Energy Recovery from Anaerobic Digestion of Banana Peels

A'isyah Mardhiyyah Shaharoshaha, Siti Mariam Sulaiman, Roslinda Seswoya

Abstract*: *Bananas are tropical fruits mostly eaten in Malaysia. The banana peels are high in organic, and putrescible caused the odour and leachate problem where it has been a dump. In practice, banana peels considered as a waste product that has been combined with municipal solid waste and dumped into the landfills. However, banana peels are bountiful in organic matter and high with moisture content. Thus, it could be a convincing substrate for biogas production through anaerobic digestion so that the major concerns of environmental protection is achieved aside from producing energy in a sustainable way. Therefore, this study was initiated to estimate the ultimate methane yield from the unripe banana peel (UBP) and ripe banana peel (RBP). Besides that, the assessment on the kinetics of the methane production from UBP and RBP is conducted using Modified Gompertz and first-order kinetic modelling. In this study, the anaerobic digestibility of banana peels measured in a batch reactor for 25 days each fed by UBP and RBP. The batch reactors operated at an inoculum to substrate ratio (I/S) of 1.0 and at a mesophilic temperature (37°C). The ultimate methane yields from UBP and RBP digestion were 847.57mLCH$_4$/gVS and 1405.31mLCH$_4$/gVS, respectively. The higher bioavailability (in term of COD, and solid) in RBP resulted in the higher methane production rate. Two first-order and modified Gompertz kinetic models were compared for the prediction of organic degradation, and the results indicated that the first-order kinetic model of the RBP fitted the experiment best. It concluded that ripe banana peels are the most preferable feedstock for the anaerobic digestion.

Keywords*: *Anaerobic digestion, banana peel, BMP, kinetic, methane production.

I. INTRODUCTION

Generally, bananas are the world's biggest herbaceous plant and ranked the fourth most prominent producer of more than 7 million tons among the ten most important crops produced by conventional cultivating systems [1]. Banana is an edible fruit commonly found in elliptically shaped and universally called as a banana from numerous species of genus Musa. It initially grew in India, Malaysia, and Japan countries. At the same time, the banana trees have broadly grown in Asia and Africa's tropical and subtropical regions. In the old days of human agriculture, this fruit was categorised as the fastest and multipurpose plants grown with only about year-round availability, unlike the other fruit which has a growing season. On account of this, this herbaceous plant plays a major role in the eradication of poverty since the banana production represents an important source of income to the farmers, rural populations, traders and retailers. The banana plant takes about nine months to grow up and produce a bunch of bananas with almost 20 banana fruits grow in hands, and up from 3-20 hands can grow in a cluster at one time in a cycle [2].

Banana ranked second most widely cultivated fruit in Malaysia, and it can be utilised either ripe on unripe [3]. The ripe banana is used for preparing the fried banana and the unripe banana is used for making chips [4]. Having a fried banana during tea time (coffee time in other parts of the world) is common for Malaysian [5]. Therefore, the fried banana stalls are available throughout Malaysia and contribute to an abundant banana peel waste. The banana peels that account for approximately 40% of the total weight of fresh bananas is normally dumped in landfill and resulted in environmental problems [2,6]. Farmers often face the problem of disposal the banana peels since it is generally discarded compared to the other parts of the banana plant that will be processed into different products [7].

Banana peels are organic waste that contains a large number of carbohydrates and basic nutrients that is good for microbial growth [8]. Organic, which is rich in carbohydrate, is preferable for the anaerobic digestion [9]. The utilising of banana peels in the anaerobic digester as the substrate could reduce the waste and save the capacity of landfills [10].

Anaerobic digestion generally defined as a technique of decomposing various organic materials into biogas in the oxygen-free environment through the processes of hydrolysis, acidogenesis, acetogenesis, and methanogenesis. This method is receiving great attention from numerous studies on digestion of municipal organic wastes and residues [11, 12, 13]. Biochemical methane potential (BMP) is a standard test to estimate the biomethane or biogas generated from the targeted substrate in anaerobic digestion [14]. The BMP assay was carried out at an exact temperature with a particular quantity of methanogenic inoculum, and the biogas production was observed until it was insignificant.

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* Correspondence Author

A'isyah Mardhiyyah Shaharoshaha*, Micro Pollutant Research Centre (MPRC), Faculty of Civil and Environmental Engineering, Univesiti Tun Hussein Onn Malaysia, 86400 Parit Raja,Johor, Malaysia. Email: gf180058@siswa.uthm.edu.my

Siti Mariam Sulaiman, Micro Pollutant Research Centre (MPRC), Faculty of Civil and Environmental Engineering, Univesiti Tun Hussein Onn Malaysia, 86400 Parit Raja,Johor, Malaysia. Email: sitimariam6536@gmail.com

Roslinda Seswoya*, Micro Pollutant Research Centre (MPRC), Faculty of Civil and Environmental Engineering, Univesiti Tun Hussein Onn Malaysia, 86400 Parit Raja,Johor, Malaysia. Email: roslinda@uthm.edu.my

Recently, BMP assays were carried out utilising the Automatic Methane Potential Test System (AMPTS II) for rapid and accurate online measurements in conducting batch BMP assays [15].

Meanwhile, several kinetic models were suggested to understand the degradation process and the behavioural prediction of the substrate, as well as to optimise the digestion process and biogas production. However, simulation of the model and the discontinuous anaerobic digestion performed previously were predominantly in accordant with first-order or modified Gompertz models [16]. The first-order models known as the simplest model was applied to estimate the parameter, to improve the understanding of the biological process and predict the behaviour of the biological system in developing the anaerobic system [17]. The modified Gompertz model has been adopted to analyse the production of methane from batch experiments [18,19].

Previously, the anaerobic digestion studies were conducted either for banana wastes as a whole or comparison of several fruit peels without considering the maturity of the fruit or peel [9,20,21]. For instance, Sanjaya *et al.* [12] reported the ultimate methane yield for the ripe banana peel at batch digestibility study under the mesophilic condition that is 342.25mLCH_4/gVS. The study on methane potential and kinetic of banana peels (unripe and ripe) as less documented. Therefore, this study was initiated to estimate the ultimate methane yield and kinetics from anaerobic digestion of ripe and unripe banana peel. Besides, the characteristic of banana peels in term of the complex organic compound was also analysed.

II. MATERIALS AND METHODS

A. Substrates and inoculum

In this study, the fresh samples (substrate and inoculum) were used. The substrates for anaerobic digestibility study were the ripe banana peel (RBP) and unripe banana peel (UBP). The banana peels were collected from Batu Pahat, Johor, Malaysia as shown in Fig.1 and 2. The substrate slurry was prepared; starting with the addition of tap water into the banana peels at a ratio of 1: 1 (banana peels: tap water) followed the procedure as described by Divyabharathi *et al.* [9]. Next, the slurry was ground by a home-used blender for homogenization before use [22].

Fig. 1. Samples of unripe banana peel

Fig. 2. Samples of ripe banana peel

Anaerobically digested sludge was used as inoculum and taken from an existing full-scale anaerobic digester treating palm oil mill effluent (POME) [23,24]. The substrate slurry and inoculum were placed in a cold room at 4°C when it is not in use [25].

B. BMP batch assay

The batch BMP tests were performed through AMPTS II as shown in Fig. 3. The reactor is a 500 mL Duran glass bottles with the active volume of 400mL [26]. The BMP assays were carried out using a mixture of substrate and inoculum in triplicate sample reactors, and duplicate blank reactors filled solely with inoculum in exact mass into the reactors [27,28]. Inoculum to substrate (I/S) ratio of 1.0 was applied [16]. The mass of substrate and inoculum were measured by using VS (in percentage) [23]. The initial pH of mixture and blank were recorded; the pH was observed between 7.2-7.5. These pH values are acceptable for the anaerobic process [22]. Then the reactor was flushed with pure nitrogen gas for two minutes to make an oxygen-free environment in the headspace [10]. Next, the reactor was sealed with a rubber cap and placed into the water bath at a temperature of 37°C [29]. The reactors were agitated at 150 rpm and daily monitored for methane production until it becomes insignificant [21]. The AMPTS II software recorded the data and automatically transferred to a MS Excel™ file for the following analysis and visualisation [27].

Fig. 3. Automatic Methane Potential Test System (AMPTS II) for BMP assay

C. Analytical methods

Samples of UBP and RBP were analysed in term of total solids (TS), volatile solids (VS), alkalinity, pH, carbohydrate, protein, and chemical oxygen demand (COD). TS, VS, pH, alkalinity were evaluated following the standard methods of the American Public Health Association (APHA, 2005) [30]. The COD measurement was based on the HACH 8000 method [31].

Carbohydrate and protein were measured using the phenol-sulfuric method and Lowry–Folin method, respectively [32].

D. Batch kinetic analysis

The first-order kinetics was applied to model the accumulated methane production over time as in Equation (1) and modified Gompertz as in Equation (2) that was commonly used in modelling batch methane production to describe the kinetics of the anaerobic digestion process [18, 26, 27].

$$M = M_o \times [1 - exp(-kt)] \qquad (1)$$

$$M = M_o \times \exp[- \exp\left(\frac{R_m e}{M_o}\right)(\lambda - t) + 1] \qquad (2)$$

Where M is the cumulative methane production at digestion time t (mL/gVS). M_o is the methane production potential (mL/gVS), k is the first-order hydrolysis rate constant (d^{-1}), t is time (h), R_m is the maximum methane production rate (mL/gVS/day), λ refer to the lag phase (days) and e is the Euler's constant (2.7183). The experimental data from the BMP test are used to estimate the kinetic parameter reaction. Microsoft Excel was used to compute all the graph and Excel Solver functional to estimate M_o, R_m, and λ from the graph [33,34].

III. RESULTS AND DISCUSSION

A. Characteristic of substrates

The characteristics of the banana peels were presented in Table I. It was observed that the UBP had low TS and VS compared to RBP. TS and VS of the UBP in this study are smaller than the value stated by Khan *et al.* [20]. TS and VS of the RBP were quite close to the observation by Deressa *et al.*[11]. The VS content of both peels are higher than 75% and this is an indication that the peels are rich in organic solid subsequently is preferable for the anaerobic digestion [35]. The alkalinity of UBP and RBP were 50.00mg $CaCO_3$/L and 116.67mg $CaCO_3$/L, respectively. Pisutpaisal *et al.* [10] reported the alkalinity of banana peels is in the range 1000-5000mg $CaCO_3$/L.

Besides that, the protein was detected in the banana peels with RBP have almost fivefold protein as compared to UBP. Higher protein content could help to increase methane production [13]. In contrast, the carbohydrates in UBP and RBP is slightly different. In general, the carbohydrate is much higher in UBP and RBP.

Table-I: Characteristics of the substrates feed into the batch reactors (N=3)

Characteristics	Substrate	
	UBP	RBP
pH	7.00	7.20
TS (g/L)	60.90	88.43
VS (g/L)	44.62	79.55
VS/TS (%)	73.27	89.96
Alkalinity (mg $CaCO_3$/L)	50.00	116.67
COD (mg/L)	563.33	1841.00
Protein (mg/L)	80.81	400.45
Carbohydrates (mg/L)	222.00	221.10

In this study, the inoculum used was taken from the existing full-scale anaerobic digester treating POME. The characteristics of the inoculum fed into the batch reactors were presented in Table II. The pH of the inoculum obtained was neutral. This condition also was observed from the inoculum taken from the full-scale anaerobic digester [36]. The TS concentration of inoculum was lesser than 30g/L, similar as what was reported by Chan *et al.* [36].

Table-II: Characteristics of the inoculum feed into the batch reactors (N=3)

Characteristics	This study	Chan *et al.* (2010)
pH	7.00	7.40
TS (g/L)	21.10	19.37
VS (g/L)	9.10	-

B. Methane accumulation

The profile of cumulative methane for UBP and RBP during the 25 days assay are presented in Fig. 4 and Fig. 5. The net cumulative methane of UBP and RBP, after subtracting the methane from blank of each substrate was approximately 720mL and 1260mL, respectively. This value is higher compared to the cumulative methane of 612mL from UBP as observed by Pisutpaisal *et al.* [10]. In addition to that, the RBP completed the methane production earlier than UBP (at day 12).

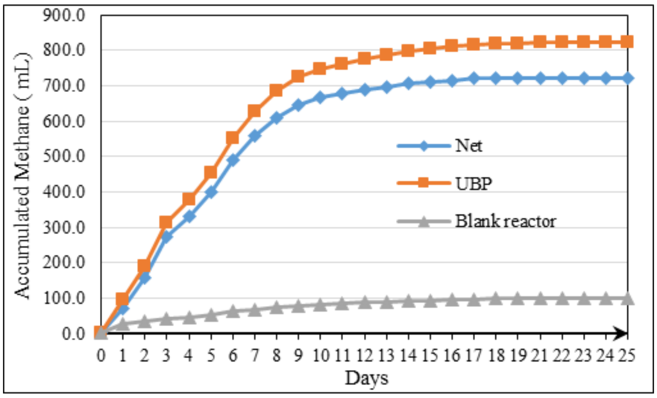

Fig. 4. Methane accumulation from the digestion of UBP

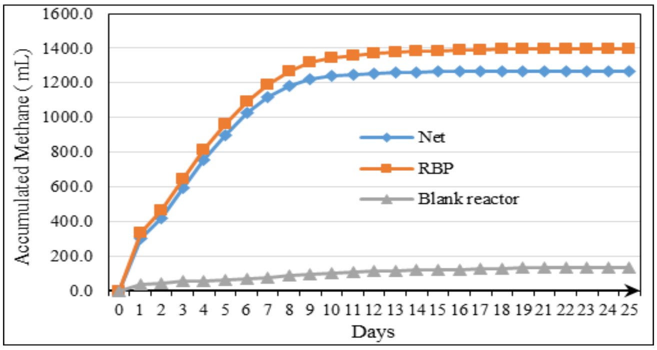

Fig. 5. Methane accumulation from the digestion of RBP

C. Methane production from banana peels

The methane yield curve was plotted from UBP and RBP as shown in Fig. 6. As expected, the methane yield curve from RBP plotted the higher value. However, both substrates start to reach plateau starting on day 10.

No lag phase was observed from the assay in all substrates tested.

The methane production rate of UBP and RBP from the methane yield curve was 102.71mLCH_4/VS/day and 333.96mLCH_4/VS/day.

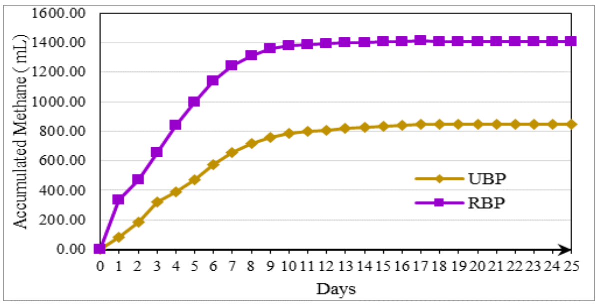

Fig. 6. The methane yield curve of UBP and RBP (average)

Again, the methane production rate of RBP was higher since RBP contained with higher organic matter. The higher ultimate methane yield was monitored from RBP at 1405.31mL CH_4/gVS, which is about 40% more than that of UBP digestion. In other studies, the methane yield obtained from RBP ranged from 331.00 to 351.00 mLCH_4/gVS [12, 20, 21, 37, 38].

D. Kinetics of methane production

In this study, there were two kinetics modelling applied to fit and determine the methane production in a batch anaerobic digestion that was First-order and Modified Gompertz. The experimental results have been reported in Table III and Table IV. Table III summarised the First-Order kinetics model to the digestion fitting results. The methane production potential was expressed as M_o (mL CH_4/gVSd) while k is the first-order hydrolysis rate that represents the speed of degradation [26]. The values of methane production potential (M_o) of the first-order kinetic model from UBP and RBP were higher than the one obtained in the BMP laboratory test.

Table-III: Kinetics parameter of UBP and RBP from BMP and modelling of kinetics first-order

	UBP		RBP	
	BMP	Model	BMP	Model
Methane production potential, M_o (mL CH_4/gVS)	847.57	995.92	1405.31	1471.35
Hydrolysis rate constant, k (d^{-1})	0.13	0.11	0.20	0.22
Coefficient of determination, R^2	0.895		0.910	

Parra-Orobio *et al.* [39], reported that the *k* value in the range of 0.025-0.2d^{-1} for the substrate is rich in carbohydrate. The *k* value from the digestion of UBP is within the range as stated above and UBP had higher carbohydrate. However, the *k* value represents the trend slope of the methane production process, in which a desirable k value is a higher k value that implies a higher degradation rate [16]. Between UBP and RBP, *k* value is higher in RBP, and this is expected because RBP contained higher bioavailability in term of a complex organic compound and solid concentration.

Besides, RBP showed that the best fit to first-order kinetics model with a coefficient of determination 0.91. Khan *et al.* [20], also reported a coefficient of determination of 0.96. In contrast, the fitting between laboratory data and modelling of UBP did not show a good fit. In general, when a coefficient of determination (R^2) is less than 0.9, the data do not give a good fit between laboratory and modelling results [39]. In contrast, the fitting on the laboratory data to modified Gompertz modelling is not fitted well (Table IV).

Table-IV: Kinetics parameter of UBP and RBP from BMP and modelling modified Gompertz

	UBP		RBP	
	BMP	**Model**	**BMP**	**Model**
Methane production potential, M_o (mL CH_4/gVS)	847.57	843.21	1405.31	1411.02
Hydrolysis rate constant, k (d^{-1})	102.71	116.40	333.96	231.73
Lag phase, λ (days)	0.04	0.54	0.04	0.00
Coefficient of determination, R^2	0.8698		0.8947	

The BMP assay of UBP and RBP determined a short lag phase that is 0.04 days. The short lag phase conveys that the soluble material in the substrate was rapidly disposed of by the anaerobic microorganisms [40]. Y. Li *et al.* [17] reported a lag phase of 0.05 days to 0.52 days using modified Gompertz modelling suggested that a short lag phase for the biodegradation of the total solid.

IV. CONCLUSION

The current study was carried out to estimate the ultimate methane yield from the UBP and RBP. The results showed a significant difference in methane yield from the UBP and RBP batch digestion at inoculum to substrate (I/S) ratio of 1.0 under mesophilic condition. From the observation, RBP gave the highest ultimate methane yield at 1405.31mL CH_4/gVS. As a result of this, the maturity of banana peel has greatly affected the ultimate methane yield, hence this kind of waste recommended for anaerobic digestion.

Besides that, the acclimation period is negligibly indicated by the smaller value of the lag phase. In this study, first-order modelling seems to have a better fit for the banana peels than modified Gompertz. Therefore, the modified Gompertz model is not suitable to determine the methane production process for both substrates.

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AUTHORS PROFILE

A’isyah Mardhiyyah Shaharoshaha is a second-year Master of Civil Engineering (MEng) student at the Universiti Tun Hussein Onn Malaysia (UTHM), Batu Pahat Johor, Malaysia. She has completed Bachelor of Civil and Environmental Engineering with honors from UTHM in 2018. Her research interest is anaerobic digestion of organic waste. She has been appointed as a Graduate Research Assistant by the Research Management Centre (RMC) of UTHM to carry out her current research.

Siti Mariam Sulaiman is a third-year Master of Civil Engineering (MEng) student at Universiti Tun Hussein Onn Malaysia (UTHM), Batu Pahat Johor, Malaysia. She has completed Bachelor of Civil and Environmental Engineering with honors from UTHM in 2017. Her research interest is anaerobic digestion of organic waste. She has been appointed as a Graduate Research Assistant by the Research Management Centre (RMC) of UTHM to carry out her current research.

Roslinda Seswoya* is a Senior Lecturer in Faculty of Civil and Environmental Engineering. She graduated in Doctor of Philosophy (Civil Engineering) in the year 2017. Her research interests are wastewater treatment, anaerobic digestion of organic waste, and river management. She has been awarded several fundings from university and Ministry of Education Malaysia. Currently, she is developing the mini digester integrated with automation and the transformation of methane to electric power. Besides, she is collaborating with other researchers in getting the data for suggesting a tool for river management. She is also working together with industry in monitoring the wastewater treatment plant performance.