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Research Article

Preliminary Observation of Biogas Production from a Mixture of Cattle Manure and Bagasse Residue in Different Composition Variations

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Abstract. The need of renewable energy is paramount important as it is expected to replace fossil energy. One of renewable energy commonly used for rural area is biomass-based energy. Biogas is a biomass-based energy where organic materials are converted to methane gas via anaerobic digestion process. The limitations of mono-feedstock biogas are instability digestion process, low yield biogas produced and require readjusting C/N ratio, therefore co-digestion process was proposed to overcome these problems. This study aims to investigate the feasibility of anaerobic co-digestion of a mixture of cattle manure and bagasse residue in different weight ratio combinations. Biogas was generated by anaerobic digestion using a mixed substrate composed of a combination of weight ratios of bagasse:cattle manure (1:5, 1:2, 1:1, and 3:1). The kinetic analysis was evaluated by fitting Gompertz and Logistic model to experimental data of cumulative biogas. The result showed that the combination of 1:5 ratio of bagasse waste to cattle manure obtained the best biogas yield with cumulative biogas at 31,000 mL. The kinetic model of Gompertz and Logistic were able to predict the maximum cumulative biogas at ratio of 1:5 (cattle: bagasse) at 31,157.66 mL and 30,112.12 mL, respectively. The other predictions of kinetic parameters were maximum biogas production rate (Rm)= 1,720.45 mL/day and 1,652.31 mL/day for Gompertz and Logistic model, respectively. Lag periods were obtained at 2.403 day and 2.612 day for Gompertz and Logistic model, respectively. The potential power generation of 338.71 Watt has been estimated from biogas. This research has proven a positive feasibility of co-digestion of two feed-stocks (cattle manure and bagasse) for biogas production.

Keywords: Anaerobic co-digestion, bagasse, Gompertz model, Logistic model, biogas, cattle manure

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1. Introduction

Biogas is biomass-based energy sources which derived from anaerobic digestion process. The biomass sources can be gained from food production waste, agricultural production wastes, and animal production wastes (Buraczewski 1989; Atelge *et al,* 2020). Moreover, organic resources in the form of vegetable waste, fruit trash, home garbage, restaurant waste, and animal excrement may also be utilized to produce biogas (Harlia, Diaz, & Kurnani 2017).

Biogas is produced through anaerobic digestion which consists of four successive phases: Hydrolysis, Acidogenesis, Acetogenesis, and Methanogenesis. In Hydrolysis stage, some complex polymers are converted into simpler polymer. Acidogenesis stage consists of the monomers breakdown to form short-chain organic acids. Acetogenesis is a stage where acetogenic bacteria from the slurry will consume the dissolved oxygen generated from acidogenesis process. In the last stage (methanogenesis), methanogenic bacteria convert acetic acid to methane and carbon dioxide under anaerobic conditions (Anukam *et al.*, 2019).

The cattle population in Indonesia is currently about 16.6 million heads and will produce manure 400,000 tons/day (Agus and Widi. 2018). For years, cattle manure has been used as a natural agricultural fertilizer, however, the waste from cattle agriculture lead to environmental issues. Therefore, the processing cattle manure to biogas is one of alternative to mitigate this environmental issue. Biogas produced from cattle manure saves 63.5 TWh of energy (Baek *et al.* 2020).

Commonly, biogas is generated from anaerobic digestion (AD) of mono-feedstock (Ichsan *et al*, 2014). However, some limitations are discovered by using this mono-feedstock biogas production such as low biogas yield (Zahan *et al.*, 2018), feedstock availability (Karki *et al.*, 2021), require adjusting (C/N)

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ratios and poor microbial diversity (Kaur and Kommalapati, 2021). To overcome these limitations, one of alternative technologies is via Codigestion of multiple feedstocks (Okonkwo *et al,* 2018; Jaml *et al*, 2020; Taghinazhad *et al* 2017). Previous studies showed the positive result of this codigestion process. Awosusi *et al.* (2021) have studied the co-digestion of animal manure and kitchen waste for biomethane production and revealed that ratio of 3:1 of kitchen waste to animal manure was an optimum for biogas production during 30 days of digestion. A co-digestion of feed mixture of cow dung and horse dung has been successfully investigated by Alfa *et al.* (2020) and the highest daily biogas production was recorded at a feedstock mix of 25% cow dung and 75% horse dung. Oladejo *et al.* (2020) reported the biogas production potential of cow dung, food waste and piggery dung in a co-digestion experiment and the highest cumulative biogas production was obtained when all three feedstocks were co-digested for 30 days. Anaerobic Co-digestion of water hyacinth (*E. crassipes*) with ruminal slaughterhouse waste has been also investigated by Omondi *et al* (2019) and they reported thatCo-digestion with 30% RSW at 24°C improved biogas yield by 75% from 8.05 to 14.09 L/kg biomass.

As the abundant amount of cattle manure in Indonesia, therefore, the biogas production is one of interesting strategies to reduce its environmental impacts. However, there are some limitations and one of which are, cattle manure has C/N ratio of 5-8, which need to be upgraded to reach optimum C/N ratio level (C/N=15-30) (Baek *et al.* 2020). Since Indonesia has also many sugar industries, the bagasse trash is abundantly produced after extraction of juice and it is almost 25% of the total processed sugarcane. Bagasse is a lignocellulosic material with a substrate that is quite complex due to the presence of lignin, polysaccharides, extractive chemicals, and other organic compounds and therefore it could be used as an enhanced alternative/additive for production for biogas generation using anaerobic digestion (Raposo *et al,* 2009). The presence hard biodegradable materials in lignin make it a potential source for anaerobic digestion either pre-treating it or co-digestion with other organic waste. The aim of this study was to produce biogas from anaerobic co-digestion of mixture of cattle manure and bagasse residue. The Gompertz and Logistic equations were used to predict the trend of cumulative biogas in digester.

2. Material and Methods

2.1 Pre-treatment of cattle manure and bagasse residue

In this work, anaerobic fermentation under mesophilic conditions was used to examine the biogas generation from cattle manure and bagasse waste. Four different weight ratios of bagasse residue:cattle manure were examined (1:5, 1:2, 1:1, and 3:1) and incubated for 28 days. The created digestate was in the form of slurry. The bagasse waste was dried until all of the water evaporated and then crushed using a grinding machine. The mixture of cattle manure and bagasse trash were then weighed at a necessary ratio in a total amount of 2 kg.

2.2 Biogas Production

The experiments were carried out in a batch digester of 1 L capacity glass bottles with 500 mL effective volume. The batch reactor were kept under ambient conditions for further study. Each batch reactor was initially inoculated with mixture of cattle manure and bagasse residue. The volume of biogas produced was measured by water displacement method.

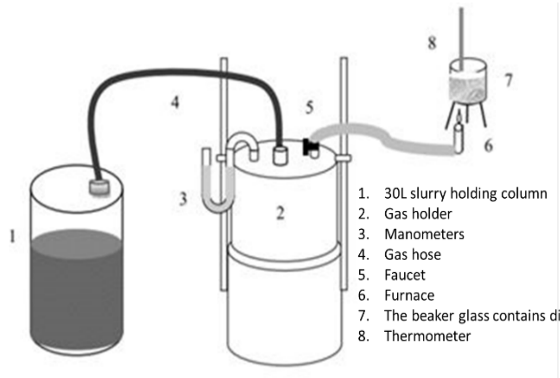

Fig. 1 Experimental set-up of biogas production from cattle manure

2.3 Biogas quality analysis

The actual pressure was determined in the digester during the fermentation process using a manometer. The absolute pressure of the biogas was then determined and the quality of the biogas was evaluated for their colour during burning of biogas. In this burning evaluation, 100 mL of 40°C water was heated with biogas until the gas ran out and the time was monitored. The temperature differences was used to calculate the power produced by the biogas by using the following equation (1) and (2):

$$Q = P\ x\ t \tag{1}$$

$$m\ x\ Cp\ x\ \Delta T = P\ x\ t \tag{2}$$

Where m is the water mass (kg), Cp is specific heat capacity (J/kg°C), ΔT is temperature difference (°C), P is power (watt). And t is time (s).

2.4 Kinetics analysis

The kinetics of fermentation were determined using the Gompertz technique and Logistic model. Both models were evaluated for three parameters including the period of the lag phase, the maximum biogas production rate, and the potential biogas yielded (Azka 2019). The form of the Gompertz and Logistic equations is described by Eq 3 and 4:

$$Y(t) = Y\ \cdot exp\left[-\exp[Rm \cdot \frac{e}{Y}(\lambda - t) + 1]\right] \tag{3}$$

$$Y(t) = \frac{Y}{1+exp\left[4\cdot\frac{Rm}{Y}(\lambda-t)+2\right]} \tag{4}$$

Where Y(t) is cumulative biogas (mL), t is fermentation time (day),Y is yielded biogas potential (mL), λ is lag phase (day) and Rm is maximum biogas production rate (mL/day).

3. Results and Discussion

3.1 Biogas production analysis

Figure 2 shows the daily volume biogas produced from the co-digestion of cattle manure and bagasse residue for 28 days retention time. For all ratio with larger cattle manure composition, the biogas can be immediately produced, while the larger portion of bagasse will inhibit the biogas production. Consequently the production of biogas with 3:1 (bagasse:cattle manure) ratio has long lag period. Figure 2 also shows that the production of biogas tends to decrease after 12 days with maximum of 2000 mL for substrate with 1:5, 1250 mL for ratio 1:2 and 1050 mL for ratio 1:1. The ratio of bagasse:cattle manure 3:1 resulting 1900 mL, however, occur after 25 days of fermentation. These phenomena might be due to the attribution of the positive synergetic effect of the co-digestion of bagasse and cattle manure in providing more balanced nutrients, increased buffering capacity, and decreased effect of toxic compounds (Aragaw *et al*., 2013). This was also induced by the ratio of bagasse waste composition to cattle manure composition that was set. Bagasse waste contains hard biodegradable materials; thus, cattle manure plays role to provide components to anaerobic microbial for the decomposition. Therefore, the inclusion of cattle manure may increase the work of anaerobic bacteria to decompose substrate components, leading to speeding up the biogas generation process. Consequently, the amount of biogas generated also increased (Harlia *et al.* 2017). This is also shown by the trial with ratio of 3:1 which has the lowest biogas volume build-up because bagasse has a greater content than cattle manure and therefore difficult to be decomposed (Rubner *et al.* 2019; Suwannarach *et al.* 2022).

Figure 3 shows the cumulative volume biogas produced from mixture of cattle manure and bagasse within the retention period 28 days. For biogas produced in ratio of 3:1 (bagasse:cattle manure) produced for the first 11 days because it takes more time for bagasse to decompose after which gas is being produced. This is predicted because biogas production rate in batch condition is directly equal to specific growth of methanogenic bacteria (Nopharatana *et al.,* 2007). This can also be traced to the fact that most bagasse contains fibrous materials and microorganisms require a longer time to degrade fibrous materials. The maximum cumulative biogas for 1:5, 1:2,1:1 and 3:1 are 31,000 mL, 14,200 mL, 8,600 mL and 15,000 mL, respectively.

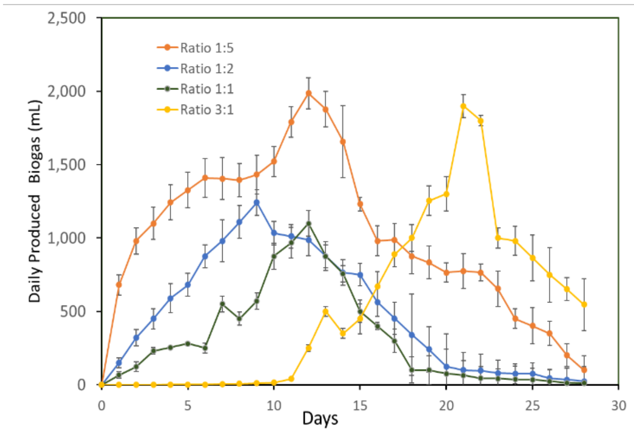

Fig. 2 Daily biogas production during 28 days incubation for different ratio variation of bagasse: cattle manure

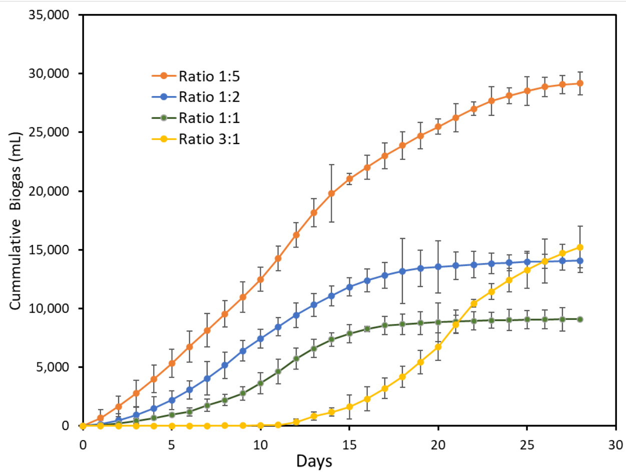

Fig. 3 Cumulative biogas production during 28 days incubation for different ratio variation of bagasse: cattle manure

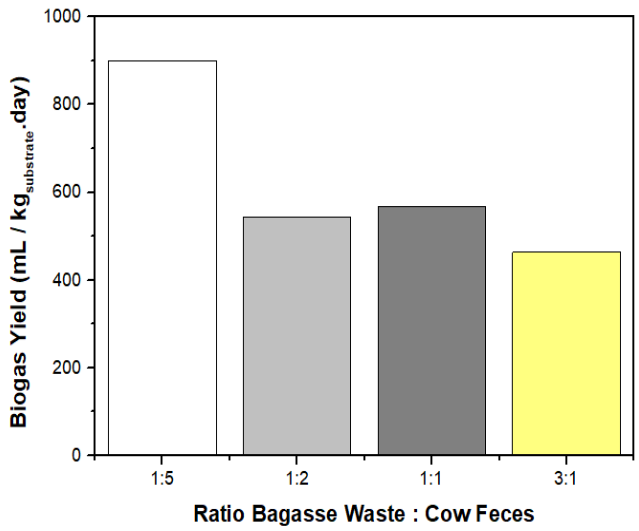

Fig. 4 The biogas yield from different bagasse residue:cattle manure ratios

The increase in bagasse concentration will improve the biogas production, however, the it takes longer time for the production. Larger portion of cattle manure will increase the ability of digestion by bacteria (Rubner *et al.* 2019). It can easily go through the cycle of anaerobic microbial stages quickly and produce more biogas (Rabii *et al.* 2019). In this study, increasing the proportion of bagasse waste in the feedstock decrease the biogas yield 899.17 to 463.45 mL/$kg_{substrate}$.d during anaerobic digestion (Figure 4).

Table 1
Analysis of the power of the biogas produced

Ratio	Heat properties			
	ΔT (°C)	t(s)	P(Watt)	Flame
1:5	5	31	338.71	Blue
1:2	3	19	331.58	Yellow
1:1	3	20	315.12	Yellow
3:1	2.5	16	328.13	Yellow

3.2 Biogas quality analysis

The quality of the biogas in term of flame test and its potential generated power are shown in Table 1 and Fig 5. The quality of the biogas was evaluated on the final day of incubation, which was 28th day. The biogas flame test study was conducted by connecting the stove to the biogas storage reactor through a hose. It was discovered that biogas with a variation in composition of 1:5 creates a blue flame (indicating high caloric value), but biogas with variations in composition of 1:2, 1:1, and 3:1 produce a yellow flame (low caloric values). In addition, according to our observation, none of these biogas combinations emit an unpleasant odor.

The biogas produced mainly contains methane gas (CH_4). The flame was caused by a combustion reaction by CH_4 gas as shown by equation (5). The complete combustion reaction of CH_4 gas produces carbon dioxide gas and water vapor (H_2O) (Kusuma 2017).

$$CH_4 + O_2 \rightarrow CO_2 + H_2O \quad (5)$$

The purity of CH_4 produced from the biogas formation process is a very important consideration, this is because it affects the calorific value (heat) produced. The presence of CO_2 in biogas is very undesirable, this is because the higher CO_2 content in the biogas, the lower the calorific value of biogas. The study showed that a small amount of CO_2 causes a flame colour in the stoichiometric mixture which is blue. This indicates that the combustion is complete. Meanwhile, with the presence of more CO_2 levels, by 25% and 50%, the colour of the fire turns yellowish. This shows that combustion occurs incompletely (Akhtar *et al.*2018). In this study, it was found that the variables 1:2, 1:1, and 3:1 produced a yellowish flame, so it can be concluded that these three variables had less CH_4 content than the 1:5 variable, which produced a blue flame.

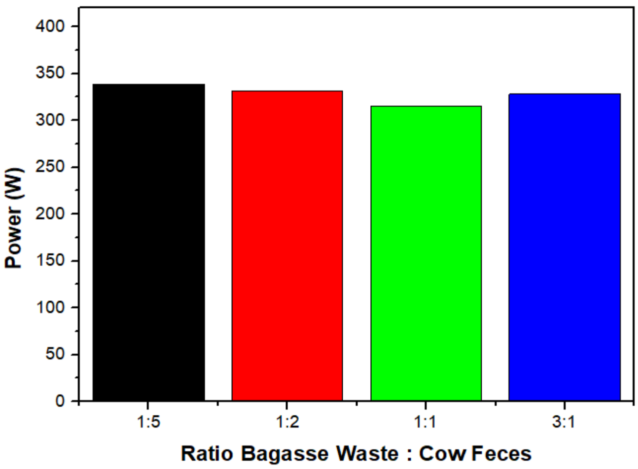

Fig. 5 The power of biogas produced

CH_4 gas can produce fire/heat if its concentration has at least 54% in the biogas produced (Silva *et al.* 2021). From this statement, it was found that the four variables had gone through the methanogenesis stage which is the last stage in the formation of biogas and had sufficient CH_4 content to carry out the combustion reaction. The methanogenesis stage has the following reactions as shown in equation (6) and (7) (Sriharti *et al.* 2018):

$$CH_3COOH \rightarrow CH_4 + CO_2 \quad (6)$$

$$CO_2 + 4H_2 \rightarrow CH_4 + H_2O \quad (7)$$

These three variables produce a yellow flame because the methanogenesis stage imperfectly took place, resulting in less CH_4 and more CO_2.

3.3 Fermentation kinetics analysis

Gompertz models and Logistic models were applied on the experimental results of biogas production to predict and estimate the kinetic coefficients for anaerobic digestion of cattle manure and bagasse residue as substrates. The experimental data and predicted values of the kinetic coefficient estimated using both models were reported in Table 2. Fig. 6(a-d) shows the plot of the experimental and modelled values of the biogas produced using GM and LM models. Results indicate that the biogas produced experimentally were well supported using Gompertz and Logistic model as insignificant deviation observed in experimental and modelled values. The predicted biogas from Gompertz models shows a higher correlation coefficient, than Logistic models indicating that the Gompertz model fitted better than Logistic models.

Three parameters were evaluated by using both models and indicated that the lag period (λ) of biogas production with ratio of 1:5 is shortest than other variables. This indicates that larger proportion of cattle manure leads to easy adaptation to new fermentation conditions (Bertranda *et al,* 2019). In addition, the maximum biogas produced (Y) was also highest among the others. The production rate of biogas (Rm) with ratio of 1:5 is the highest followed by bagasse:cattle manure ratio of 3:1, 1:2 and 1:1.

Biogas produced by ratio of 3:1 shows longer lag period which indicating the microbes need longer adaption time. In this lag phase, the bacteria are in the process of acclimatization to environmental conditions (Rabii *et al.* 2019). Bagasse waste acts as a source of nutrients for anaerobic microbes to form biogas. Bagasse residue as a nutrient contains elements C, N, P, and K (Wea *et al.* 2020). Microbes need source of carbon and energy sources which can be derived from substrate. This explains that the increasing bagasse portion will increase the potential constants for the formation of biogas -Y (Zieliński *et al.,* 2019; Tian *et al.* 2018).

Table 2
Model parameters of Gompertz and Logistic models as result of fitting to the experiment data

Ratio	Gompertz				Logistic			
	Y (mL)	λ(day)	R_m(mL/day)	R^2	Y (mL)	λ(day)	R_m(mL/day)	R^2
1:5	31,157.66	2.403	1,720.45	0.997	30,112.12	2.612	1,652.31	0.897
1:2	14,407.33	3.484	1,175.12	0.993	13,960.51	3.986	1,205.22	0.893
1:1	9,310.68	5.521	921.82	0.895	9,280.19	5.631	920.56	0.976
3:1	18,719.83	14.778	1,384.35	0.970	15,825.29	15.522	1,565.02	0.910

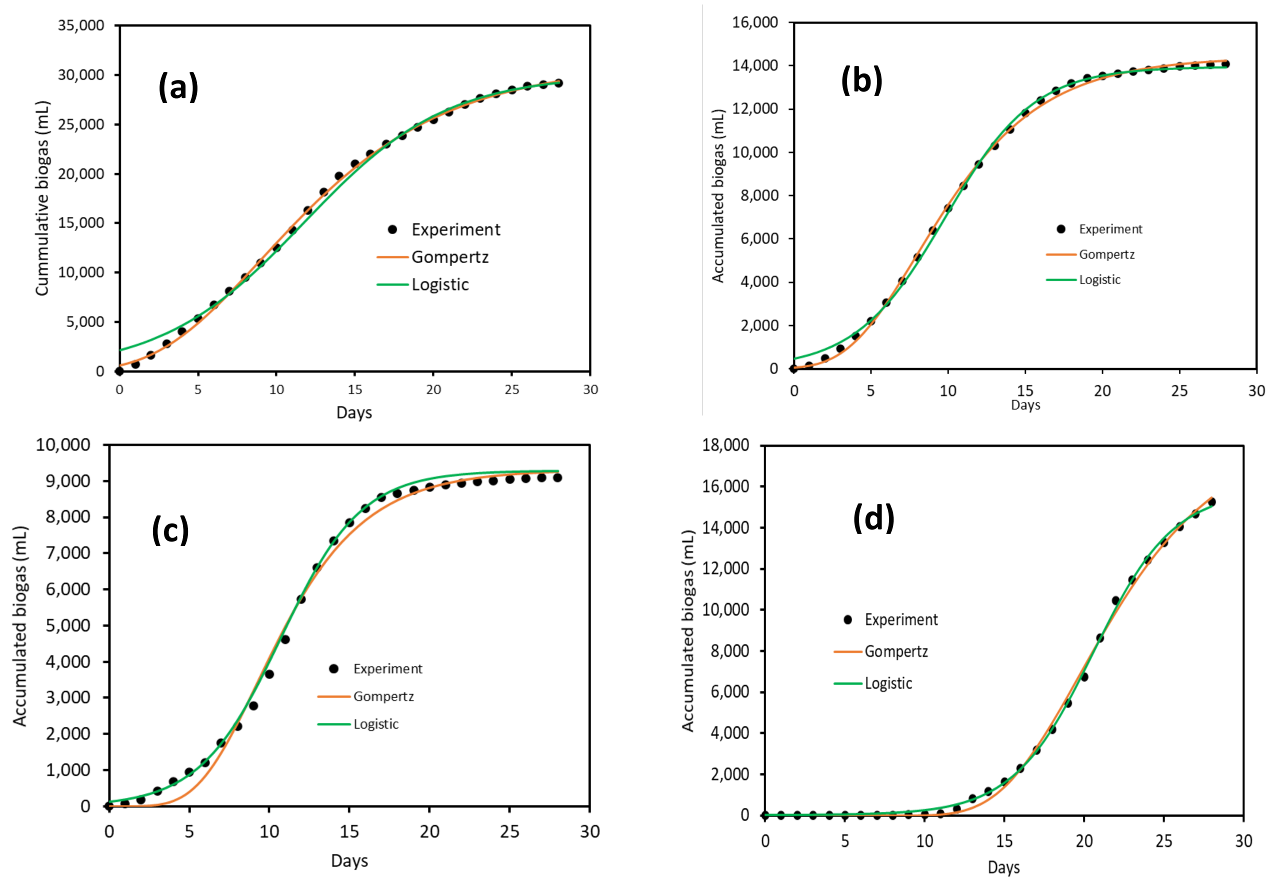

Fig. 6 The kinetic prediction using Gompertz and Logistic models of each variation (a) Ratio 1:5, (b) Ratio 1:2, (c) Ratio 1:1 and (d) Ratio 3:1

4. Conclusions

This study has investigated co-digestion of cattle manure and bagasse residue in four variations of concentration to produce biogas during 28 days fermentation time. It is concluded that ratio of 1:5 (bagasse residue:cattle manure) resulted highest biogas yield and best quality of heating value and power. The potential power generated from this biogas was 338.7097 Watts. Experimental results were well supported using Gompertz and Logistic models for cumulative biogas generation since no deviation observed in modelled and experimental values. The ratio of 3:1 showed longer lag period as it has larger portion of bagasse which have hard components to decompose. All three evaluated kinetic models displayed high R^2 values ($R^2 > 0.900$) for Gompertz model than Logistic model.

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Conflict of interest statement

The Authors declared that there is no conflict of interest with any financial organization regarding the material discussed in the article.

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