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Biomethane Potential of Some Agroresources in Burkina Faso: Case Study of Vegetable Residues, Pig Manure, Mango Waste and Bovine Manure

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Authors' contributions

This work was carried out in collaboration between all authors. Author DT designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author DD managed the analyses of the study and revised the draft of the manuscript. Authors AST and DD managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Burkina Faso urban area is confronted to hygiene, wash and energy supply problems due to an important demographic growth. Methanization of organic wastes has been demonstrated by several studies as a solution to energy crisis and environmental pollution. The aim of this study is to use anaerobic digestion process as a sustainable technology to produce biomethane from vegetable residues (VR), mango waste (MW), pig manure (PM), bovine manure (BM) in order to diversify the sources of renewable energy as well as to reduce environmental pollution in Burkina Faso urban area. The physicochemical parameters of these organic wastes were determined using standard methods (AFNOR, APHA) and the biogas produced was analyzed by gas chromatography. From the physicochemical analysis, dry matter rates were 22.61±0.3% for PM, 15.3±0.3% for BM; 11.78±0.6% for VR and 8.04 ± 0.02% for MW. The highest volume of CH_4 was obtained with PM

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(17526.43µl CH_4), followed by VR (14359.19 µl CH_4), BM (12460.89µl CH_4) and finally mango waste (12460.89 CH_4 µl). The rate of CH_4 content in biogas produced was 61.6%; 59.1%; 57.6 and 53.3 for PM, VR, MW and BM.

Keywords: Vegetable residue; mango waste; pig manure; bovine manure; anaerobic digestion; biogas; methane; Burkina Faso.

1. INTRODUCTION

In developing countries, the production of urban waste has increased in recent decades with the changing lifestyles and fast population growth. Mechanisms and management systems are almost nonexistent. These wastes are often disposed of by stockpiling and land filling because these have been found the cheapest waste disposal methods in the world. Unfortunately, these waste disposal methods are often source of visual pollution, water contamination, health hazards and greenhouse gas emission [1,2,3]. The population of Burkina Faso is estimated to 17.000.000 inhabitants which is mainly concentrated in the big cities. Due to this demographic explosion, important wastes are generated in urban area, leading to environmental, hygiene and sanitation problems. In Ouagadougou city, the solid waste production is estimated to 300 000 tons per year [4]. Unfortunately, this pile of waste undergoes an unsuitable treatment. A large part of the waste is disposed into gutters or burned in the street, with a drastic consequence on environmental pollution and living conditions (increase in greenhouse gas emission, microbial contamination, infestation of atmospheric air by noxious odors, etc.) [1,2,3]. The World Health Organization (WHO) [5] estimated that waste deposition favors the growth of harmful insects responsible of several diseases such as typhoid fever, dysentery, cholera. Thus, one of the main point targeted by the Ministry of Environment in Burkina Faso is the efficient management of environmental pollution and the promotion of renewable energies.

In the framework of national sanitation policy and strategy, Ouagadougou municipality created a Waste Treatment and Valorization Center (WTVC), that became in fact a waste burial center with about 6 million m^3 of waste buried per year. Unfortunately, this method of waste treatment results in organic matter loss, soil and underground water contamination, and contributes up to 5% of the world global gas emission [2,3,6].

The report of UNCCD [7] estimated the electrification level of Burkina Faso cities to approximately 10%. As energy is considered as an indicator and a driving force of a country development, researches are focusing compensatory alternatives for an efficient management of environment to meet the concept of eco-citizenship promotion, along with the promotion of renewable energy.

Methanization of organic matter has been demonstrated by several studies as a solution to energy crisis problems and environmental pollution [6,7]. The process is a fermentation carried out by a mixed population comprising various types of bacteria that live in symbiosis and convert organic matter to methane and carbon dioxide. Thus, (i) the methane produced can be used for domestic energy production [8,9], (ii) the sludge from the anaerobic digestion can serve as food for animal [10,11], soil fertilizer for the improvement of agricultural yields [12,13], and (iii) the process can also contribute to a considerable reduction of waste mass for a sustainable environmental depollution [2,3,14,15,16,17].

The main objective of this research is to employ anaerobic digestion process as a sustainable technology for digesting agricultural wastes, produced in large amounts during harvesting, handling, transportation, storage, marketing and processing, and to provide a renewable source of energy as well as to reduce the potential greenhouse gas emission in Burkina Faso.

2. MATERIALS AND METHODS

2. 1. Inoculums

Pig manure sludge (PMS) and bovine manure sludge (BMS) collected from two digesters of the National Biodigester Program (NBP) at Nioko II and Loumbila (peripheral districts of Ouagadougou city), were used for wastes anaerobic digestion with regard to methane production. The inoculum samples were anaerobically collected into serum bottles, carried to laboratory according to Trine et al. [18]

and then, stabilized during seven days without adding a substrate to avoid biogas production during storage. After stabilization, they were stored at 4°C until use.

2.2 Feedstock

2.2.1 Mango waste

Mango waste (MW) was collected from two mango transformation plants in Burkina Faso (GEBANA AFRICA in Bobo Dioulasso and DAFANI SA in Orodara) and from two mango markets in Ouagadougou ("*Sankara Yaar*" and "*Katre Yaar*"). After pulp and seed separation, a portion of mango waste was grounded by electric blender and passed through 2-mm mesh. The juice obtained was then diluted with distillated water (1/1) and stored at 4°C until use.

2.2.2 Bovine manure

Bovine manure (BM) was freshly taken from the cattle market of "Paag layiri" district and transported to laboratory. The bovine manure was then mixed with distilled water, passed through a 2-mm diameter sieve, homogenized, distributed in 500 ml vials and stored at 4°C for future use.

2.2.3 Pig manure

Pig manure (PM) was freshly harvested from a farm in Nioko II, a peripheral district of Ouagadougou city. The method of preparation and storage of loading substrate from pig manure is the same as for bovine manure described above.

2.2.4 Vegetable residue

Samples used in this study were collected from the restaurants of Ouagadougou University at Zogona and Patte d'Oie (two districts of Ouagadougou city) and from two vegetable markets located in the same districts. The vegetable residues consisted of a mixture of courgette peel, potato, eggplant and lettuce leaves, cabbage leaves, and onion. After sun drying for three to five days, an uniform mixture (same weight) of all components was prepared. This mixture was ground and then passed through a 1-mm mesh sieve in order to obtain a fine powder. The powder obtained was packaged in sterile plastic bags and kept at room temperature in the laboratory until use.

2.3 Experimental Procedure

Batch studies were carried out in reactors of 250 and 120 ml to monitor and measure biogas and methane produced, respectively. The experiments were carried out at laboratory temperature (28- 32°C). Separately, each reactor was initially inoculated with 36 ml of inoculum (pig manure sludge or bovine manure sludge) for the 120 ml reactor, and 75 ml for the 250 ml one before different organic loads of substrate were added.

The organic loads of each substrate were chosen based on the optimum loads determined in our previous studies [19,20].

Vegetable residue was subjected to an aerobic pre-incubation for 48 hours, a condition for optimizing the biomethanization of this substrate [19], before being transferred to the biodigesters at an organic loading of 2%. The organic loads for pig and bovine manures were 10%, respectively, according to the organic load recommended by the National Biodigester Program. The organic load of the mango waste was 10% [20].

After the reactors of 120 and 250 ml were diluted respectively to 50 ml and 150 ml working volume with a buffer solution to avoid pH dropping, biogas production was measured daily by water displacement method. The volume of water displaced from the bottle was equivalent to the volume of gas generated. Reactors were mixed manually by means of shaking and swirling once a day.

2.4 Analytical Methods

Mango waste, vegetable residues, pig and bovine manure samples were analyzed for total solids, volatile solids, ash mater, pH and total organic carbon, using standard methods [21,22]. The pH was measured using a digital pH meter (WTWpH340).

The methane content in biogas was determined by taking 500 µl of the reactor headspace gas at three days intervals using a thermal conductivity gas chromatograph Girdel series 30 catharometer, equipped with porapak Q 80/100 and Q 100/120 columns assembled in parallel and connected to a thermal conductivity detector (TCD) and a potentiometric recorder (SERVOTRACE type sefram Paris 1 mV). The temperature was set at 90°C for the injector, 60°C for the column and 100°C for the detector; N_2 was used as carrier gas. Methane standard (90% purity) supplied by Burkina Industrial Gas, allowed to establish the following regression equation from that the production of CH_4 during the experiments was deduced: Volume CH_4 (µL) = 0.1094 X – 5.0911 (r^2= 0,9958), with X the area of methane peak.

2.5 Statistical Analysis

The data collected were subjected to analysis of variance (ANOVA) using XLSTAT-Pro 7.5.2 software. Means were compared through Fisher test to determine significant differences among variables at α= 0.05.

3. RESULTS AND DISCUSSION

3.1 Physicochemical Characteristics of Inoculums and Substrates

3.1.1 Physicochemical parameters of inoculums

The physicochemical characteristics of the pig manure sludge and bovine manure sludge used as inoculums in the study are shown in Table 1. The pH values were 6.51 ± 0.01 and 7.4 ± 0.14 for bovine manure sludge (BMS) and pig manure sludge (PMS), respectively. These pH values were comparable to those of Dhanalakshmi and Ramanujam [23] who reported that pH of effluent in a digester oscillates between 6.15 and 7.26.

The dry matter content of bovine manure effluent (3.98 ± 0.12%) and that of pig manure one (6.9 ± 0.1%) corresponded to the ones (1.5% - 45.7%) reported by Guster et al. [24] and Svoboda *et al.* [25]. The dry matter rates varied inversely to the moisture ones, which were 96.02 ± 0.3% and 93.49 ± 0.09% for PMS and BMS, respectively.

The PMS and BMS total volatile matter (TVM) rates corresponded to the range of volatile matter (38.6 - 75.4%) reported by Moller et al. [26] and Voca et al. [27].

3.1.2 Physicochemical parameters of substrates

Among the samples studied, pig manure had the highest pH (7.24) followed by bovine manure (7.02), vegetable residues (5.87) and finally mango waste (4.32). Our results were consistent with those of Charney [28] who found that the pH of solid waste suspensions varied between 5 to 9 and Hossain et al. [29] who reported pH values between 4 to 6 for different varieties of mango. The low pH values of vegetable residues (5.87 ± 0.23) and mango waste (4.32 ± 0.08) may be explained by the presence of organic acids in these substrates. The pH of pig manure was consistent with that of Peu [30] and the one of bovine manure is comparable to that of Lacour [31].

The moisture levels were 77.34% for pig manure, 84.6% for bovine manure, 88.22% for vegetable residues and 91.96% for mango waste (Table I). The moisture levels of MW and VR were comparable to the results of Gunaseelan [32], who reported that the moisture content of fruits and vegetables is over 80%, compared to those of Parra et al. [33], Parra and Escobar [34] for pig manure (75%) but higher than the moisture of bovine manure reported by the same authors (75%). The moisture content varied inversely to that of dry matter.

Dry matter content is a criterion allowing to classify a substrate according to its capacity to be more or less degradable by biochemical means. Dry matter rates were 22.61 ± 0.3% for PM, 15.3 ± 0.3% for BM, 11.78 ± 0.6% for VR and 8.04 ± 0.02% for MW (Table I). These dry matter rates were comparable to the results reported by Lacour [31], Parra et al. [33] and Kirtane et al. [35] for pig manure, bovine manure and mango waste, respectively. The dry matter levels (8.04 ± 0.02% to 22.61 ± 0.3%) of these substrates, rather indicated a high water content in agreement with Askar et al. [36] who mentioned that dry matter rate increases with the decrease in water content and vice versa.

Volatile matter (VM) is a parameter that allows the evaluation of specific biomethane production from substrates [37]. The highest volatile matter content was observed for mango waste (99.7%) (Table 1). The VM contents of mango waste (99.7%) and vegetable residues (80.46%) were comparable to those reported by Gunaseelan [32], who showed that the VM of fruits and vegetables is 95%, and with those of Nastaein [38] who obtained 84 ± 3% for household waste, while the VM rates for pig manure (97.90%) and bovine manure (97.3%) were relatively lower than the data reported by Lacour et al. [31] (82.2% for pig manure and 83.1% for bovine manure). The concentration and nature of volatile matter determine the ultimate methanogenic potential of substrates [39].

Table 1. Physicochemical characteristics of inoculums and substrates tested

Parameter	Inoculum		Substrate			
	PMS	BMS	MW	VR	BM	PM
pH	7.4±0.14	6.51±0.01	4.32±0.08	5.87±0.23	7.02 ±0.1	7.24±0.13
Moisture (%)	96.02±0.3	93.49±0.09	91.96±0.5	88.22±0.1	84.6±0.04	77.34±0.04
Dry matter (%)	3.98±0.12	6.9±0.1	8.04±0.03	11.78±0.6	15.3±0.3	22.61±0.3
Volatile matter (%)	98.86±0.3	97.9±0.01	99.7±0.1	80.46±0.02	97.3±0.33	97.90 ±0.07
Ash (%)	1.14±0.02	2.1±0.33	0.27±0.02	1.36±0.06	2.6 ±0.09	2.09±0.01
Total carbon (%)	57.34±0.1	56.43±0.4	57.83±0.5	46.68±0.07	56.43±0,3	53.06±0.11

PMS= pig manure sludge; BMS= bovine manure sludge; MW= mango waste; VR= vegetable residues; BM= bovine manure; PM= pig manure

From the physicochemical parameters analysis (Table 1), four substrates (mango waste, vegetable residues, bovine manure and pig manure) appeared favorable to biochemical treatment through anaerobic digestion with regard to their dry matter content (between 5 and 50%).These results were supported by the findings of Djaâfri et al. [40] and Traoré et al. [19] for vegetable residues, Lacour et al. [31] for pig manure, Trazié and Irje [41] for bovine manure and with those of Madhukara [42] and Kirtane et al. [35] for mango waste.

3.1.3 Kinetics of substrates biotransformation into biogas

Biogas production was monitored daily and the methane concentration in biogas was analyzed at three days interval. The results of biogas and CH_4 productions are presented in Figs. 1 and 2, respectively. Significant biogas and methane productions were observed during the first ten days of incubation for all the substrates tested (BM, MW, PM, VR) (Figs. 1 and 2). Then, the productions decreased progressively with fluctuations over the incubation period (Figs. 1 and 2).

The biogas and methane productions from the beginning to the end of the anaerobic digestion depend on the nature of substrate and the mode of digestion.

In batch mode, after substrate loading and inoculum addition, the digester remains hermetically closed until biogas production becomes almost zero [43,44]. Under these circumstances, the substrate is widely available during the first days of the process. Depending on the nature of the substrate, two cases occur: (i) if the substrate is readily biodegradable, such as fruit and vegetable waste [45,46], biogas production is maximum during the first 10 days [23]; conversely, (ii) if the substrate is difficult to biodegrade (substrates often referred as recalcitrant) such as municipal waste, abattoir waste, refinery waste, etc., the time for biogas generation becomes prolonged [47-53].

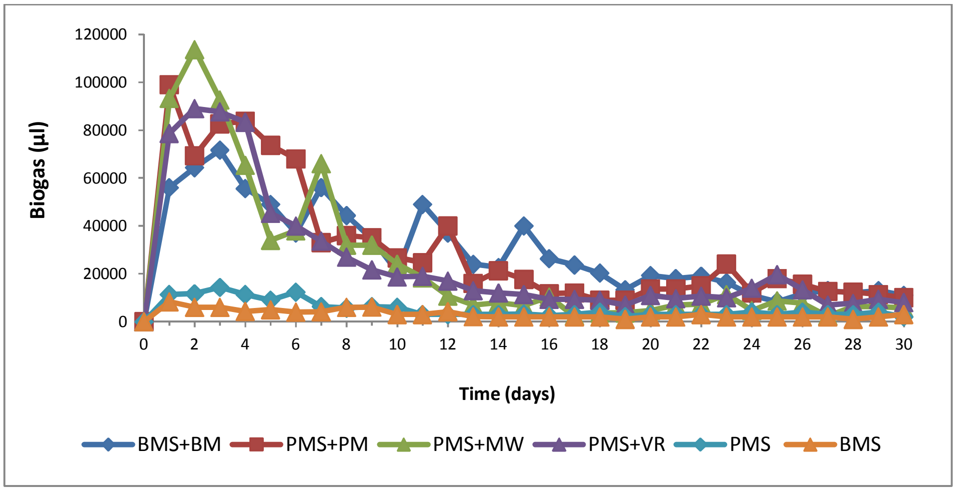

Fig. 1. Biogas production in relation to substrate and incubation time
BM= bovine manure; PM= pig manure; MW= mango waste; VR= vegetable residues; PMS= pig manure sludge; BMS= bovine manure sludge

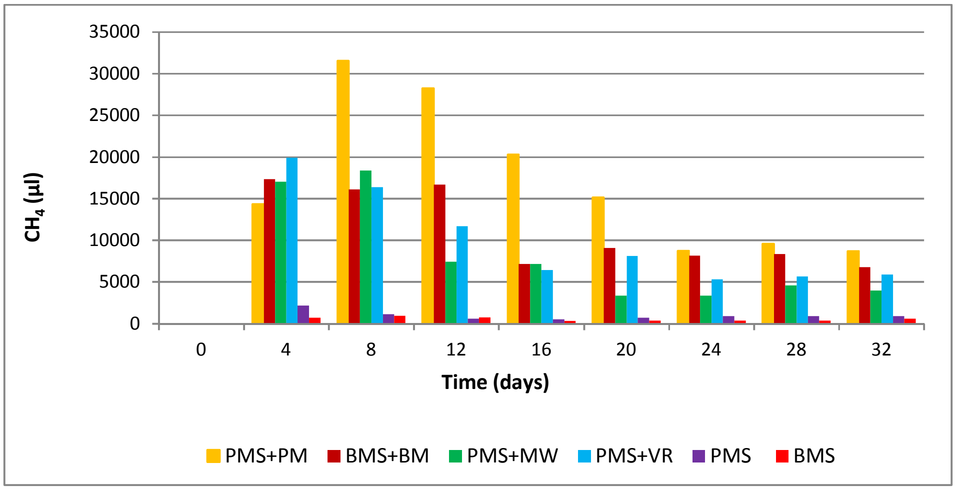

Fig. 2. CH_4 production in relation to substrate and incubation period

PMS= pig manure sludge; BMS= bovine manure sludge; PM= pig manure; BM= bovine manure; MW= mango waste; VR= vegetable residues

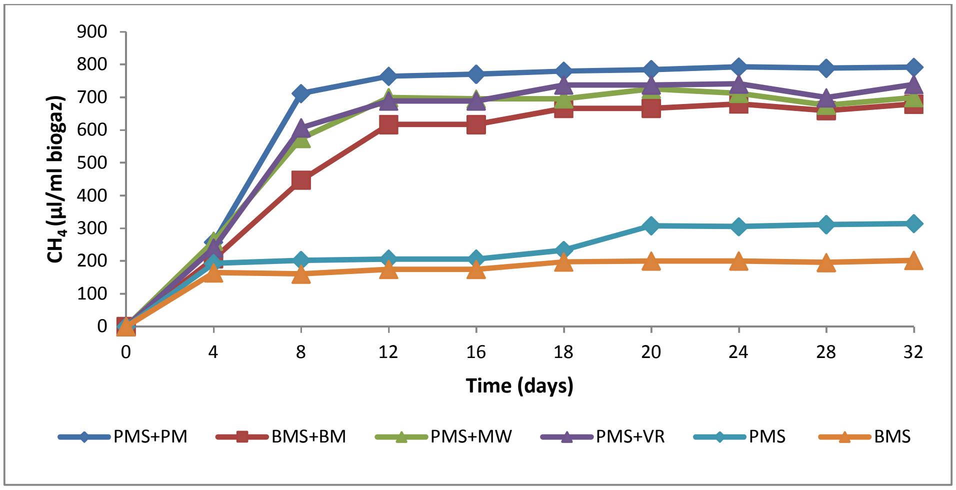

Fig. 3. Evolution of CH_4 concentration in relation to substrate and incubation period

PMS= pig manure sludge; BMS= bovine manure sludge; PM= pig manure; BM= bovine manure; MW= mango waste; VR= vegetable residues

Contrary to the high biogas and methane productions in the early days of experiment (Figs. 1 and 2), chromatographic analysis of biogas revealed low concentration of methane in biogas at the same period, which gradually increased to a maximum at the end of the process (Fig. 3). The same pattern was observed by Igoud et al. [54], which reported an increase in CH_4 concentration from 58.30% to 65.35% between the 18th and 31st day of the incubation period.

The low concentration of methane in the early days (Fig. 3) is explained by the prolonged duration of the anaerobic digestion process staked by a succession of four different phases i.e. hydrolysis, acidogenesis, acetogenesis and methanogenesis [55-58]. In addition, it should be noted that the bacterial groups involved in anaerobic digestion are growing slowly. Acetogenic bacteria have a multiplication time of 1 to 7.5 days [59,60] and the generation time of methanogenic bacteria is 3 days [61]. Therefore, inoculum effectiveness may influence anaerobic digestion, as perforate inoculum considerably shortened the time for biogas generation and increased CH_4 concentration [62-64].

Variance analysis of biogas production and methane evolution in relation to substrate and incubation period are presented in Tables 2 and

3. It appeared that substrate, period of anaerobic digestion and their combined actions had a very significant effect on biogas production and CH_4 content (P <0.0001).

Table 2. Variance of biogas and methane productions in relation to substrate and incubation period

Source	ddl	F	Pr > F
Period	9	1057.881	< 0.0001**
substrate	5	1828.611	< 0.0001**
Period * substrate	45	46.297	< 0.0001**

*F= F of Fisher; **= Significant at P= 0.01*

Table 3. Variance of CH_4 concentration in relation to substrate and incubation period

Source	ddl	F	Pr > F
Period	30	273.383	< 0.0001**
substrate	5	574.132	< 0.0001**
Period * substrate	150	26.658	< 0.0001**

*F= F of Fisher; **= Significant at P= 0.01*

3.1.4 Impact of substrate nature on its bioconversion into methane

Table 4 shows biogas production and its CH_4 content from the anaerobic digestion of pig manure (PM), bovine manure (BM), vegetable residues (VR), mango waste (MW), in relation to inoculum addition (pig manure sludge: PMS or bovine manure sludge: BMS). It also shows biogas production and its methane content for the inoculums incubated alone (PMS or BMS) as controls.

It clearly appeared a significant difference between the production of biogas and CH_4 content for the inoculums and for all the substrates studied. A significant difference between these substrates was also observed for biogas production and its related methane content. As underlined some studies, the molecular and macromolecular composition of a substrate can greatly influence its biotransformation to methane [8,44]. We recall that our results obtained from physicochemical analysis (Table 1) showed that the physicochemical parameters differ from one substrate to another.

We noted that there is no significant difference between the volume of biogas produced from bovine manure, mango waste and vegetable residues (Table 4). In decreasing order, the average volumes of biogas produced were 28452 µl for PM, 24280 µl for VR µl, 23333 µl for BM and 21624 µl for MW. However, CH_4 values obtained from these substrates did not follow the same order as biogas production. The highest volume of CH_4 was obtained with PM (17526.43 µl CH_4), followed by VR (14359.19 µl CH_4), BM (12460.89 µl CH_4) and finally mango waste (12460.89 µl CH_4). The rate of CH_4 content in biogas produced was 61.6%; 59.1%; 57.6 and 53.3% for PM, VR, MW and BM, respectively (Table 4).

The fluctuations of the parameters, in particular pH, dry matter, volatile matter, carbon, phosphorus, lignin, cellulose, hemicellulose, the particle size of a substrate etc. are significantly determining in biomethane potential of a substrate [65,66]. These factors may justify in our case, the different levels of methane produced: 61.6%, 59.1%, 57.6% and 53.3% for PM, VR, MW and BM, respectively.

Our study results are comparable to those of Sumithra and Nand [67]. However, our data are superior to those of Madhukara et al. [43] who reported 58% and 48-52% respectively for MW. The methane content obtained from pig manure (61.6%) is comparable to that reported by Castaing et al. [68] who founded 62% CH_4, but

Table 4. Biogas production and methane content in relation to loading substrate (average of 3 replicates)

Inoculum/Substrate	Biogas (µl)	CH_4 (µl)	CH_4/Biogas (%)
PMS+PM	28452a	17526.43ab	61.6 ab
PMS+VR	24280b	14359.19 b	59.1b
BMS+ BM	23333b	12457.25b	53.3b
PMS+MW	21624bc	12460.89b	57.6b
PMS	4109d	853c	20.7e
BMS	3452d	657.15c	19e

In a column, values sharing a same letter are not significantly different according to the Fisher test at 5% threshold. PMS= pig manure sludge; BMS= bovine manure sludge; PM= pig manure; BM= bovine manure; MW= mango waste; VR= vegetable residues lower than the results of De la Farge et al. [69], who reported 71 to 78% of CH_4. The CH_4 level of VR (59.1%) is comparable to the data reported by Lane et al. [70] (60% CH_4).

4. CONCLUSION

The study aimed to use anaerobic digestion process as a sustainable technology for digesting agricultural wastes, and to provide a renewable source of energy. From the physicochemical parameters analysis, mango waste, vegetable residues, bovine manure and pig manure appeared favorable to biochemical treatment through anaerobic digestion. The highest volume of CH_4 was obtained with pig manure, followed by vegetable residues, bovine manure and mango waste. This study showed that there is no significant difference between the biomethane potential of vegetable residues, mango waste and bovine manure. It especially highlighted that, in addition to bovine manure and swine manure, which are the only wastes recovered for the production of biogas in Burkina Faso, mango waste and vegetable residues can also serve as substrates for biogas production, along with biomethane.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Enetimi I. Seiyaboh and sylvester chibueze izah. bacteriological assessment of a tidal creek receiving slaughterhouse wastes in Bayelsa State, Nigeria. Journal of Advances in Biology & Biotechnology. 2017;14(1):1-7. Article no. JABB. 34593 ISSN: 2394-1081
2. Jean Fidele NZIHOU, Salou Hamidou, Medard Bouda, Jean Koulidiati, Gerard Segda B. Using dulong and vandralek formulas to estimate the calorific heating value of a household waste model. International Journal of Scientific & Engineering Research. 2014;5(1):1878-1883. Available:http://www.ijser.org ISSN 2229-5518
3. Jean Fidèle Nzihou. Improving municipal solid waste land filling disposal process: Experiments with a laboratory scale rotary kiln. Journal of Environmental Protection. 2013;4:753-759. Available:http://www.scirp.org/journal/jep http://dx.doi.org/10.4236/jep.2013.48087. (Published Online August 2013)
4. Ebou Mireille Bayala, Félicité Zongo. Traitement des déchets á Ouagadougou : nos ordures s'étendent, Polesgo aussi. Observateur Paalga du; 2016. Available:http://news.aouaga.com/h/96709.html, (Consulté le 01/10/2017 à 18 h 04 mn)
5. World Health Organisation (WHO). Report on health in Africa. 2014;202. Available:http://www.who.int/gho/publications/world_health_statistics/2014/fr/
6. Bogner J, Abdelrafie Ahmed M, Diaz C, Faaij A, Gao Q, Hashimoto S, Mareckova K, Pipatti R, Zhang T. Waste Management, In Metz, B., Davidson, O.R., Bosch, P.R., Dave, R., Meyer, L.A. (eds), Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. 2007;Chap.10:585-618. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
7. United Nations Convention to Combat Desertification (UNCCD). Chemistry, and climate. The Asian Brown Cloud: Climate and Other Environmental Impacts. Nairobi UNEP; 2002.
8. Buffiere P, Loisel D, Bernet N, Delgenes, JP. Towards new indicators for the prediction of solid waste anaerobic digestion properties. Water Sci. Technol. 2006;53(8):233–241.
9. Amarante JAL. Biométhanisation des déchets putrescibles municipaux – technologies disponibles et enjeux pour le Québec. Mémoire de maître en environnement Université de Sherbrooke, Québec, Canada. 2010;89.
10. Angelidaki I, Ellegaard L. Codigestion of manure and organique wastes in centralized biogas plants. Appl. Biochem. Biotech. 2003;109:95-105.
11. Schievano A, Pognani M, D'Imporzano G, Adani F. Predicting anaerobic biogasification potential of ingestates and digestates of a full-scale biogas plant using chemical and biological parameters. Bioresource Technology. 2008;99:8112-8117.

12. Wu YZ, Liu KJ. An Introduction to the state of research and development of biogas in rural areas of china in recent years and discussion on improvement of old biogas technology (Chinese), Biogas Technology and Utilization Research, Chengdu Biological Science Research Institute. 1988;1-13.
13. Di CL. Characteristics and role of good cycle system for rural biogas in jiangsu province (Chinese). China Biogas. 1993; 11(2):51-53.
14. Lei Gu, Yi-Xin Zhang, Jian-Zhou Wang, Gina Chen, Hugh Battye. Where is the future of China's biogas? Review, forecast, and policy implications. Petroleum Science. 2016;13(3):604–624. Available:https://link.springer.com/article/10.1007/s12182-016-0105-6
15. Schröder P, Herzig R, Bojinov B, Ruttens A, Nehnevajova E, Stamatiadis S, Memon A, Vassilev A. Bioenergy to save the world producing novel energy plants for growth on abandoned land. Env. Sci. Pollut. Res. 2008;3(15):196-204.
16. Nikolov L, Simeonov I, Karakashev D, Chorukova E, Gulubova D. Anaerobic biodegradation of complex mixtures of organic wastes. Ecol. Eng. Envir. Protect. 2004;3:42-52.
17. Simeonov I, Mihajlova A, Mirkov A, Petkov I, Chorukova E. Biogas production from organic wastes in laboratory pseudo-homogenious bioreactors. Ecological Engineering and Environmental Protection. 2007;6(2):23-32.
18. Trine LH, Jens ES, Angelidaki I, Marca E, la Cour JJ, Mosbæk H, Thomas HC. Method for determination of methane potentials of solid organic waste. Waste Management. 2004;24:393–400.
19. Traoré D, Dianou D, Traoré AS. Valorization of mango waste by biomethane production in Burkina Faso. Current Research in Microbiology and Biotechnology. 2017;5(5):1212-1218.
20. Désiré Traoré, Mahamadi Nikiema, Marius K. Somda, Joseph B. Sawadogo, Dianou Dayeri et Alfred S. Traore. Contribution à la biométhanisation de la biomasse végétale: Cas des résidus de légumes au Burkina Faso. Int. J. Biol. Chem. Sci. 2016; 10(1):35-47.
21. American Public Health Association (APHA). Standard Methods for the Examination of Water and Wastewater, 20th ed. APHA, Washington, DC. Anaerobic Ecosystem. Adv. Microbiol. Ecol. USA. 1998;3:49-77.
22. NF-ISO-11465-AFNOR-X-90-029. Détermination de la teneur pondérale en matière sèche et en eau Méthode gravimétrique. Organisation A. A. F. D. N. I. I. S.
23. Dhanalakshmi SV, Alwar RR. Performance of mixture of vegetable wastes with high carbohydrate content in anaerobic digestion process. International Journal of Environmental Sciences. 2012;3(1):181-191.
24. Guster R, Ebertseder T, Weber A, Schraml M, Schmidhalter U. Short-term and residual availability of nitrogen after long-term application of organic fertilizers on arable land. J Plant Nutr. Soil Sci. 2005;168:439-446.
25. Svoboda N, Taube F, Wienforth B, Kluß C, Kage H, Herrmann A. Nitrogen leaching losses after biogas residue application to maize. Soil Tillage Res. 2013;130:69-80. DOI: 10.1016/j.still.2013.02.006
26. Moller K, Stinner W, Deuker A, Leithold G. Effect of different manuring systems with and without biogas digestion on nitrogen cycle and crop yield in mixed organic farming systems. Nutr. Cycl. Agroecosyst. 2008;82(3):209-232. Available:https://link.springer.com/article/10.1007/s10705-008-9196-9
27. Voca N, Kricka T, Cosic T, Rupic V, Jukic Z, Kalambura S. Digested residues as a fertilizer after the mesophilic process of anaerobic digestion. Plant Soil Environ. 2005;51:262-266.
28. Charnay F. Compostage des dechets urbains dans les pays en developpement: elaboration d'une demarche methodologique pour une production perenne de compost, these de doctorat, Université de Limoges. 2005;229.
29. Hossain MM, Haque MA, Rahim MA, Rahman MH. Physio-morphological and compositional variation in ripe fruit of tree mango varieties. J. Bio. Sci. 2001;1(11): 1101-1102.
30. Peu P. La gestion des effluents d'élevage et la production d'hydrogène sulfuré, cas particulier de la méthanisation. Thèse de doctorat, Université de Rennes 1. 2011;165.
31. Lacour J, Bayard R, Emmanuel E, Gourdon R. Evaluation du potentiel de valorisation par digestion anaérobie des gisements de déchets organiques d'origine

agricole et assimilés en Haïti. Déchets - Revue Francophone d'Écologie Industrielle. 2011;60:30-41.
32. Gunaseelan NV. Anaerobic digestion of biomass for methane production: A Review. Biomass and Biornergy. 1997; 13(1-2):83-114.
33. Parra R, Escobar A, Gonzalez E. El potencial de los recursos agricolas fibrosos. Jornadas Agronomicas. 1997;XI: 12-15.
34. Parra R, Et Escobar A. Use of fibrous agricultural residues (FAR) in ruminant feeding in Latin America. In: FAO. Better utilization of crop residues and by-products in animal feeding: research guidelines - State of Knowledge. Rome. 1985;213.
35. Kirtane RD, Suryawanshi PC, Pati MR, Chaudhari, Kothari. Optimization of organic loading rate for different fruit waste during biomethanization. Journal of Scientific & Industrial Research. 2009;68:252-255.
36. Askar A, El-Tamani A, Raouf M. Constituent of mango fruit and their behaviour during growth and ripening. Germany. Mitteihungen: Rebe, wein, obstban and fruchtever werting. 1972; 22(2):120-125.
37. Angelidaki I, Sanders W. Assessment of the anaerobic biodegradability of macropollutants. Reviews in Environmental Science and Biotechnology. 2004;3(2): 117-129.
38. Nastaein Qamaruz Zaman. The applicability of batch tests to assess biomethanation potential of organic waste and assess scale up to continuous reactor systems. PhD Thesis, University of Canterbury. 2010;300.
39. Møller HB, Sommer SG, Ahring BK. Methane productivity of manure, straw and solid fractions of manure. Biomass and Bioenergy. 2004;26:485-495.
40. Djaâfri M, Khelifi S, Kalloum A, Tahri K, Kaidi et Touzi A. Effet de l'ensemencement sur la digestion anaérobie des déchets ménagers de la ville d'Adrar. Revue des Energies Renouvelables. 2009;12(3):369-374.
41. Trazie G. Et Irje BI. Etude technique d'une unité de biométiianisation destinée a l'électrification rurale: Application au monastère de Keur Moussa. Diplôme d'ingénieur de conception, Université Checkh Anta Diop de Dakar. 2007;108.
42. Madhukara K, Nand K, Raju NR, Srilatha HR. Ensilage of mango peels for methane generation. Process Biochemistry. 1992; 28:119-123.
43. Raposo CJ, Banks I, Siegert S, Heaven, Borja R. Influence of inoculum to substrate ratio on the biochemical methane potential of maize in batch tests. Process Biochemistry. 2006;41(6):1444-1450.
44. Angelidaki I, Alves M, Bolzonella D, Borzacconi L, Campos JL, Guwy AJ, Kalyuzhnyi S, Jenicek P, Van JBL. Defining the biomethane potential (BMP) of solid organic wastes and energy crops: A proposed protocol for batch assays. 2006; 927-934.
45. Kalia V, Sonakya V, Raizada N. Anaerobic digestion of banana stem waste. Bioresource Technology. 2000;73(2):191-193.
46. Biswas J, Chowdhury R, Bhattacharya P. Mathematical modeling for the prediction of biogas generation characteristics of an anaerobic digester based on food/vegetable residues. Biomass and Bioenergy. 2007;31:80-86.
47. Kivaisi AK, Mukisa J. Composition and anaerobic digestion of single and combined organic fractions of municipal solid waste of Dares Salaam. Tanz. J. Sci. 2000;26:67-78.
48. Lopes WS, Leite VD, Prasad S. Influence of inoculum on performance of anaerobic reactors for treating municipal solid waste. Bioresource Technol. 2004;94:261-266.
49. Nordberg A, Edstrom M. Co-digestion of energy crops and the source-sorted organic fraction of municipal solid waste. Wat. Sci. Technol. 2005;52:217-222.
50. Igoni AH, Ayotamuno MJ, Eze CL, Ogaji S. OT, Probert SD. Designs of anaerobic of digesters for producing biogas from municipal solid-waste. Appl. Energ. 2008; 85:430-438.
51. Ojolo SJ, Bamgboye AI, Ogunsina BS, Oke SA. Analytical approach for predicting biogas generation in a municipal solid waste anaerobic digester. Iran. J. Environ. Health. Sci. Eng. 2008;5(3):179-186.
52. Siles LJ, Santos M, Pérez A, Martín A. Anaerobic digestion of glycerol derived from biodiesel Manufacturing. Bioresourse Technology. 2009;100:5609–5615.
53. Robra S, Serpa R, Oliveira A, Almeida J, Santos J. Generation of biogas using crude glycerin from biodiesel production as a supplement to cattle slurry. Biomass and Bioenergy. 2010;34:1330-1335.

54. Igoud S, Tou I, Kehal S, Mansouri N, Touzi A. Première approche de la caractérisation du biogaz produit à partir des dejections bovines. Rev. Energ. Ren. 2002;5:123-128.
55. Batstone DJ, Keller J, Angelidaki I, Kalyuzhnyi S, Pavlostathis SG, Rozzi A, Sanders W, Siegriest H, Vavilin VA. The IWA anaerobic digestion model N°1 (ADM1). Water Science and Technology. 2002;45(10):65-73.
56. Kaseng K, Ibrahim K, Paneerselvam SV, Hassan RS. Extracellular enzyme and acidogen profiles of a saboratory-scale two-phase anaerobic digestion system. Process Biochemistry. 1992;27:43-47.
57. Angelidaki I, Ahring BK. Effect of the clay mineral bentonite on ammonia inhibition of anaerobic thermophilic reactors degrading animal waste. Biodegradation. 1993;3: 409-414.
58. Hattori S. Syntrophic acetate-oxidizing microbes in methanogenic environments. Microbes and Environments. 2008;23:118-127.
59. Lokshina LY, Vavilin VA. Kinetic analysis of the key stages of low temperature methanogenesis. Ecological Modelling. 1999;117(2-3):285-303.
60. Vavilin VA, Lokshina LY, Rytov SV, Kotsyurbenko OR, Nozhevnikova AN, Parshina SN. Modelling methanogenisis during anaerobic conversion of complex organic matter at low temperatures. Water Science and Technology. 1997;36(6-7): 531-538.
61. Schink B. Energetics of syntrophic cooperation in methanogenic degradation. Microbiology and Molecular Biology Reviews. 1997;61(2):262-280.
62. Dangaggo SM, Aliya M, Atiku AT. The effect of seeding with bacteria on biogas production rate. Renew. Energy– An Int. J. 1996;9(1–4):1045–1048.
63. Kanwar SS, Guleri RL. Biogas production from mixture of poultry litter and cattle dung with an acclimatised inoculum. Biogas Forum I. 1995;60:21–23.
64. Kotsyurbenko OR, Nozhevnikova AN, Kalyuzhnyy SV, Zavarzin GA. Methanogenic digestion of cattle manure at low temperature. Mikrobiologiya. 1993; 62(4):761–771.
65. Ojolo SJ, Bamgboye AI, Ogunsina BS, Oke SA. Analytical approach for predicting biogas generation in a municipal solid waste anaerobic digester. Iran. J. Environ. Health. Sci. Eng. 2008;5(3):179-186.
66. Palmowski LM, Muller JA. Influence of the size reduction of organic waste on their anaerobic digestion. Water Sci. Technol. 2000;47(12):231–238.
67. Sumithra S, Nand K. Microbiological pretreatment of mango peel for biogas production. J. Microbial Biotechnology. 1989;4(2):110-115.
68. Castaing J, Pouech P, Coudure R. Digestion anaérobie de lisier de porcs en mélange avec des déchets agro-industriels. Journées de la Recherche Porcine. 2002;34:195-202.
69. De la Farge B, Heduit M, Brondeau P, Mongin JP, Saugère D, et Cambus L. La méthanisation des lisiers de porcs. Journées Rech. Porcine en France. 1983; 15:11-12.
70. Lane A. Methane from anaerobic digestion of fruit and vegetable processing wastes, Food Technology in Australia. 1984;5: 245–259.

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