International Scientific Organization
http://iscientific.org/
Chemistry International
www.bosaljournals.com/chemint/

Biogas production: Anaerobic digestion of food waste using cattle rumen content

Chukwuemeka Peter Ukpaka* and Joshua Godwin Azuatalam

Department of Chemical Engineering, Rivers State University, Port Harcourt, Nigeria
*Corresponding author's E. mail: peter.ukpaka@ust.edu.ng

A R T I C L E I N F O

Article type:
Research article
Article history:
Received December 2023
Accepted March 2024
April 2024 Issue
Keywords:
Cattle rumen content
Food waste
Anaerobic digestion
Co-digestion

A B S T R A C T

This work aims to study the effect of inoculum dosage on anaerobic digestion of food waste using cattle rumen content, CRC, as the bio-stimulant. Four different batch runs were carried out which were 0% (control sample), 25% dosage, 50% dosage and 75% dosage. The results showed that increasing the inoculum dosage up to 25% led to higher biogas and methane yields respectively while the 50% dosage was slightly lower in performance; signalling a decline. A further increase in the inoculum dosage to 75% inoculation led to a sharp decline in the biogas and methane yields indicating that self-inhibition had set in. Therefore, it suffices it so say that while CRC was effective in furnishing the reacting media with the essential micro-organisms needed for optimal reaction, beyond 25% inoculation, CRC becomes counterproductive due to the presence of inhibitory substances.

Capsule Summary: This study investigates the impact of inoculum dosage on anaerobic digestion of food waste using cattle rumen content (CRC) as a bio-stimulant. Results indicate that up to 25% inoculation enhances biogas and methane yields, but higher dosages, particularly 75%, lead to diminishing yields.

Cite This Article As: C. P. Ukpaka and J. G. Azuatalam. Biogas production: Anaerobic digestion of food waste using cattle rumen content. Chemistry International 10(2) (2024) 69-74.
https://doi.org/10.5281/zenodo.11035137

INTRODUCTION

Inoculum to substrate ratio (I/S), is the ratio of the bio-stimulant to the substrate used during digestion and measured on the same basis (unit). Alternatively, it is the percentage (dosage) of the inoculum used to bio-stimulate the digestion process. Research has shown that different inoculum dosages have resulted in varying performances depending on the substrate used as well as the bio-stimulant. Even the same dosage used with different substrates does not guarantee the same outcome.

The effects of inoculum to substrate ratio on anaerobic digestion were studied by Asante-Sackey *et al.,* (2018). In this study, they used cow dung as the bio-stimulant and *miscanthus fuscus* (a plant similar to elephant grass that grows as tall as 3m) as the feedstock. The I/S for the different batch runs were 1: 0, 0: 1, 1: 1, 1: 3 and 3: 1 for 33 days HRT at a controlled pH range of 6.2-7.8 and temperature range of $35°C \pm 2$. The result of this experiment showed that the I/S of 3: 1 gave the highest biogas production while I/S of 0: 1 had the least biogas production. In all the samples, the biogas, methane and carbon dioxide daily production increased overall.

Mohamed et al. (2016) compared the production of biogas from MSW using cow dung and sewage sludge as the inoculums. The 60-day reaction was carried out at mesophilic temperature (not specified) and controlled pH range of 6.8-7.3 using sodium hydroxide (NaOH) solution. The I/S were 0%, 10%, 20% and 30% respectively for both the cow dung and the sewage sludge. At the end of the digestion period, it was observed that an increase in I/S led to a corresponding increase in biogas production both for the samples seeded with cow dung and those seeded with sewage sludge. The maximum cumulative biogas productions for the 30% bio-stimulants using cow dung and sewage sludge were 567ml and 383.52ml respectively. This indicates that cow dung was more effective as an inoculum than sewage sludge. It is uncertain how these dosages affect the methane content of the gas.

Ihoeghian et al. (2022) studied the effects of cattle rumen content (CRC) on the anaerobic digestion of food waste. Seven different samples were prepared with inoculum to substrate dosage such as: 0:1, 1: 4, 2: 3, 1:1, 3: 2, 4: 1 and 1: 0 respectively. They found that the sample with an equal blend of CRC and food waste gave the maximum biogas yield $0.32052l/gVS$. From the outcome of this study, we can assert that although cattle rumen content is a good bio-stimulator, beyond a certain dosage, it becomes counterproductive. Hence, it needs to be used in the right proportion. Bello et al. (2015) studied the effects of rumen fluid dosage in co-digestion with food waste. Their results indicate that there was a general antagonistic effect during the digestion as the quantity of rumen fluid increased.

Rumen fluid has also been used as inoculum in the co-digestion of cattle manure with kitchen waste as studied by Argaw et al. (2013). According to them, increasing the dosage of the cow manure resulted in poorer performance while increasing the dosage of the kitchen waste improved the result. It was evident that similar to CRC, cow manure exhibits an inhibitory effect beyond a certain dosage. Pathak and Srivastava (2020) studied the effects of inoculum dose on methane production from the food industry's effluent. Five different percentage concentrations of inoculums used were: 0%, 10%, 20%, 30% and 40% respectively. The inoculums were taken from a digested slurry of cow dung biogas plant while the substrate or feedstock was wastewater from a food industry. The outcome of the studies revealed that the biogas yields were respectively: ≈ 0 ml/ml, 0.97 ml/ml, 1.05 ml/ml, 1.35 ml/ml and 1.23 ml/mL. The 30% concentration of bio-stimulant had the best performance in terms of both biogas production and methane content. This result attests to the inhibitory effect of cow dung above a certain percentage concentration. The agreement among the results of different researchers using different substrates cannot be a mere coincidence and conclude that for the bio-digestion of any organic feedstock, using the appropriate inoculum dosage will ensure maximum productivity as well as gas quality, which has been evaluated in this study.

MATERIAL AND METHODS

Instrumentation and samples

The following materials were used during this research work: nylon bags, a blender (shredder/crusher), a storage container for cattle rumen's content, a digital weighing balance M411L by M-METLAR, refrigerator and food wastes (substrate), which was a blend of several kitchen wastes such as rice, beans, bread, carrot, cucumber, banana, plantain, baked cassava flakes, meat and fish fragments, spaghetti, etc.

Biogas production and analysis

A known amount (kgVS) of inoculum and crushed substrate were measured using a weighing balance and mixed with water using a water-to-substrate ratio proportional to the percentage MC of the feedstock. Four different samples of different inoculum to substrate ratios of 0: 1, 1: 3, 1: 1 and 3: 1 respectively were used.

Each mixed sample was charged into the reactor and covered tightly to prevent both air and light from gaining access. All kinetics data such as temperature, pressure, pH, concentrations as well as the volume of biogas and volume of its constituent gases were measured daily for each digester for 20 days.

Readings of temperature, pressure and pH were done using their respective instruments embedded with the reactor. Bacteria's concentration was determined using the cell count technique and the substrates' concentration was determined by measuring the VS of the reactor's content while the gas composition was determined using gas chromatography fitted with a mass spectrophotometer (GC/MS). The gas volume was read using the water displacement method described by Ojikutu and Osokoya (2014).

RESULTS AND DISCUSSION

Inoculum dosage effect on biogas volume and quality

Figure 1 shows the results of the cumulative biogas volume and the quality of the gas respectively for the control sample (0% biostimulation). A total of $29.7l$ biogas was produced from 574.6gVS of waste food. This would translate to a biogas yield of $0.0517l/gVS$. The quality of biogas was quantified in terms of gas composition. Spectrophotometric analysis revealed that the biogas had an average methane content of 43.4%. When expressed in terms of yield, the biogas had a methane yield of $0.0224l/gVS$. Due to the high cost associated with gas analysis via GC/MS and other contingencies, gas analysis was carried out at certain intervals beginning from the day each reactor started producing a significant amount of gas.

In Figure 2, the variation in the percentage of selected biogas composition with time is shown. The result shows that biogas quality increased with time while the impurity decreased over time. This is because microbes always try to detoxify the media and attain stability during anaerobic digestion. More importantly, very high biogas purity was witnessed during this continuous operation due to the use of one-time biostimulation instead of continuous co-digestion of food waste and the cattle rumen's content. Hence, the inhibitory substances or toxins accompanying the inoculum were eventually all washed off through gradual digestate removal.

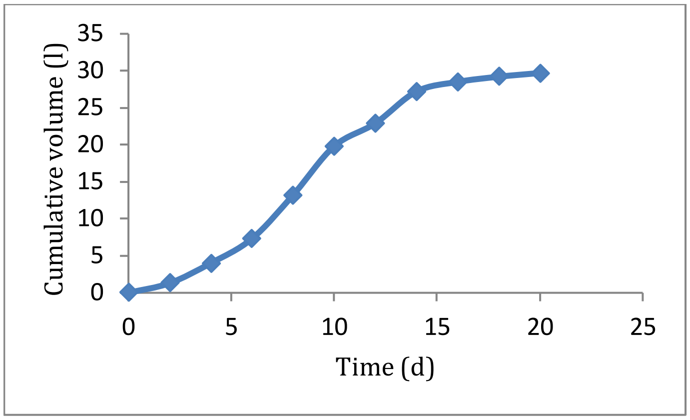

Fig. 1: Effect of 0% bio-stimulant on biogas volume.

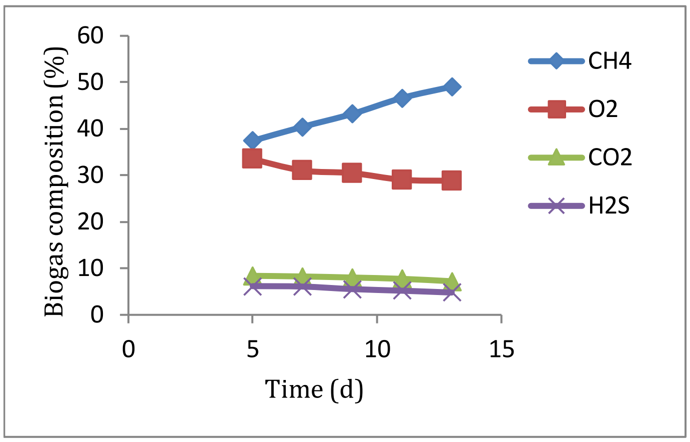

Fig. 2: Effect of 0% bio-stimulant on select biogas composition.

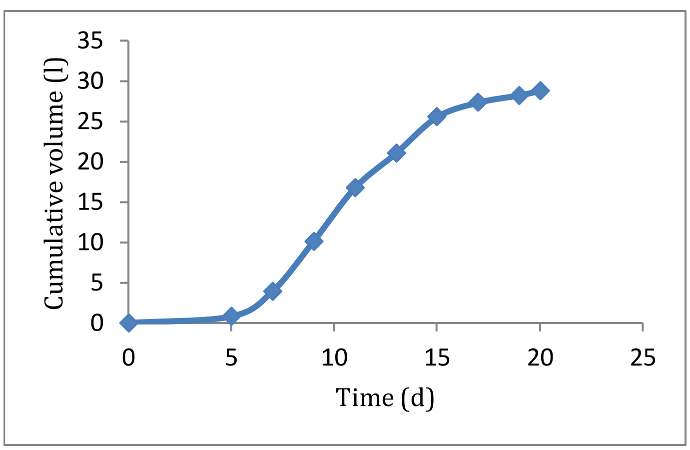

Fig. 3: Effect of 25% bio-stimulant on cumulative volume.

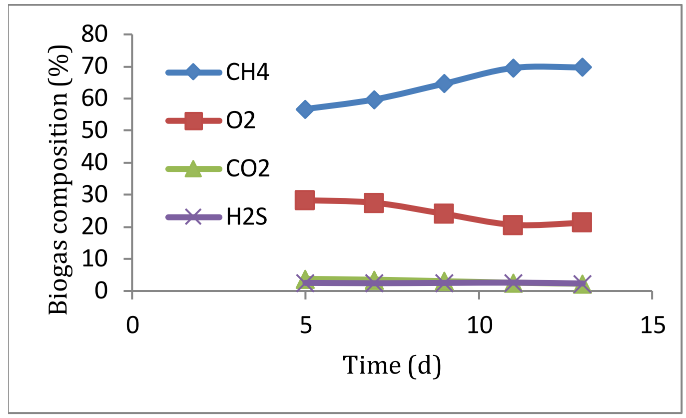

Fig. 4: Effect of 25% bio-stimulant on select biogas composition.

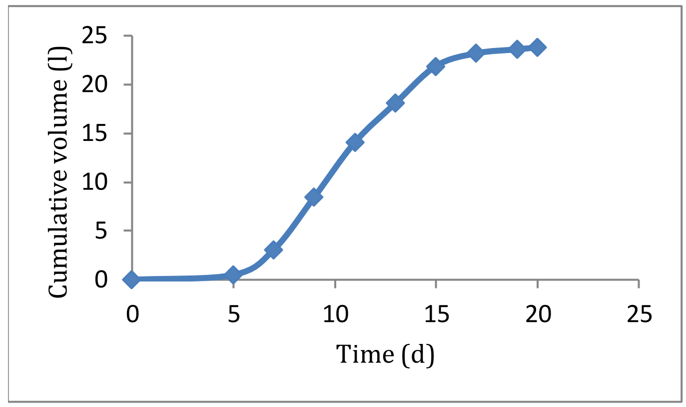

Fig. 5: Effect of 50% bio-stimulant on cumulative volume.

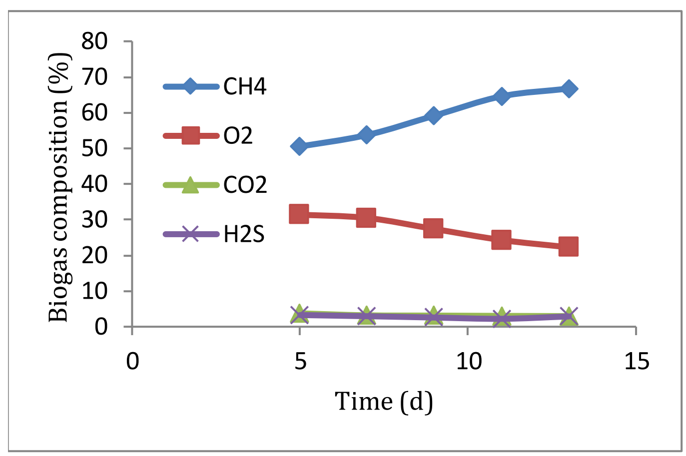

Fig. 6: Effect of 50% bio-stimulant on select biogas composition.

Figure 3 reveals that a total of $28.75l$ was produced from 2kg (511.4gVS) of codigestion of food waste and rumen content in ratio 3:1. This translates to a biogas yield of $0.0562l/gVS$. The average methane content for the entire duration was 64.08%. At this percentage, the methane yield of the methane gas was $0.036l/gVS$. based on biogas yield, one might think that the control sample had a close competition with the 25% dosage. But based on the fuel (methane), the 25% inoculum dosage proves to be more than 1.5 times better.

Figure 4 shows the variation in percentages of some select biogas compositions with time. For this batch run, the quality of gas increased with an increase in HRT while the presence of impurities decreased with time. This is an indication that the microbes adapted better with time and as a result, were able to properly digest the substrates.

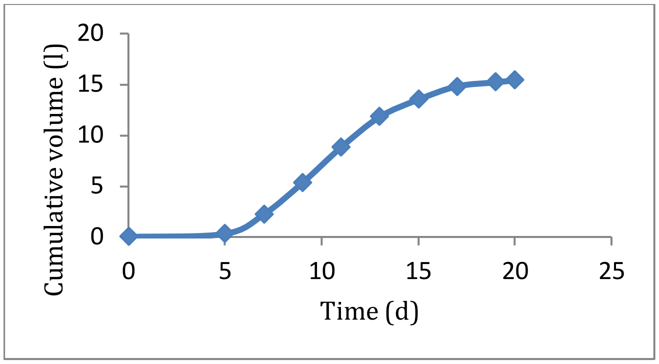

Fig. 7: Effect of 75% bios-stimulant on cumulative volume

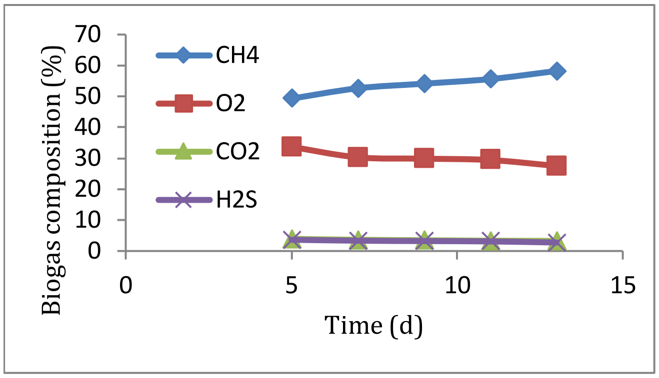

Fig. 8: Effect of 75% bio-stimulant on biogas composition.

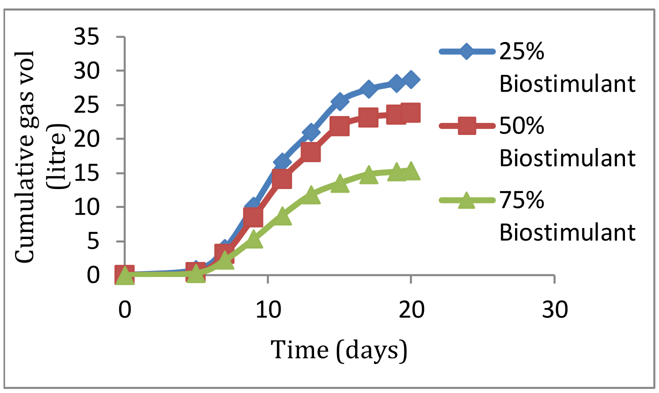

Fig. 9: Effects of I/S ratio on biogas volume for 20 days HRT.

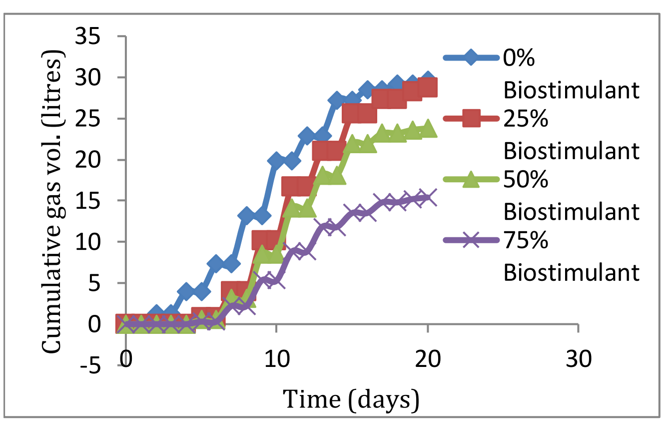

Fig. 10: Effects of I/S ratio on biogas volume.

In Figure 5 the outcome for the digestion of food wastes with cattle rumen content in equal ratio are shown. A total of 23.8l biogas was produced from 2kg (448.2gVS) of waste food; translating to a biogas yield of $0.0531l/gVS$.

The average methane content calculated from Figure 6 was 58.950%. It was found that the methane yield was $0.0313l/gVS$. Given this value of biogas and methane yields respectively, the 50% dosage had a close competition with the 25% bio-stimulant. Also, the biogas quality improved over time in the course of digestion as shown in Figure 6.

In Figure 7, a cumulative of 15.4l biogas was produced from the digestion of 2kg (385gVS) of food waste and CRC in ratio $1:3$. Based on this, the gas yield was calculated and found to be $0.04l/gVS$. This quantity of gas is way less than the 28.48l produced by Bagudo *et al.,* (2011) from an equivalent of 2kg cow dung. This may be attributed to the CRC which might have contained some toxic compounds alongside possessing the requisite microbes required for anaerobic digestion.

Figure 8 reveals that the percentage of methane gas was increased with time while other components of the biogas that constitute impurities decreased with time. The average percentage of methane was 53.96% and this was used to calculate the methane yield of the sample as 0.0216l/gVS. For all the samples, the cumulative biogas curve was steeply initially and nearly flattened out from the 18th day of digestion indicating that the reaction was coming to an end.

Generally, the volume of biogas improved with a decrease in the inoculum (cattle rumen's content) dosage. That is, while CRC supplies the necessary species of microbes to the substrate, it has an inhibitory effect such that beyond a certain dosage a decline in performance sets in. This was confirmed by the pH content of the samples. The pH of the control fluctuated between 6.8 and 7.2 which are within the acceptable optimal pH range of anaerobic digestion while the pH of the other samples where less than this with increasing percentage dosage.

Putting this in perspective, comparative analyses of the different samples are presented in Figure 9 to Figure 11. It observed that gas production commenced much earlier with the control sample at day 2 while the other dosages commenced at approximately on the 5th day with the 25% dosage starting around the 4th day. This increase in time required for the commencement of gas production with higher inoculum could be attributed to the adaptation period required by these microbes in their new environment. For this reason, the control sample commenced earlier because the microbes came naturally with the food wastes, as such, there was rapid acclimatization.

The amount of biogas one can extract from an organic waste will depend on the waste itself and the process condition. The results of all the different dosages samples fall within the range of $0.02m^3$ to $0.8m^3$ per kilogram of waste (Biogas world, 2022).

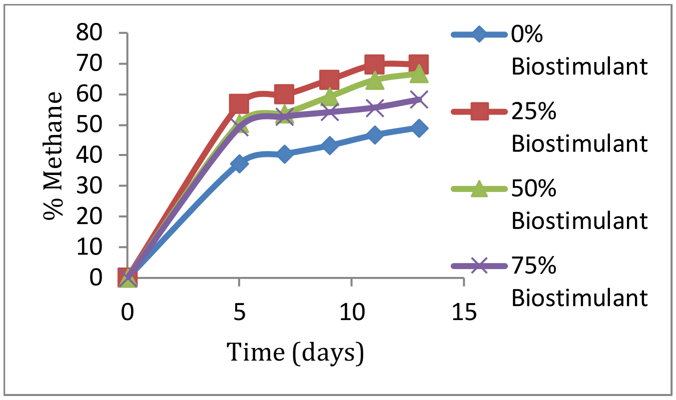

Fig. 11: Effect of inoculums to substrate ratio on methane content.

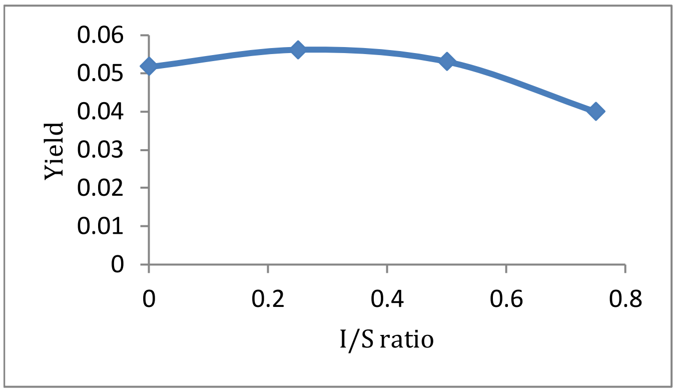

Fig. 12: Effect of I/S ratio on biogas yield

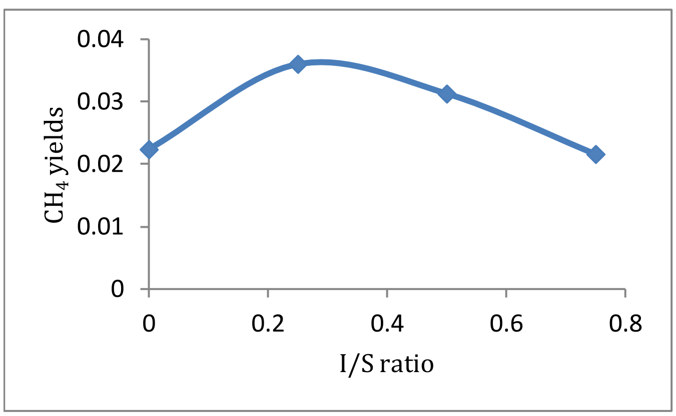

Fig. 13: Effect of I/S ratio on methane yield

Effects of inoculum dosage on biogas and methane yield

As mentioned earlier, the inoculum-to-substrate ratio I/S affects both the gas and methane yields. It is evident that at a certain concentration of the rumen's content, the rumen's content becomes counterproductive to the bioprocess. These effects are more pronounced when the methane yields are plotted against the I/S ratio as seen in Figure 12 and Figure 13 for the biogas and methane yields respectively. Although the 50% biostimulant had close competition with the 25% biostimulant, we can see a gradual decline beyond the I/S ratio of 0.25. The severity increases as the I/S ratio increases. This observation is consistent and agrees with that obtained by Ihoeghian et al. (2022). However, in their investigation, the 50% equal blend gave the maximum cumulative biogas yield of $0.32052 l/gVS$. Similarly, others such as Bello *et al.,* (2015) also observed a general decline in biogas production as the inoculum dosage increased. In previous studies where cow dung was used as inoculum, Pathak and Srivastava (2020) witnessed a decline beyond the certain optimum inoculum dosage. It suffices to say that from the current study, at a certain concentration of the cattle rumen content, the bio-stimulant becomes inhibitory. Hence, digestion must be done within an acceptable dosage to have optimal results.

CONCLUSIONS

Apart from knowing the necessity for inoculation, the problem of percentage dosage is equally important. In the effect of I/S dosage, it was found that the 25% bio-stimulation gave the best result in terms of both biogas and methane yield, followed by 50% and then 75%. The poorer performances of higher concentrations of the other inoculums were attributed to inhibition. We can conclude that while inoculation is necessary for the digestion of food waste, it must be done in the right proportion to avoid inhibition.

DECLARATION OF COMPETING INTEREST

The authors declare no competing financial interest.

REFERENCES

Aboelwafa, A., Alwasify, R., 2009. Biodegradation of crude oil using local isolates. Australian Journal of Basic Applied Sciences 3, 4742-4751.

Adebusoye, S.A., M.O. Ilori, Amund, O.O., Teniola, O.D., Olatope, S.O., 2007. Microbial Degradation of Petroleum Hydrocarbons in A polluted Tropical Stream. World Journal of Microbiology and Biotechnology 23, 1149-1159.

Adelekan, A.B., Bamgboye, A.I., 2009. Effect of Mixing Ratio of Slurry on Biogas Productivity of major Farm Animal Waste Types. Journal of Applied Biosciences 22, 1333-1343.

Argaw, T., Andargie, M., Gessesse, A., 2013. Co-digestion of Cattle Manure with Organic Kitchen Waste to Increase Biogas Production using Rumen Fluid as Inoculum. International Journal of Physical. Science 8(11), 443-450.

Asante-sackey D., Tetteh, E.K., Nkosi, N., Boakye, G.O., Ansah Amano, K.O., Boamah, B.B., Armah, E.K., 2018. International Journal of Hydrology 2(5), 567-571.

Atlas, R.M., 1981. Microbial Degradation of Petroleum Hydrocarbons: an Environmental Perspective. Microbiology Review 45(1), 180-209.

Bagudo, B.U., Garba, B., Dangogo, S.M., Hassan, L.G., 2011. The Qualitative evaluation of Biogas Samples Generated from Selected Organic Wastes. Arch. Applied Science Resources 3(5), 549-555.

Bello, Y.O., Olugbemide, A.D., Adeogun, O., Bello, M.B., 2015. African Journal of Hospitality, Tourism and Leisure. 4(1), 1-9.

Bento, F.M., Camargo, F.A.O., Okeke, B.C., Frankenberger, J.W.T., 2005. Diversity of Biosurfactant Producing Microorganisms Isolated from Soils Contaminated with Diesel Oil. Microbiology Resources 160, 249-255.

Biogas World, 2022. Biogass. Retrieved from: https://www.biogasworld.com/biogas-faq/[Accessed May 28, 2022.

Ihoeghian, N.I., Amenaghawon, A.N., Ajieh, M.U., Oshoma, C.E., Ogofure, A., Erhunmwunse, N.O., Edosa, V.O., Tongo, I., Obuekwe, I.S., Isagba, E.S., Emokaro, C., Ezemonye, L.I.N., Lag-Brotons, A.J., Semple, K.T., Martins, A.D., 2022. Anaerobic Co-digestion of Cattle Rumen Content and Food Waste for Biogas Production: Establishment of Co-digestion Ratios and Kinetic Studies. Bioresource Technology Reports 18, 101033.

Kong, J.D., 2017. Modeling Microbial Dynamics: Effects on Environmental and Human Health. University of Alberta, Canada. https://doi.org/10.7939/R3FT8DZ73 [Accessed March 14, 2022].

Krishna, K. M., Verma, A. K., Srivdya, A., Papic, L., 2010. Integration of Black-Box and White-Box Modeling Approaches for Software Reliability Estimation. International Journal of Reliability, Quality and Safety Engineering 17(3), 100 – 110.

Li, R., Chen, S., Li, X., Lar, J. S., He, Y., Zhu, B., 2009. Anaerobic codigestion of kitchen waste with cattle manure for biogas production. Energy Fuels 23, 2225–2228.

Li, X., Li, L., Zheng, M., Fu, G., Lar, J. S., 2009. Anaerobic co-digestion of cattle manure with corn stover pretreated by sodium hydroxide for efficient biogas production. Energy Fuels 2009, 23, 4635–4639.

Mohamed, A.A., J., Mohan, S., Velayutham, T., Sankaran, S., 2016. Comparative Study of Biogas Production from Municipal Solid Waste using Different Inoculum Concentration on Batch Anaerobic Digestion. Asian Journal of Engineering and Technology 4(4), 1-8.

Momoh, O.L.Y., Nwagozie I.L., 2008. Effect of Waste Paper on Biogas Production from Co-digestion of Cow Dung and Water Hyacinth in a Batch Reactor. Journal of Applied Science and Environmental Biology 12(4), 95-98.

Nwankwo, J.I., 2014. Production of Biogas from Waste Paper Blended with Cow Dung. IOSR Journal of Environmental Science, Toxicology and Food Technology 8 (10), 58-68.

Obara, N., Ishida, M., Hamada-Sato, N., Urano, N., 2012. Efficient bioethanol production from paper shredder scrap by a marine derived Saccharomyces cerevisiae C-19. Studies in Science and Technology 1(2), 1-11.

Ofoefule, A.U., Nwankwo, J.I., Ibeto, C.N., 2010. Biogas Production from Paper Waste and its Blend with Cow Dung. Advances in Applied Science Research 1(2), 1-8.

Ogur, E.O., Mbatia, S., 2013. Conversion of kitchen wastes into Biogas. International Journal of Engineering and Science 2(11), 70-76.

Ojikutu, A.O., Osokoya, O.O., 2014. Evaluation of biogas production from food waste. International Journal of Engineering and Sciences 3(1), 1-7.

Olawole, A., 2022. FCTA: Satellite Towns Waste Removal Costs N8bn Annually. Retrieved from https://www.thisdaylive.com/index.php/2021/08/03/fcta-satellite-towns-waste-removal-costs-n8bn-annually/ [Accessed July 25, 2022]

Onwuliri, F.C., Onyemba, I.A., Nwaukwu, I.A., 2013. Generation of Biogas from Cow Dung. Journal of Bioremediation and Biodegradation 18, 1-3.

Pathak, J., Srivastava, R.K., 2020. Determination of Inoculum Dose for Methane Production from Food Industry Effluent. Journal of Industrial Pollution Control 23, 49-54.

Visit us at: http://bosaljournals.com/chemint
Submissions are accepted at: editorci@bosaljournals.com