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Anaerobic digestion of vegetables processing wastes with catalyst metaferm

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Abstract. There are 54 active biogas plants in Latvia today. It is necessary to investigate the suitability of various biomasses for energy production. Maize is the dominating crop for biogas production in Latvia. The cultivation of more varied crops with good economical characteristics and a low environmental impact is thus desirable. One of the ways for improving biogas yield in Latvian conditions is using biological catalysts. This paper explores the results of the anaerobic digestion of vegetables' processing wastes using the new biological catalyst Metaferm. The digestion process was investigated in view of biogas production in sixteen 0.7 l digesters operated in batch mode at the temperature of 38 ± 1.0 °C. The average methane yield per unit of dry organic matter added (DOM) from the digestion of onions was 0.433 l g_{DOM}^{-1}; with 1 ml of Metaferm: 0.396 l g_{DOM}^{-1}, and with 2 ml of Metaferm: 0.394 l g_{DOM}^{-1}. The average methane yield from the digestion of carrots was 0.325 l g_{DOM}^{-1}; with 1 ml of Metaferm: 0.498 l g_{DOM}^{-1}, and with 2 ml of Metaferm: 0.426 l g_{DOM}^{-1}. The average additional methane yield per unit of dry organic matter from the digestion of 50%:50% mixed onions and carrots was 0.382 l g_{DOM}^{-1} with 2 ml of Metaferm. The average additional methane yield per unit of dry organic matter from the digestion of cabbage leftovers was 0.325 l g_{DOM}^{-1}; with 1 ml of Metaferm: 0.375 l g_{DOM}^{-1}, and with 2 ml of Metaferm: 0.415 l g_{DOM}^{-1}. The average additional methane yield per unit of dry organic matter from the digestion of potato cuttings was 0.570 l g_{DOM}^{-1}; with 1 ml of Metaferm: 0.551 l g_{DOM}^{-1}, and with 2 ml of Metaferm:0.667 l g_{DOM}^{-1}. The average additional methane yield per unit of dry organic matter from the digestion of 50%:50% mixed cabbages and potatoes was 0.613 l g_{DOM}^{-1} with 2 ml of Metaferm. All investigated vegetable wastes can be successfully cultivated for energy production under agro-ecological conditions in Latvia. Adding the catalyst Metaferm increased methane yield, except for onions.

Key words: anaerobic digestion, onion, carrot, cabbage, potato, biogas, methane, biological catalyst.

INTRODUCTION

Energy production from renewable sources plays an important role in European energy policies. The share of renewable energy is expected to rise further to 21% by 2020 and 24% by 2030 (COM (2014) 15 final). According to calculations provided during the implementation of the Biomass Action Plan, 8% of Europe's energy needs covered by biomass can reduce greenhouse gas emissions equivalent to 209 million tonnes of CO_2 per year and create up to 300,000 new jobs in the agricultural and forestry sectors.

According to Directive 2009/28/EC, Annex I, Part A, the goal for Latvia is to increase the share of energy produced from renewable energy sources (RES) in gross final energy consumption from 32.6% in 2005 to 40% (1918 toe) in 2020 (Ministry of Economic, 2010).

One of the most promising renewable energy sources is biogas. Biogas production must be developed, as methane collection also helps to implement the Kyoto Protocol provisions. The Latvian Action Plan envisages the total electricity generation capacity of 92 MW for biogas plants in 2020. The number of working biogas cogeneration plants will increase up to 54 in Latvia in 2014 (Ministry of Economics, 2015). There is around 369,000 ha of available land suitable for growing energy crops and the production of biogas in Latvia (Dubrovskis, et al., 2011). However, many biogas plants are built in areas, e.g., in the subregion Zemgale, with little or no free additional land for growing biomass (mainly maize) for biogas plants. High cereals yields and increasing grain prices on the market can cause the further decreasing of maize areas, potentially limiting this traditional source for biogas production. Therefore, it is necessary to find new biomass sources to stabilise or increase biomethane production in biogas plants in Latvia.

An additional way for increasing biogas production is improving the anaerobic fermentation process itself. Currently, within some European countries, a variety of specific additives are being rapidly developed and their use is undergoing innovation (Feng, at al., 2010; Lemmer, at al., 2011; Irvan, 2012; Facchina, at al., 2013) with the aim of increasing biogas yield.

One available biomass source is vegetable and fruit waste from the food industry and/or households. Vegetable and fruit wastes have high initial moisture content in the range of 60–93%, and the wastes are easy degradable under anaerobic conditions.

The anaerobic processing of quickly degradable vegetable or fruit wastes can help avoid carbon dioxide emissions and runoff from biomass, facilitating biogas and fertilizer production in an environmentally friendly way. Research should be conducted on food industry waste processing to evaluate local or regional biogas potential. The aim of the research is to evaluate biogas and methane production from different vegetable residues, clarify whether the addition of biocatalyst Metaferm (made in Latvia) in substrates causes any positive effects, establish effective doses for optimised fermentation and determine the highest doses capable of inhibiting the anaerobic digestion process.

MATERIALS AND METHODS

In order to achieve greater statistical confidence, heated camera (Memmert incubator) and a number of small bioreactors were used. Small bioreactors were filled with substrate and placed in a heat chamber, and gas from each bioreactor was directed into a separate storage bag located outside the camera. Widely applied methods were used for obtaining results (Kaltschmitt, 2010).

The amount of dry matter was determined by investigating the initial biomass sample weight and dry weight with Shimazu scales at 105 °C and by investigating ash content with the help of a Nabertherm furnace, with which the samples were burnt at 550 °C. All mixtures were prepared, carefully mixed and all sealed bioreactors were put in heated camera within same time period before starting anaerobic digestion. The composition of the gas collected into the storage bags was measured with the gas analyser GA 2000. With the help of this instrument, oxygen, carbon dioxide, methane and hydrogen sulphide were registered in the gas. Substrate pH value was measured before and after finishing the anaerobic fermentation process using a pH meter (PP–50) with accessories. Scales (Kern KFB 16KO2) were used for weighing the substrate before anaerobic processing and for weighing the digestate after finishing the fermentation process. Dry matter content and ash content were measured in the digestate originating from each of the bioreactors to determine dry organic matter (DOM) content.

Bioreactors with the volume of 0.7 l were filled with biomass samples of 20 ± 0.05 g and with 500.0 ± 0.2 g inoculum (fermented cattle manure from a 120 l bioreactor working in continuous mode). For calculation purposes control bioreactors were filled only with inoculum. All data were recorded in the journal of experiments and in a computer. All bioreactors were placed into an incubator with the operating temperature of 38 ± 0.5 °C, and every bioreactor had a flexible pipe connected to a gas storage bag positioned outside the heated camera. Every gas bag has a port normally closed with a tap for gas measurement. The quantity and composition of gases were measured every day. Bioreactors were also gently shaken to mix the floating layer regularly. The fermentation process was started with a single filling in batch mode until the biogas emission ceased. The final digestate was weighed; dry matter and ashes were investigated to evaluate organic dry matter content. The total biogas and methane production values were calculated using the normal biogas volumes and quality parameters obtained from the gas collected to the gas storage bags from each bioreactor. For statistical accuracy all final data values were calculated as averages on the basis of two identical substrates positioned in the heat camera.

In the **first study,** raw onion and carrot processing residues were studied. In the **second study,** cabbage leaves and potato processing wastes were used as raw material in the bioreactors. The methods of the experiments were the same for both projects.

RESULTS AND DISCUSSION

The results of analysing raw material samples in view of the anaerobic digestion of onion and carrot wastes in the **first study** are shown in Table 1.

The results of the digestate analysis after the anaerobic digestion process are shown in Table 2.

The production of biogas and methane from onion and carrot wastes and in control reactors is presented in Table 3.

Adding the biocatalyst Metaferm resulted in a considerably higher methane production compared to the control reactors (with onion or carrot substrates only) in all bioreactors except for reactors with onions. This indicates that onions contain substances that can facilitate active anaerobic fermentation processes on their own, or the substances may act as stimulants both with and without adding the biocatalyst MF.

It is necessary to research the subject further to clarify the biological impact of onions on anaerobic fermentation processes.

Table 1. Results of analysing raw material samples before anaerobic digestion

Bioreactor/Raw material	pH substr	TS %	TS g	ASH %	DOM %	DOM g	Weight g
R1, R16 IN	7.86	4.22	21.1	20.71	79.29	16.73	500
R2, R320 g ON		12.63	2.53	6.8	93.2	2.35	20
500g IN + 20 g ON	7.84	4.54	23.63	19.22	80.78	19.09	520
R4, R520gON		12.63	2.53	6.8	93.2	2.35	20
500gIN+20gON+1 ml MF	7.86	4.54	23.65	19.22	80.78	19.1	521
R6, R720gON		12.63	2.53	6.8	93.2	2.35	20
500gIN+20g ON+2ml MF	7.88	4.53	23.65	19.22	80.78	19.1	522
R8, R920g CR		10.64	2.128	9.74	90.26	1.92	20
500gIN+20g CR	7.82	4.47	23.24	19.69	80.31	18.66	520
R10, R1120g CR		10.64	2.128	9.74	90.26	1.92	20
500gIN+20g CR+1ml MF	7.85	4.47	23.28	19.69	80.31	18.7	521
R12, R1320 g CR		10.64	2.128	9.74	90.26	1.92	20
500gIN+20g CR+2ml MF	7.89	4.46	23.29	19.69	80.31	18.7	522
R14, R15		12.63	1.26	6.8	93.2	1.175	10*
10gON+10g CR+500gIN	7.91	10.64	1.064	9.74	90.26	0.96	10**
+2ml MF		4.44	23.41	19.49	80.51	18.85	522

Abbreviations: IN – inoculum; ON – onions; CR – carrots; MF – biocatalyst Metaferm; TS – total solids; ASH – ashes; DOM – dry organic matter; *carrots – 10g; **onions – 10g.

Table 2. Results of digestate analysis for onion and carrot substrates

Bioreactor/Raw material	pH	TS %	TS g	ASH %	DOM %	DOM %	Weight g
R1 IN	7.21	4.48	22.19	14.57	85.43	18.96	495.4
R16 IN	7.20	4.44	21.71	24.55	75.45	16.38	488.9
R2 ON+IN	7.21	4.38	22.36	19.11	80.89	18.08	510.4
R3 ON+IN	7.21	4.64	23.74	21.87	78.13	18.55	511.6
R4 ON+IN +1ml MF	7.18	4.20	21.45	32.84	67.11	14.40	510.8
R5 ON+IN +1ml MF	7.20	3.97	20.29	28.36	71.64	14.54	511.2
R6 ON+IN +2ml MF	7.21	4.23	21.59	23.48	76.52	15.44	510.4
R7 ON+IN +2ml MF	7.14	4.06	20.72	26.20	73.80	15.29	515.4
R8 CR+IN	7.15	4.37	22.37	20.17	79.83	17.86	511.8
R9 CR+IN	7.23	4.24	21.73	27.87	72.13	15.67	512.6
R10 CR+IN+1ml MF	7.25	4.74	22.23	22.84	77.16	27.15	512.2
R11 CR+IN+1ml MF	7.16	4.31	22.09	23.21	76.79	16.96	512.6
R12 CR+IN+2ml MF	7.24	4.51	23.11	22.89	77.11	17.82	512.4
R13 CR+IN+2ml MF	7.21	4.57	23.36	22.96	77.04	17.99	511.2
R14 ON+CR+IN+2ml MF	7.25	4.61	23.66	22.61	77.39	18.31	513.4
R15 ON+CR+IN+2ml MF	7.22	4.67	23.98	23.30	76.70	18.39	513.6

Table 3. Production of biogas and methane from onion and carrot wastes in bioreactors

Bioreactor/Raw material	Biogas l	Biogas l g_{DOM}^{-1}	Methane aver.%	Methane l	Methane l g_{DOM}^{-1}
R1 IN	0.3	0.018	13.00	0.039	0.0023
R16 IN	0.3	0.018	14.00	0.042	0.0025
R2 ON+IN	2.3	0.978	43.87	1.009	0.429
R3 ON+IN	2.3	0.978	44.82	1.031	0.438
R4 ON+IN +1ml MF	2.1	0.894	45.47	0.959	0.408
R5 ON+IN +1ml MF	1.9	0.808	47.47	0.902	0.384
R6 ON+IN +2ml MF	2.1	0.894	43.81	0.920	0.391
R7 ON+IN +2ml MF	1.9	0.808	49.05	0.932	0.396
R8 CR+IN	1.5	0.781	47.13	0.707	0.368
R9 CR+IN	1.2	0.625	44.92	0.539	0.281
R10 CR+IN+1ml MF	2.0	1.041	47.75	0.955	0.497
R11 CR+IN+1ml MF	2.0	1.041	47.9	0.958	0.499
R12 CR+IN+2ml MF	1.7	0.885	42.00	0.714	0.372
R13 CR+IN+2ml MF	1.9	0.989	48.52	0.922	0.480
R14ON+CR+IN+2ml MF	1.5	0.703	44.13	0.662	0.310
R15 ON+CR+IN+2ml MF	1.6	0.749	60.50	0.968	0.453

Note: The average biogas and methane values obtained from reactors 1 and 16 have been already subtracted from the biogas and methane values for bioreactors 2–15 with fresh biomass. Abbreviation: l g_{DOM}^{-1} – litres per 1 g of added dry organic matter (fresh organic matter added into inoculum)

Specific biogas and methane production volumes calculated for added onion and carrot biomass are shown in Fig. 1.

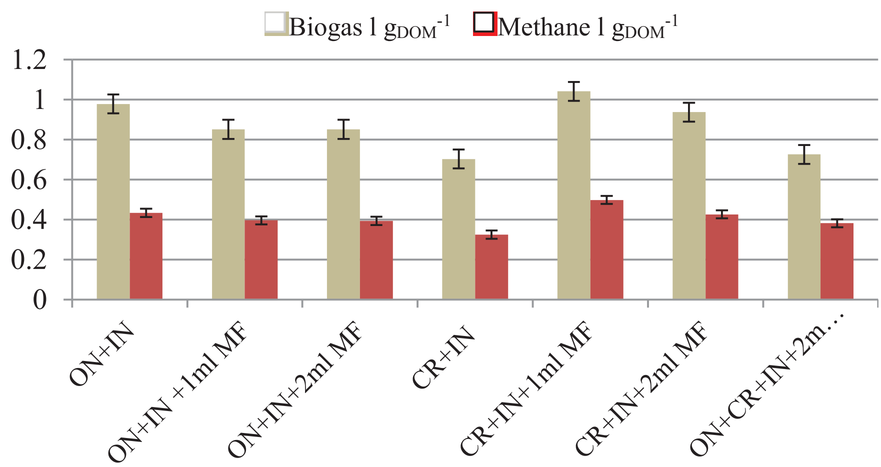

Figure 1. Specific production of biogas and methane from onion and carrot wastes with and without adding the biocatalyst MF.

A good biogas yield was obtained owing to the characteristics of the raw materials but also owing to the fact that the liquid fraction (also inoculum) still had a lot of utilizable substances for the bacteria (e.g., acetic acid) that was no reflected in the dry organic matter analysis.

Substrates with onion wastes provide relatively high methane yields, 0.433 l g_{DOM}^{-1} (litres per 1 g added dry organic matter) on average. Onion substrates with 1 ml or 2 ml of the biocatalyst Metaferm had a 0.396 l g_{DOM}^{-1} and 0.394 l g_{DOM}^{-1} specific methane production respectively. This may be explained by the bioreactors containing substances which inhibit the biocatalyst Metaferm. It is necessary to identify the precise reasons for such inhibition in further research.

Adding 1 ml of the biocatalyst Metaferm to substrates with carrots resulted in a very high average specific methane production of 0.498 l g_{DOM}^{-1} or more than the average methane yield of 0.325 l g_{DOM}^{-1} obtained from control bioreactors without the biocatalyst. Adding 2 ml of Metaferm to substrates with carrot wastes resulted in an average methane yield of 0.426 l g_{DOM}^{-1}. Adding 2 ml of the biocatalyst Metaferm to a carrot–onion 50%:50% mixture resulted in a bigger methane yield increase compared to that of the control bioreactors containing carrots, but smaller than that of control bioreactors with onions. This result also confirms the incompatibility or inhibitive interaction between onions and Metaferm in an anaerobic digestion process.

The results of analysing raw material samples in view of the anaerobic digestion of cabbage and potato wastes in the **second study** are shown in Table 4.

Table 4. Results of analysing raw material samples before anaerobic digestion

Bioreactor/Raw material	pH substr.	TS %	TS g	ASH %	DOM %	DOM g	Weight g
R1, R16 IN	7.54	3.98	19.9	27.72	72.28	14.38	500
R2, R320gCL	7.53	10.87	2.17	9.36	80.64	1.75	20
500g IN + 20gCL		4.24	22.57	25.68	74.32	16.41	520
R4, R520gCL	7.5	10.87	2.17	9.36	80.64	1.75	20
500gIN+20gCL+1mlMF		4.24	22.07	25.69	74.31	16.4	520
R6, R720gCL	7.5	10.87	2.1748	9.36	80.64	1.75	20
500gIN+20gCL+2mlMF		4.24	22	25.69	74.31	16.45	522
R8, R920gCL	7.48	19.36	3.87	5.45	94.55	3.66	20
500gIN + 20gPO		4.57	23.77	23.66	76.34	18.146	520
R10, R1120gPO	7.48	19.36	3.87	5.45	94.55	3.66	20
500gIN+20gPO+1mlMF		4.56	23.77	23.66	76.34	18.15	521
R12, R1320gPO	7.48	19.36	3.87	5.45	94.55	3.66	20
500gIN+20gPO+2mlMF		4.56	23.77	23.66	76.34	18.15	522
R14, R15	7.48	10.87	1.087	9.36	80.64	0.875	10
10gON+10gPO+500gIN +		19.36	1.98	5.45	94.55	1.83	10
2mlMF		4.39	22.92	24.64	75.36	17.27	522

Abbreviations: IN – inoculum; CL – cabbage leaves; PO – potato wastes; MF – biocatalyst Metaferm; TS – total solids; ASH – ashes; DOM – dry organic matter.

Results of the digestate analysis are shown in Table 5.

Table5. Results of the digestate analysis of substrates with cabbage and potato wastes

Bioreactor/Raw material	pH	TS %	TS g	ASH %	DOM %	DOM %	Weight g
R1 IN	7.25	3.58	17.78	22.72	77.28	13.74	496.6
R16 IN	7.27	3.5	17.26	20.64	79.36	13.7	293.2
R2 CL+IN	7.27	3.69	18.94	22.14	77.86	14.75	513.4
R3 CL+IN	7.25	3.58	18.29	20.16	79.84	14.6	510.8
R4 CL+IN +1ml MF	7.33	3.25	16.71	20.34	79.66	13.31	514.2
R5 CL+IN +1ml MF	7.35	3.27	16.83	22.92	77.08	12.98	514.8
R6 CL+IN +2ml MF	7.14	3.34	17.23	21.69	78.31	13.49	515.8
R7 CL+IN +2ml MF	7.19	3.63	18.53	21.34	78.66	14.58	510.5
R8 PO+IN	7.27	3.25	16.54	21.66	78.34	12.96	509
R9 PO+IN	7.31	3.38	17.16	22.18	77.82	13.36	507.8
R10 PO+IN+1 ml MF	7.21	3.29	16.92	20.13	79.87	13.51	514.2
R11 PO+IN+1 ml MF	7.16	3.49	17.88	23.68	76.32	13.64	512.2
R12 PO+IN+2 ml MF	7.25	3.38	17.35	24.53	75.47	13.09	513.2
R13 PO+IN+2 ml MF	7.21	3.23	16.53	22.95	77.05	12.74	512
R14 CL+PO+IN+2 ml MF	7.17	3.29	16.86	24.61	75.39	12.71	512.6
R15 CL+PO+IN+2 ml MF	7.25	3.22	16.54	26.56	73.44	12.15	513.8

The production of biogas and methane from cabbage and potato wastes is presented in Table 6 and Fig. 2.

Table 6. Production of biogas and methane from cabbage and potato wastes in bioreactors

Bioreactor/Raw material	Biogas l	Biogas l g_{DOM}^{-1}	Methane aver.%	Methane l	Methane l g_{DOM}^{-1}
R1 IN	0.3			0.039	
R16 IN	0.4			0.02	
R2 CL+IN*	1.2	0.685	50	0.597	0.341
R3 CL+IN	1.1	0.628	51	0.561	0.32
R4 CL+IN +1ml MF	1.3	0.742	51.92	0.675	0.385
R5 CL+IN +1ml MF	1.2	0.685	53.42	0.641	0.366
R6 CL+IN +2ml MF	1.5	0.857	49.4	0.741	0.423
R7 CL+IN +2ml MF	1.7	0.971	41.82	0.711	0.406
R8 PO+IN	4.1	1.12	52.71	2.161	0.59
R9 PO+IN	3.4	0.928	59.14	2.011	0.549
R10 PO+IN+1ml MF	4.1	1.12	53.68	2.201	0.601
R11 PO+IN+1ml MF	3.3	0.902	55.48	1.831	0.5*
R12 PO+IN+2ml MF	4.7	1.284	53.21	2.501	0.683
R13 PO+IN+2ml MF	4.7	1.284	50.66	2.381	0.651
R14 CL/PO+IN+2ml MF	3.1	1.034	49.39	1.531	0.565
R15 CL/PO+IN+2ml MF	3.7	1.367	48.41	1.791	0.662

*Reactor R11 had technical problems during fermentation; therefore, the data collected from it were replaced by data obtained from the reactor R10 (with the same substrate composition) in calculations.

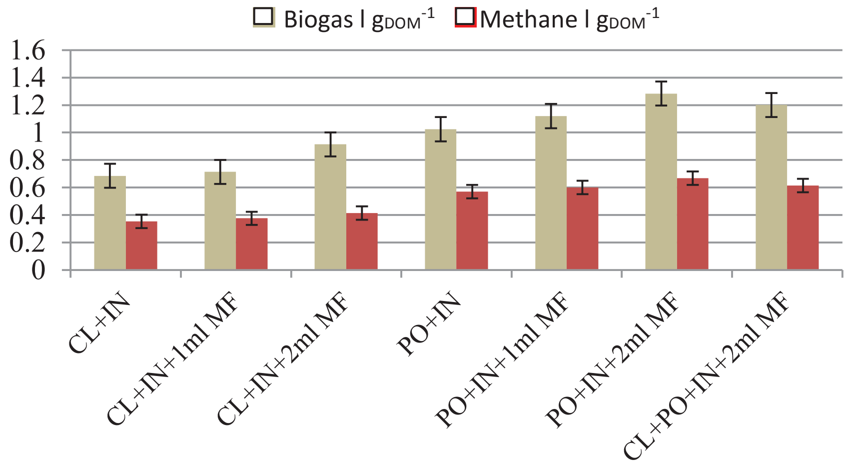

Figure 2. Specific production of biogas and methane from cabbages and potatoes with and without adding the biocatalyst Metaferm.

The main results obtained from the **second study** are the following:

Adding the biocatalyst Metaferm increased biogas and methane production for all reactors compared to the control reactors. Adding 1 ml of the biocatalyst Metaferm to substrates with cabbage leaves resulted in an average specific methane production of 0.376 l g_{DOM}^{-1}. Adding 2 ml of the biocatalyst MF to substrates with cabbage leaves resulted in a very high specific methane production (0.415 l g_{DOM}^{-1}). Adding 1 ml or 2 ml of the biocatalyst MF to substrates with potatoes increased the average specific methane production compared to the control bioreactors (potato without MF). Less methane was produced in the bioreactor R11 due to technical problems, therefore, data from this reactor were not included in calculations.

Adding 2 ml of the biocatalyst MF to substrates with cabbage leaves and potato cuttings (50 : 50) resulted in very high specific methane production (0.613 l g_{DOM}^{-1}).

CONCLUSIONS

Adding the biocatalyst Metaferm had an impact on the fermentation processes in all substrates compared to the control group without MF.

Adding 1 ml and 2 ml of the biocatalyst Metaferm to substrates with onions lowered methane production by 8.5% and 9% respectively compared to the control substrate. Interactions between inoculum, onion and biocatalyst should be investigated more thoroughly in further research.

Adding 1 ml of the biocatalyst Metaferm increased methane production by 5.5%, 13.6% and 53.2% in substrates with potato, cabbage and carrot wastes respectively compared to the control substrates.

Adding 2 ml of the biocatalyst Metaferm increased methane production by 17%, 25.2% and 31.1% in substrates with potato, cabbage, and carrot wastes respectively compared to the control substrates.

Adding 2 ml of the biocatalyst MF to substrates with cabbage and potato cuttings (50:50) caused the methane production to increase by 7.63% compared to the average methane production in cabbage and carrot substrates with 2 ml of MF.

Adding 2 ml of the biocatalyst Metaferm to a carrot–onion mixture (50%:50%) caused the methane yield to increase by 17.5% compared to the control bioreactors containing carrots, but the yield was 11.8% smaller than that of control bioreactors with onions. This result also confirms the inhibitive interaction between onions and Metaferm and/or inoculum in anaerobic digestion processes.

Adding 2 ml of the biocatalyst Metaferm to a cabbage–potato mixture (50%:50%) caused the methane yield to increase by 33% compared to the average value of control bioreactors containing cabbage and potato mixtures without MF. This result also confirms the positive effect of the biocatalyst Metaferm on cabbage or potato substrates undergoing anaerobic digestion processes.

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