13-R15 KP		22.63	2.263	22.63	77.37	1.751	10
R13-R15 KP + In	7.85	4.95	25.263	25.22	74.78	18.891	520

Note: R- bioreactor, In – inoculum, TS – total solids, DOM – dry organic matter

Table 2

Biogas and methane yields

Bioreactor/Raw material	Biogas, L	Biogas, $L \cdot g^{-1}_{DOM}$	Methane, aver.%	Methane, L	Methane, $L \cdot g^{-1}_{DOM}$
R1 In	0.1	0.006	7.60	0.008	0.0005
R16 In	0.1	0.006	7.20	0.007	0.0005
R1, R16 average	0.1	0.006	7.40	0.0075	0.0005
R2 BP	1.40	0.872	38.00	0.532	0.331
R3 BP	1.70	1.058	35.88	0.610	0.380
R4 BP	1.30	0.809	32.46	0.422	0.263
R5 BP	1.50	0.934	34.87	0.523	0.326
R2 - R5 average	1.475 ± 0.125	0.918 ± 0.078	35.30 ± 1.638	0.522 ± 0.05	0.325 ± 0.031
R6 MP	6.60	1.116	46.29	3.055	0.512
R7 MP	5.70	0.964	48.60	2.770	0.470
R8 MP	5.40	0.913	52.56	2.938	0.480
R9 MP	5.70	0.964	49.81	2.839	0.480
R6 - R9 average	5.85 ± 0.375	0.989 ± 0.063	49.32 ± 1.87	2.876 ± 0.096	0.487 ± 0.013
R10 OR	3.50	1.474	49.37	1.413	0.595
R11 OR	2.60	1.095	42.04	1.093	0.460
R12 OR	2.60	1.095	47.15	1.226	0.516
R10 – R12 average	2.90 ± 0.4	1.221 ± 0.168	43.18 ± 2.758	1.244 ± 0.113	0.523 ± 0.048
R13 KP	2.40	1.371	37.42	0.898	0.513
R14 KP	1.80	1.028	42.67	0.768	0.439
R15 KP	1.90	1.085	40.05	0.761	0.435
R13, R14, R15 average	2.033 ± 0.24	1.161 ± 0.14	39.79 ± 1.751	0.809 ± 0.059	0.462 ± 0.034

Note: BP – banana peels, MP – mandarin (orange) peels, OR- onion residues, KP – kiwi peels, In – inoculum

Specific biogas and methane yields from each bioreactor are shown in Fig. 1, and average methane content of each bioreactor biogas is shown in Fig. 2.

The relatively low methane content in the figure can be explained by the fact that these are average results over 26 days. The maximum methane content obtained from individual raw materials is as follows: BP – 51.82%; MP – 74.0%; OP – 69.1% and CP – 63.41%.

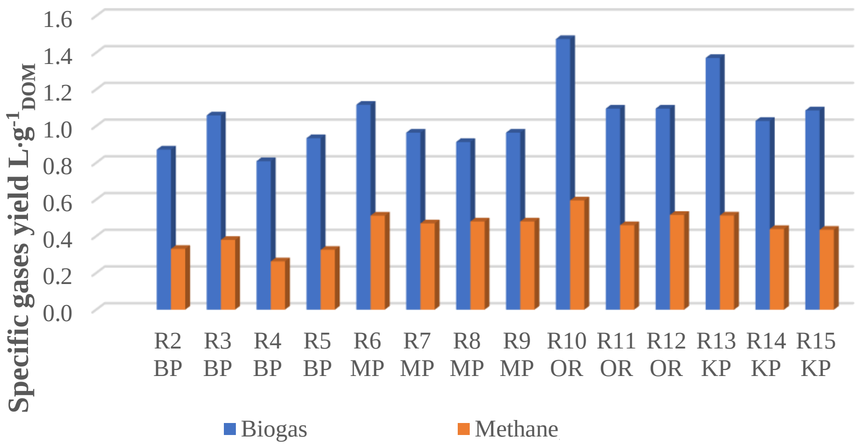

Fig. 1. **Specific biogas and methane yields from each bioreactor**

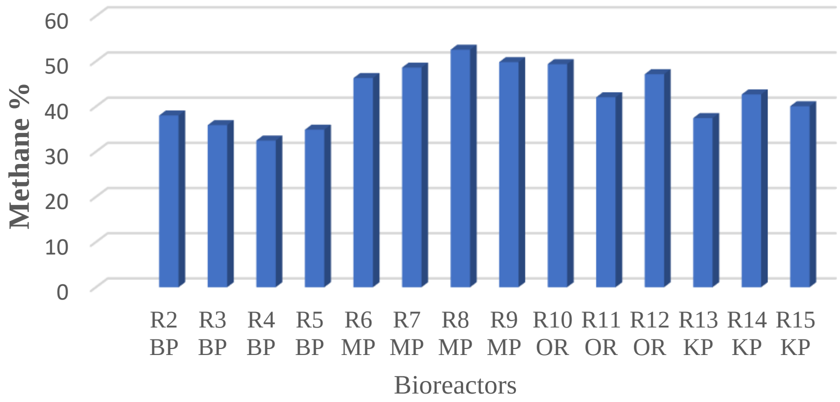

Fig. 2. **Average methane content of each bioreactor biogas**

Conclusions

1. Average methane yield from banana peels is 0.325 $L \cdot g^{-1}_{DOM.}$ This result is quite similar to the results obtained by other researchers.
2. Average methane yield from mandarin peels is 0.487 $L \cdot g^{-1}_{DOM.}$ The result is about 121 $L \cdot g^{-1}_{DOM}$ better than the results obtained by other researchers.
3. Average methane yield from onion residues is 0.523 $L \cdot g^{-1}_{DOM.}$ This result is very good, better than the results obtained by other researchers.
4. Average methane yield from kiwi peels is 0.462 $L \cdot g^{-1}_{DOM.}$ This result is a little less as obtained by other researchers.
5. The study shows that kitchen waste from the tested fruit is a good raw material for biogas production.

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Author contributions

Contribution of each author. Conceptualization, V.D.; methodology, V.D.; software, V.D.; validation, V.D; formal analysis, V.D. and I.P.; investigation, V.D., and I.P.; data curation, V.D.; writing – original draft preparation, V.D.; writing – review and editing, V.D.; visualization, V.D. and I. P.;

project administration, V.D.; All authors have read and agreed to the published version of the manuscript.

References

[1] Dubrovskis V. Biogāzes ražošana Latvijā (Biogas production in Latvia) 2018, Jelgava, Latvia, 152 p. (In Latvian).
[2] Achinas S., Krooneman J., Willem G.J. Euverink Enhanced Biogas Production from the Anaerobic Batch Treatment of Banana Peels. Engineering 2019, Volume 5, Issue 5, pp. 970-978.
[3] Harish K.R.Y., Srijana M., Madhusudhan R.D., Gopal R. Co-culture fermentation of banana agro-waste to ethanol by cellulolytic thermophilic Clostridium thermocellum CT2. Afr. J. Biotechnol. 2010; 9 (13): pp. 1926-1934.
[4] Tock J.Y., Lai C.L., Lee K.T., Tan K.T., Bhatia S. Banana biomass as potential renewable energy resource: a Malaysian case study. Renew Sustain Energy Rev 2010; 14 (2): pp. 798-805.
[5] Clarke WP., Radnidge P., Lai TE., Jensen PD., Hardin MT. Digestion of waste bananas to generate energy in Australia. Waste Manag 2008; 28 (3): pp. 527-533.
[6] Wikandari R., Nguyen H., Millati R., Niklasson C., Taherzadeh M.J. Improvement of Biogas Production from Orange Peel Waste by Leaching of Limonene. Hindawi Publishing Corporation, BioMed Research International Volume 2015, pp. 6-12.
[7] Sanjaya A.P., Cahyanto M.N., Millati R. Mesophilic batch anaerobic digestion from fruit fragments. Renewable Energy 2016, 98, pp. 135-141.
[8] Zema D. A., Fòlino A., Zappia G., Calabrò P.S., Tamburino V., Zimbone S. M. Anaerobic digestion of orange peel in a semi-continuous pilot plant: An environmentally sound way of citrus waste management in agro-ecosystems. Sci. Total Environ. 2018, 630, pp. 401-408.
[9] Campaña H., Benedetti P., Airasca A., Mairosser A. ONION WASTE TREATMENT PRELIMINARY ANAEROBIC RESEARCH DATA. Proceeding of International Symposium 12-13, 03 2013. pp. 4-8.
[10] Romano R., Zhang R. Anaerobic digestion of onion residuals using a mesophilic Anaerobic Phased Solids Digester. October 2011 Biomass and Bioenergy 35 (10), pp. 4174-4179.
[11] Martins R., Boaventura R.A.R., Paulista L. Anaerobic Digestion Performance in the Energy Recovery of Kiwi Residues. December 2017, IOP Conference Series Earth and Environmental Science 95 (4): 04. pp. 2044-2048.
[12] Angelidaki I., Alves M., Bolzonella D., Borzacconi L., Campos J., Guwy A., Kalyuzhnyi S., Jenicek P., Van Lier J. Defining the biomethane potential (BMP) of solid organic wastes and energy crops: a proposed protocol for batch assays. Water Sci.Technol. 2009, 59(5), pp. 927-934.
[13] Thran D. Methodenhandbuch Energetische Biomassenutzung, (Methods Manual Energetic use of biomass), 2010, Leipzig, 161 p. (In German).
[14] VDI 4630 (2006). Vergärung organischer Stoffe Substrat charakterisierung, Probenahme, Stoffdatenerhebung, Gärversuche. Vereindeutscher Ingenieure (Fermentation of organic substances Substrate characterization, sampling, substance data collection, fermentation tests. German engineers) Düsseldorf, 48 p. (In German).