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Original Research Article

Predicting the rate of biogas production from the anaerobic digestion of blends of cassava (*Manihot esculenta*) peels with poultry manure

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In this study, blends of cassava peels (CP) with poultry manure (PM) were co-fermented to evaluate the performance and predict the rate of biogas production. The physicochemical characteristics of the bioreactor feeds were estimated by standard methods. Four bioreactors (BR) of 12 L capacity labeled BR_1 – BR_4 were charged with 65 g/L of the feeds in different ratios, giving a final weight of 520 g in 8 L. The fermentation was operated in a batch mode under ambient temperature conditions (25 – 35 °C) for 28 days. The substrates showed good physicochemical characteristics, indicative of their prospects in bioenergy production. The means of cumulative biogas yield (dm^3) were BR_1 2.93 (0.008 dm^3/gVS), BR_2 13.65 (0.04 dm^3/gVS), BR_3 21.44 (0.05 dm^3/gVS) and BR_4 1.10 (0.003 dm^3/gVS). Analysis of variance (ANOVA) indicated a significant difference ($P \leq 0.05$) in biogas yield in all the treatments. Modified Gompertz model gave a suitable description of the kinetics of the anaerobic digestion process, predicting biogas production rate (U), biogas production potential (Y_m), and the lag period (λ). The experimental and predicted data of biogas production were properly fitted, with correlation coefficients (R^2) > 099, which indicates good process performance.

Keywords: Cassava peels, poultry manure, co-fermentation, biogas yield, kinetics.

INTRODUCTION

The over-reliance of economic growth and development of any nation on unsustainable and non-renewable natural resources is a threat to the environment. Recent findings by Greenpeace Southeast Asia and the Center for Research on Energy and Clean Air (CREA) showed that air pollution from burning of fossil fuels (coal, oil, and natural gas) accounts for an estimated 4.5 million deaths each year worldwide, and estimated global economic losses from air pollution caused by combustion of fossil fuel at $2.9 trillion each year, or approximately 3.3 percent of global GDP. In the United States alone, air pollution from burning fossil fuels is linked to an estimated 230,000 deaths and $600 billion in economic losses annually (Schleeter, 2020).

Unguarded exploration and exploitation of carbon-rich natural resources (fossil fuels) have consequently led to excessive emission of greenhouse gas (GHG) and ecological degradation. Mobilizing resources toward a low-emission and climate-resilient development pathway, bioenergy may offer promising and considerable opportunities (UNECA, 2012). Proper management of the numerous types of waste generated from different sectors is very challenging, especially in developing countries (Aliyu, 2017). In Nigeria and many other countries, peels from potatoes, yam, cassava, etc. are abundantly generated from their processing for food and industrial uses, and only small proportion is used as feed for farm animals, the rest are disposed of indiscriminately. Piles of these wastes got rotten with foul odour emanating as a result of fermentation and putrefaction by microorganisms and as such, constituting nuisance with a negative impact on the environment (Adeyosoye et al*.,* 2010).

Cassava is believed to represent the future of food security in some developing countries. It is one of the major root crops produced in sub-Saharan Africa and has been reported to be the highest supplier of carbohydrates among other staple crops and has potential to replace maize completely as an energy source in animal feeds (Morgan and Mingan, 2016). World annual cassava output skyrocketed by approximately 4.6% between 2013 and 2014. The majority (70%) of the world's cassava is produced in Nigeria, Brazil, Indonesia, the Democratic Republic of Congo (DRC), and Thailand. Almost 70% of the estimated total of 13 million hectares of cultivated area in Africa and Asia has cassava growing on it. African countries exported about one ton of cassava as at 2002, but by 2007, out of more than 228 million tonnes of cassava produced worldwide, African countries accounted for 52% and Nigeria produced 46 million tons making it the world's largest producer of cassava. It has been projected that total world cassava utilization would hit 275 million tons by 2020 (Morgan and Mingan, 2016).

The current world average yield of cassava has been on the increase from estimated 240 million metric tons from the year 2010. Within this period, Nigeria alone produced about 42.5 million metric tons which is estimated to be about 18% of total global production, and has increased by 18% of the total global production (Faostat, 2020).

Currently, there is an increase in the campaign and effort to further enlarge cassava production in Nigeria. The implication is generating a large amount of waste considered noxious to the environment due to its content of different organic compounds (Andrade et al., 2016). The huge sum of waste products in form of peels from cassava production and processing calls for the need to design and adopt a system capable of handling the waste accruing from this development and anticipated problems such as unpleasant odour production (Oparaku et al*.,* 2013).

The use of cassava peels as feeds for livestock would help to alleviate the problem of its disposal as waste and likewise reduce the monetary value of livestock production. However, cassava peels as feed for non-ruminant animals are influenced by their hydro-cyanic acid content, which would pose deleterious effects on their growth and development (Otache et al*.,* 2017). Interestingly, anaerobic digestion (AD) and biogas production from cassava peels and other agricultural wastes offer a renewable and sustainable source of alternative energy at low cost compared to fossil fuels and an eco-friendly waste management strategy, the dig estate left after anaerobic digestion is a rich soil conditioner used for the improvement of soil fertility and food productivity.

Given these benefits, therefore, in many countries of the world including Nigeria, there is a kindled interest in the replacement of fossil fuels with biogas as an alternative energy source for domestic, commercial and industrial purposes. This has underscored the need for intensive and aggressive research in anaerobic digestion and bioenergy production to ascertain and develop sets of conditions for maximum biogas production from the readily available organic wastes, including cassava peels. Anaerobic digestion for biogas production has been demonstrated to involve quite complex biochemical reactions and is influenced by several factors. It is affected by different pretreatment methods (Radmard et al., 2018; Wagne et al., 2018; Mishra et al., 2018; Kreuger et al., 2011; Mtui, 2009), temperature, organic loading rate, reactor design, inoculums, C/N ratio, and trace elements (Boontian, 2014; Ebunilo et al., 2015). Besides, it has been shown that trace elements are also required for microbial activities and the structure of enzymes, such as methyl-coenzyme M reductase and the coenzyme M methyltransferase complex (Zhang et al., 2016). Furthermore, the quality of biogas and its cumulative yield is largely dependent on the proximate composition of the feedstock; therefore, one agricultural waste may not be ideal enough to be used singly as feedstock in biogas production. To improve the efficiency of biogas production, improving the characteristics of the feedstock and operating conditions of the digester is therefore required. It has been reported that the co-digestion of two or more feedstocks improves biogas yield than a single feedstock (Sawyerr et al., 2017).

The benefits of anaerobic co-substrate digestion include increased biogas production, enhanced degradation rates etc. The beneficial effects of mixed feedstock majorly lie in balancing the C/N ratio, the nutrient contents of the given organic waste, increasing the pH buffering capacity, decreasing the ammonia toxicity and the accumulation of volatile fatty acids (VFAs) and improving the biochemical conditions for microbial growth (Lu et al., 2017), availability of micro-and macronutrient required by the microbial community, and dilution of inhibitory or toxic compounds. More so, co-digestion may improve the process kinetics rather than the bioavailability of the feedstock (Zamanzadeh et al., 2017). Evaluation of rates of hydrolysis using bio-methane potential (BMP) assays has shown that co-digestion increased hydrolysis rates when food waste and manure were co-digested compared to mono-digestion in BMP assays. The observed synergistic effect was associated with the dilution of inhibitory compounds and improved nutrient balance due to co-digestion (Zamanzadeh et al., 2017). Literature has shown that a number of researchers have evaluated the application of anaerobic digestion as a veritable approach in the waste management of agro-wastes, including cassava peels as feedstock in biogas production, thus converting this waste to energy (Nwankwo, 2014; Olaniyan et al., 2017; Ekop et al., 2019).

Zieliński et al. (2019) conducted a study the effects of nutrients supplementation during codigestion of maize silage and cattle slurry in a batch system for 20 days under mesophilic conditions, and an organic loading rate of 5.0 g VS (volatile solids)/L. The result showed that biogas yield increased with the dose of the cattle feed supplement up to 894 L/kg VS, which was 65% higher than in the control

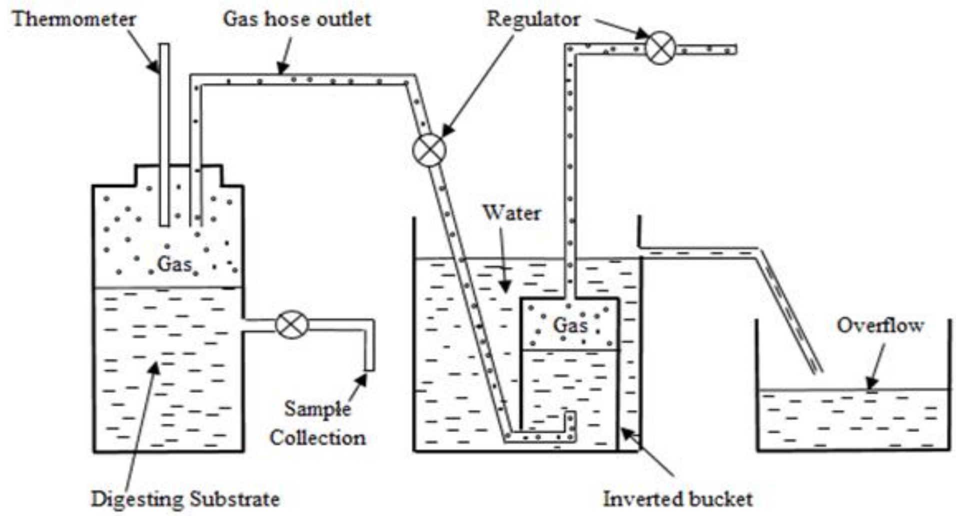

Figure 1: Schematic Diagram of the bioreactor set-up

Source: Opurum et al. (2015).

reactor. In another study, co-digestion of mixtures of cow dung, banana and mango peels for biogas production revealed a significant production of biogas from digester containing mixtures of cow dung, banana and mango peels (Gebrelibanos, 2018).

Oparaku et al. (2013) studied the anaerobic co-digestion of cassava peels with pig dung for methane production, the result showed that the ratio, 30:70 peel/dung had the highest cumulative biogas (78.5 L), the least biogas yield (61.7 L) was obtained from 10:90 peel/dung. Comparative analysis with the control setup revealed there was a blending effect resulting in increased yield in biogas over the sole digestion of cassava peel or pig dung.

Nkodi et al*.,* (2016) investigated the effect of supplementation of cassava peels with different concentrations of urea on bio-digestion for biogas production. The highest biogas (80.79 L/kgTS) yield was recorded in the digester with 0.01% of urea. A cost-effective pretreatment of cassava peels for enhanced biogas production was evaluated by Gopinatthan et al. (2015). They reported that the pretreatment adopted in their work enhanced efficiency of the process 94.15 % compared to the control, and alkaline pretreatment using sodium hydroxide increased biogas production by 11 % compared to the control. To fill in some of the existing gaps in the earlier studies, in this study, we report the prediction of the rate of biogas production from the anaerobic digestion of blends of cassava (*Manihot esculenta*) peels with poultry manure using a modified Gompertz equation.

MATERIALS AND METHODS

The bioreactor feeds used in this study include cassava peels (CP) and poultry manure (PM). The cassava peels were collected from local farmers in Umuagwo, Ohaji LGA, Imo State Nigeria, who are into cassava processing for garri production. The poultry manure was from the farm in the Department of Animal Sciences, School of Agriculture and Agricultural Technology (SAAT), Federal University of Technology, Owerri, Imo State, Nigeria.

Processing of the Bioreactor feeds

The cassava peels (CP) were steeped in water to wash off soil particles and other solid materials while the poultry manure (PM) was sorted to remove unwanted materials. The samples, CP and PM were thereafter sun-dried to a moisture content of 12. 39 and 12.36%, respectively. The dried samples were ground with a milling machine to particle size of 2.0MM, sieved, and were ready for use.

Physicochemical Analysis of the Bioreactor Feeds

The proximate composition of the substrates was determined by the standard methods of AOAC, (2012). The total solids (TS), volatile solids (VS), C/N ratio, organic carbon, moisture content, etc. were estimated.

Experimental Procedures

The bioreactors and the biogas harvesting systems were designed, built, and operated according to the methods described by Opurum et al. (2015), as schematically represented in Figure 1.

Four (4) batch system bioreactors of 12 L capacity labeled BR1 - BR4 were used to conduct the experiments. The prepared bioreactor feeds, cassava peel (CP) was co-

Table 1. Composition of the Bioreactor Content

Bioreactor	Feed Ratio	% Total Solids (TS)	% Volatile Solids (VS)
BR_1	CP/PM 1:1	5.70	4.78
BR_2	CP/PM 2:1	5.70	5.08
BR_3	CP/PM 3:1	5.70	4.94
BR_4	CP (control)	5.70	5.08

Table 2. Physicochemical characteristics of Digester Feeds

Parameters (%)	Cassava Peel (CP)	Poultry Manure (PM)
Moisture content (MC)	12.39	12.40
Ash content	9.48	18.80
Fibre content	21.50	21.10
Nitrogen	2.44	5.60
Fat content	2.59	4.46
Crude protein	15.35	35.00
Organic Carbon	33.25	53.00
Total solids (TS)	87.61	87.64
Volatile solids (VS)	78.13	68.84
C/N ratio	13.63	9.50
pH	5.59	6.38

digested with poultry manure (PM) at three dose ratios: CP/PM1:1; CP/PM2:1, and CP/PM3:1. The bioreactors were charged with 65g/L of the different feeds, giving a final weight of 520g in 8L. Thoroughly mixed slurry of each of the dose ratios was prepared before it was finally fed into each of the bioreactors, occupying 8 L of the reactor volume with a headspace of 4 L (Ojolo et al*.,* 2008). The feed ratios, total solids (TS), and volatile solids (VS) contents (% w/v) of the seeding sludge in each bioreactor are shown in Table 1.

The charged bioreactors were pitched with the earlier prepared inoculum, freshly strained cow rumen liquor, the pH adjusted to 7.5 with NaOH, and the inlets tightly covered to exclude air. The outlet hose of each of the bioreactors was connected to a gas collecting system filled with water. The reactors were subjected to periodic manual agitation to ensure: thorough distribution of substrates, extracellular enzymes, microorganisms and a homogeneous substrate to forestall stratification and surface crust formation. It also helped to promote heat transfer and release of produced biogas from the reactor contents (Jha et al*.,* 2011). Biogas collection was by downward water displacement as described by Chandra et al. (2012). The volume of the displaced water was measured every 24hrs and the volume displaced is equivalent to the volume of biogas produced. The experimental set-up was operated for 28 days hydraulic retention time and was terminated when daily gas production was less than 20 ml. During this period, the daily temperature varied between 25 - 35°C.

Analysis of Data

The means of maximum cumulative biogas production in the different treatments were compared using the Post Hoc Duncan test implemented in IBM SPSS version 20.0 Statistics software.

Biogas Production Kinetics

A modified Gompertz model equation was adopted in this study to simulate the experimental data. This was based on the assumption that biogas production rate in batch mode is equivalent to the specific growth rate of the methanogenic bacteria in the bioreactor (Zhu et al*.,* 2009; Yoon et al., 2014; Budiyono and Siswo, 2014).
The modified Gompertz equation is:

$$Y_t = Y_m.\exp\left\{-\exp\left[\frac{U.e}{Y_m}(\lambda - t) + 1\right]\right\} \qquad (1)$$

Where: Y_t = The cumulative biogas production (dm^3)
Y_m = the biogas production potential (dm^3)
U = the maximum biogas production rate (dm^3/day)
λ = Lag phase period (days)
t = cumulative time for production of biogas (days)
e = mathematical constant (2.718).

RESULTS

Physicochemical Properties of the Bioreactor Feeds

The physicochemical properties of the bioreactor feeds were evaluated to determine the availability of digestible nutrients in the feeds that could be accessed by the bacterial consortia in the course of anaerobic digestion and biogas production. Presented in Table 2 is the proximate

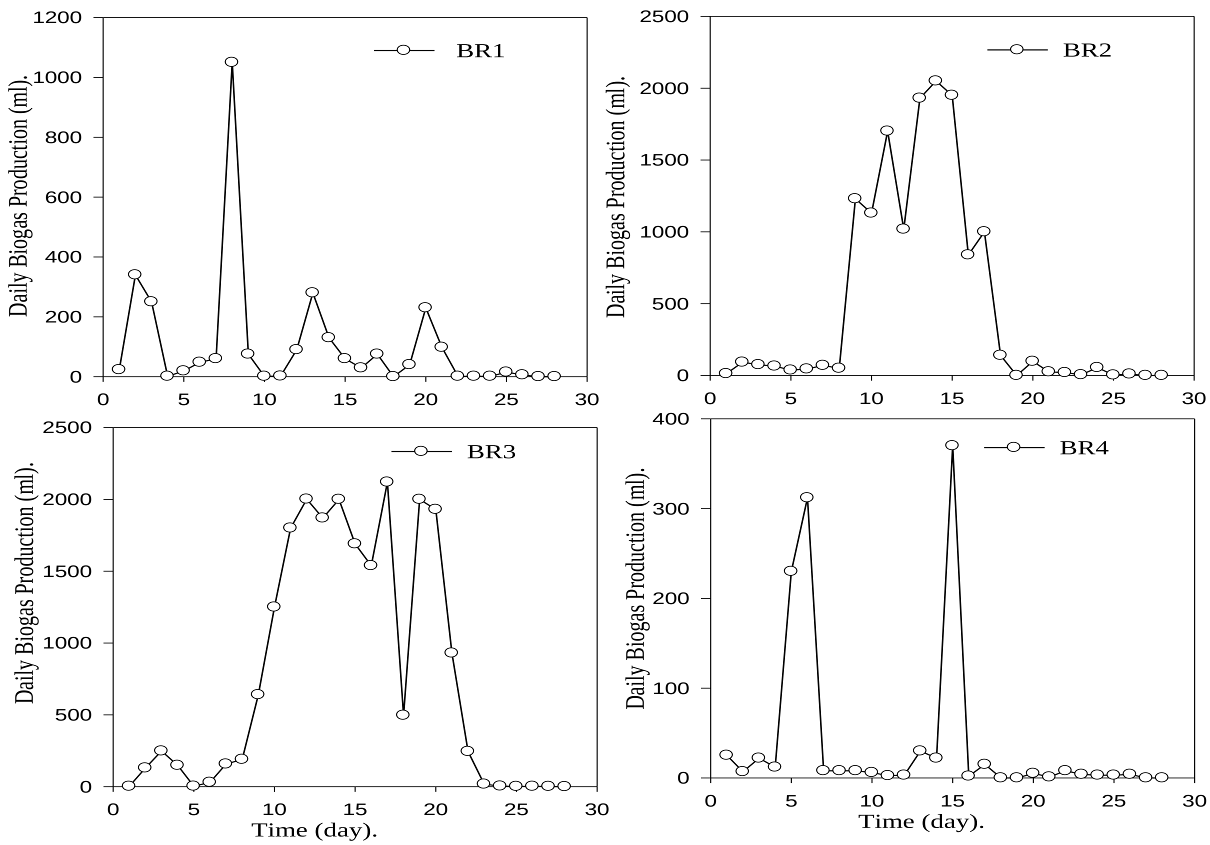

Figure 2: Anaerobic Digestion of the Different Treatments of CP/PM and Daily Biogas Production

composition of the reactor feeds. The C/N ratio of CP and PM is 13.63 and 9.50%, respectively. Though the C/N ratio of cassava peel (13.63) is below the recommended optimum range (20 -30) (Sawyerr et al., 2019; Nsair et al., 2020) it falls in the range of 10 - 20. The total nitrogen content of the poultry manure is 5.60%, 56.43% higher than that of cassava peel. The total solids (TS) and volatile solids (VS) content of CP and PM are sufficiently high (87.61; 87.64 and 78.13 and 68.8%), indicating the suitability of both substrates in biogas production.

Biogas Production

Biogas production started within 24 hrs in all the bioreactors and fluctuated as digestion progressed. In BR_1, the peak of gas production was recorded on the 8th day with 1.05 dm^3 of biogas. It drastically reduced by the 10th day and remained low throughout the remaining digestion period. Plots of the daily biogas production from the different treatments against hydraulic retention time (HRT) are shown in Figure 2. Active biogas production started on the 9th day in BR_2 through the 17th day, the peak was noted on the 14th day (2.05 dm^3). Gas production dropped below 0.1 dm^3 on the 19th day and was zero on the 26th day.

Similarly, in BR_3 active gas production started on the 9th day till the 22nd day, reduced very remarkably on the 23rd day, and stopped on the 25th day. In BR_4, gas production was moderately high on the 6th day (0.31 dm^3), with the peak gas production observed on the 15th day (0.37 dm^3), reduced very remarkably on the 16th day and finally stopped on the 27th day. Flammability check indicated that flammable gas production started on the 8th day in BR_1, 9th day in BR_2, 10th day in BR_2 and 15th day in BR_4.

Cumulative Biogas Yield from the Different Mixed Ratios

The result of the cumulative biogas yield obtained from the experiment (Table 3) indicates that BR_3 had the highest yield (21.443 dm^3), followed by BR_2 (13.649 dm^3) while the least is the BR_4 (1.10 dm^3).

Analysis of Variance (ANOVA)

Comparative analysis of the means of maximum cumulative biogas yield using the Post-Hoc Duncan test showed a significant ($P \leq 0.05$) difference in biogas production in all the treatments.

Kinetic Study

Shown in Figure 3 are plots of experimental data and

Table 3. Cumulative Biogas Yield from the Different Treatments

Treatments	Cumulative Biogas Yield (dm^3)	Cumulative Yield/gVS
BR_1	2.925	0.0077
BR_2	13.649	0.0417
BR_3	21.443	0.0544
BR_4	1.100	0.0027

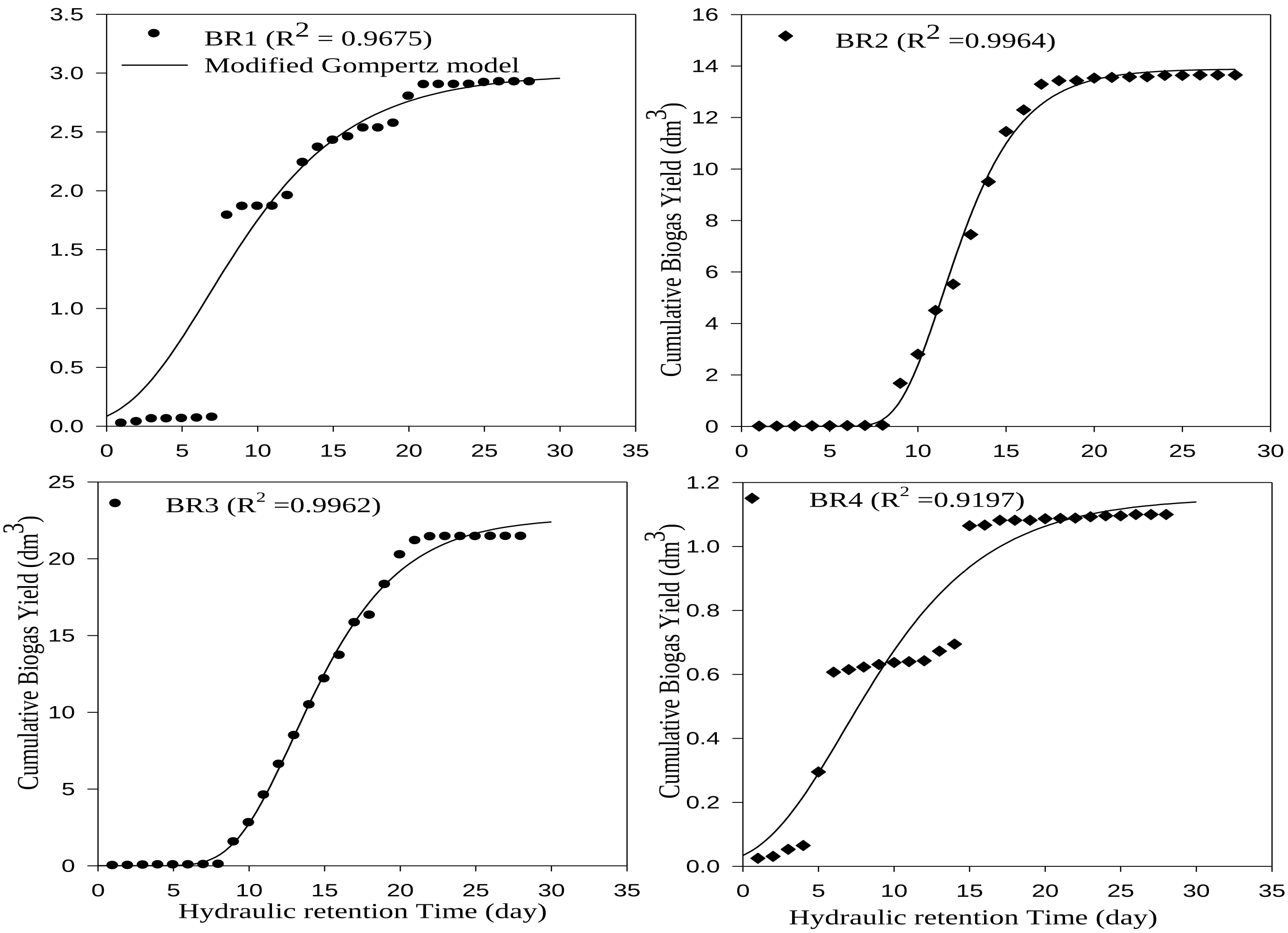

Figure 3: Plots of Experimental Data fitted with Modified Gompertz Model-Predicted biogas Production.

modified Gompertz Model-Predicted biogas Production. The correlation coefficient (R^2) in decreasing order is 0.9964 > 0.9962 > 0.9675 > 0.9197 for BR_2, BR_3, BR_1 and BR_4, respectively.

Table 4 presents the kinetic parameters obtained from the modified Gompertz model. A close similarity between the cumulative biogas yield from the experiment and the predicted biogas production potential (Y_m) using the modified Gompertz model was observed. BR_3 showed the highest biogas production potential (Y_m) of 22.691 ± 0.67 dm^3, maximum biogas production rate (U) of 2.119 dm^3/day. This was followed by BR_2 which was predicted to be 13.901 ± 0.296 dm^3 as the Y_m and U was 2.034 dm^3/day. In the treatment, BR_1 Y_m is 2.992 ± 0.168 dm^3 while U is 0.290 dm^3/day. The lowest cumulative biogas yield was observed in the BR_4 (1.153 ± 0.107) with a maximum biogas production rate (U) of 0.0780 dm^3/day.

DISCUSSION

Agricultural wastes are promising sources of feedstock for anaerobic digestion and biogas production and hold prospects in large scale production of biofuels. The physiochemical characteristics of the cassava peels used in this study, with regards to the total solid (87.61%) and

Table 4. Biogas yield parameters obtained from the modified Gompertz model

Treatment	Ym (dm^3)	U (dm^3)	λ(days)	R^2
BR_1	2.992 ± 0.17	0.290	1.434	0.9675
BR_2	13.901 ± 0.30	2.034	8.876	0.9964
BR_3	22.691 ± 0.67	2.119	8.998	0.9962
BR_4	1.153 ± 0.12	0.0780	1.393	0.9197

moisture content (12.39%), supports the report of Nkodi et al., (2016), with 87.80 ± 0.79 and 12.20 ± 0.79% as the total solid (TS) and moisture content (MC), respectively, but higher in the volatile solid (VS) content (95.98± 0.285%). A higher methane yield has been reported with lower TS in the range of dry and semidry anaerobic digestion. The difference was ascribed to the different moisture content range evaluated. The bioconversion of acids to biomethane by the methanogens can thus be influenced by the lack of water that can occur at a higher TS content in the range of dry and semidry digestion (Liotta et al., 2014).

The C/N ratio of CP (13.60%) falls in the range of 10 - 20 and PM (9.50%); it is, however below the recommended optimum range of 20 - 30 (Sapkota et al., 2018). Carbon to nitrogen (C/N) ratio is one of the important parameters to be give due consideration in anaerobic digestion. When the C/N ratio of a substrate is very high, nitrogen will be rapidly used up by the methanogenic bacteria to meet their protein needs and there will be no more reactions on the remaining carbon content of the material. The Consequence of this condition is low biogas production. Conversely, if the C/N ratio is very low, microbial metabolism will result in excessive liberation of nitrogen which will accumulate in the form of ammonia. Ammonia will increase the pH value of the digester content above 8.5 which starts to exert toxic effect on the methanogens (Ganiyu and Oloke, 2012).

The volatile solids (VS) content of the poultry manure (68.84%) is less than that reported by Patil et al., (2011), with VS content of 83.74%. However, the amount is reasonable enough for anaerobic digestion and biogas production. The proximate composition of digester feeds largely influences the quality and biogas yield. Wastes from Plant materials such as crop residues are not easily digestible as animal wastes because of difficulty in achieving hydrolysis of cellulose, hemicellulose, and lignocellulosic constituents (Bolaji and Adebayo, 2018). The quality of biogas (methane content) and its cumulative yield is largely dependent on the characteristics of the feedstock, as no one agricultural waste may be ideal enough to be used singly as biomass in biogas production (Sawyerr et al., 2019; Nsair et al., 2020). Optimum microbiological activities in anaerobic digestion and improved efficiency in biogas production therefore, requires improving the characteristics of the feedstock and other operating conditions of the digester. This has been achieved by adopting co-substrate fermentation (Tetteh et al., 2018; Sawyerr et al., 2017; Bhatnagar et al., 2017; Divyabharathi et al., 2017).

As could be observed in Figure 1, biogas production in all the treatments started on day 1 though at very low volume and not flammable. A similar observation was reported by Opurum *et al.,* (2019) in which goat manure was co-digested with poultry dropping and plantain peels for biogas production. The possible explanation for this is that many plant residues are not readily digestible, due to the slow rate of hydrolysis of complex polysaccharides and lignocellulosic constituents and hence a remarkable low gas production (Bolaji and Adebayo, 2018). The low biogas production at the early stage of anaerobic digestion is predictable because the rate of biogas production in batch operation is directly proportional to the specific growth rate of methanogenic bacteria in the bioreactor (Nnabuchi et al., 2012.) Unless pretreated, the lignin component of lignocellulosic wastes creates a protective barrier that hinders plant materials from degradation by microbial consortia for conversion to bioenergy (Latinwo and Agarry, 2015).

Analysis of variance (ANOVA) of the means of the cumulative biogas yield indicates a significant difference ($P \leq 0.05$) in all the mixed ratios compared to the control. The highest cumulative biogas yield was recorded in the bioreactor with BR_3 (21.443dm^3). The observed increase in the means of cumulative biogas yield could be attributed to the supplementary effects (synergism) of the nutrient contents of the individual feedstock blended.

Previous studies on co-digestion of different organic substrates have shown a synergic effect of the combined treatments as the biodegradability of the resulting mixture was much higher than that of the single substrates when investigated separately (Esposito et al., 2012). Similar reports on the co-digestion of food wastes with livestock manure such as poultry dropping, cow dung, sewage sludge, or effluent have been shown to improves biogas yield and methane content while mono-substrate digestion was found to be mostly unstable (Ofoefule and Uzodinma, 2009; Awogbemi, and Adeyemo, 2013; Zhang et al., 2013).

Modified Gompertz equation was applied in simulating the experimental data and predicting biogas production rate. The predicted maximum cumulative biogas yield (Y_m) was 2.992 ± 0.17, 13.901± 0.30, 22.691 ± 0.67 and 1.153± 0.12 dm^3 for BR_1, BR_2, BR_3 and BR_4, as against the means of experimental cumulative biogas yield of 2.925, 13.649, 21.443 and 1,100 dm^3, respectively. There is no significant difference ($P \leq 0.05$) between the experimental cumulative biogas yield and that predicted using the modified

Gompertz model.

In the modified Gompertz model, BR_3 showed the highest cumulative biogas yield, of 22.691 ± 0.67 dm^3, which is 38.74% higher than BR_2 (13.901 ± 0.30 dm^3). However, the two treatments exhibited similar biogas production rate (U) of 2.03 and 2.12 dm^3/day for BR_2 and BR_3, respectively, and lag phase (λ) of approximately 9 days. Though the lag phase of BR_1 is low (1.43 days), which may be an advantage, however, the biogas production rate (U) is very poor (0.3 dm^3/day).

The treatments BR_2 and BR_3 showed correlation coefficients (R^2) of 0.9964 and 0.9962 with maximum biogas production rates (U) of 2.03 and 2.12 dm^3/day, respectively. The indication is that the Modified Gompertz model suitably described the methanogenic process in biogas production. The observed result follows the prediction that in batch system operation, the biogas production rate is directly proportional to the specific growth rate of methanogens in the bioreactor (Nnabuchi et al., 2012). This observation aligns with previous reports (Yusuf et al., 2011; Yoon et al., 2014; Latinwo and Agarry, 2015; Yan et al., 2017). A similar report was made by Adamu et al. (2017), in which the rate of biogas production from abattoir waste was predicted using empirical models; the Gompertz model gave better goodness of fit with correlation coefficients of 0.998. The experimental data generated from the treatments in the anaerobic co-digestion of cattle paunch manure and cow dung for biogas production were fitted to the Modified Gompertz model and they showed adequate fit (Chukwuma and Orakwe, 2014). Ismail and Talib, (2014) evaluated anaerobic co-digestion of agro wastes for biogas recovery, the kinetics of the anaerobic digestion process was suitably described by the modified Gompertz model, the experimental and predicted data of biogas production fitted well with correlation coefficient values > 0.96 implying favorable conditions of the process.

CONCLUSION

This study has shown that blending cassava peels (CP), an abundantly available agro-waste with poultry manure (PM) at CP/PM 3:1 and CP/PM 2:1 ratios is capable of significantly improving biogas yield and could be adopted in large scale biogas production for domestic use with proper management of agro-wastes and a concomitant reduction in greenhouse gas emission. Cassava peels and poultry manure are good candidates for 'green energy' production, as suggested by the result of their physicochemical characteristics.

Modified Gompertz model gave a suitable description of the anaerobic digestion process, predicting biogas production rate (U), biogas production potential (Y_m) and the lag period (λ). The modified Gompertz equation adequately fitted into the experimental data with correlation coefficients (R^2) > 099, which indicates a good process performance operated under a set of favourable conditions.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of the paper.

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