INTERNATIONAL JOURNAL of RENEWABLE ENERGY RESEARCH
Hasanudin et al., Vol.13, No.2, June, 2023

Improving Biogas Production in Tapioca Industry by Using Onggok as Co-substrate

Udin Hasanudin*, Nadia Dwi Safira*, Fibra Nurainy*, Tanto Pratondo Utomo*, Agus Haryanto**‡

*Department of of Agroindustrial Technology, Faculty of Agriculture, University of Lampung, Jl. Soemantri Brojonegoro #1, Gedong Meneng, Bandar Lampung, INDONESIA 35145

**Department Agricultural Engineering, Faculty of Agriculture, University of Lampung, Jl. Soemantri Brojonegoro #1, Gedong Meneng, Bandar Lampung, INDONESIA 35145

(udin.hasanudin@fp.unila.ac.id, nadiadwisafira@gmail.com, fibra.nurainy@fp. unila.ac.id, tanto.utomo@fp.unila.ac.id, agus.haryanto@fp.unila.ac.id)

‡ Corresponding Author: Agus Haryanto, Jl. Soemantri Brojonegoro #1, Gedong Meneng, Bandar Lampung, INDONESIA 35145, Tel: +62 813 7907 8674,

Fax: +62 721 770 347, agus.haryanto@fp.unila.ac.id

Received: 06.01.2023 Accepted:06.02.2023

Abstract- Onggok or cassava pulp can be explored as a co-substrate for biogas production in a tapioca industry. But, its complex nature needs pretreatment to improve its digestibility, such as delaying time to facilitate hydrolysis-acidogenesis step. The purpose of this study was to determine the best delaying time for hydrolysis-acidogenesis step of onggok-wastewater mixture. The experiment was conducted using a batch reactor with active volume of 1000 mL. Substrate mixture of onggok 10% (w/w) in tapioca wastewater was added with digester sludge as bacteria source at a ratio of 1:4 (substrate mixture : sludge). The delaying time for the hydrolysis-acidogenesis stage was varied from 0 (A), 3 (B), 4 (C), and 5 days (D). For comparison, a control treatment (K) using only tapioca wastewater and sludge was also performed. Biogas production was carried out in duplicate for 20 days. The results showed that biogas production increased by 73.01%, 61.29%, 66.10%, and 46.44% for treatments A, B, C, and D, while total methane increased by 67.42%, 58.73%, 68.83%, and 48.01% as compared to control. Treatment C (4 d delaying time) was found as the best, with an increasing biogas production of 66.10%, and total methane yield of 68.83%, and average methane content of 57.58%.

Keywords Cassava, hydrolysis, methane yield, renewable energy, sustainable.

1. Introduction

Cassava (*Manihot esculenta*) is an important trading commodity in Indonesia and is one of the crops being emphasized in agricultural development [1]. Most cassava tubers are processed into starch or tapioca flour which is important for both food and non-food utilization. Tapioca starch is a very important commodity in Lampung Province because this region produces the largest cassava root, reaching 5.44 million tons or 33.3% of total cassava production (16.35 million tons) in Indonesia by 2019 [2]. The tapioca starch extraction process requires a lot of water for washing cassava tubers, grinding (grating or rasping), fiber and pulp separation (extractor), and starch separation (separator). The process produces huge waste in the form of wastewater, cassava pulp (locally called *onggok*), and peels. The quantity of waste is highly dependent on the technology used. Mass balance analysis in the modern tapioca industry shows that to produce one ton of tapioca flour around 4-ton of cassava roots (25% extracted starch) and 16 m^3 of water are required. The wastes involve 1,200 kg of onggok, 1,600 kg of peel, and 17 m^3 of wastewater [3]. Community-scale tapioca industries, with simpler technology, produce a lower starch yield, which is around 20% of the tubers [4], [5].

Both liquid and solid wastes from the tapioca industry have a high content of organic matter [6]. Tapioca wastewater has COD (chemical oxygen demand) value between 7,000 and 30,000 mg/L [7] so it can be used as a substrate to produce biogas via anaerobic digestion (AD). Renewable energy sources (biogas is one example) can be explored to balance the supply and demand of energy [8] and is considered as an efficient way to generate electricity in the future without emitting greenhouse gases [9]. In cassava mills biogas is used as fuel to generate heat for tapioca drying or generate electricity for cassava processing or is distributed through the network of the State Electricity Company (PLN). Now more and more tapioca industries in Lampung are facilitating themselves with biogas reactors, especially by using an anaerobic covered lagoon system called CIGAR (Covered in Ground Anaerobic Reactor). This digester type is extensively adopted for tapioca wastewater management in Indonesia [10], Thailand [11], and Brazil [12]. This digester is characterized by a low investment and high efficiency [13], but low biogas specific yield (Nm^3/CODremoval) [14]. Several studies reported various benefits of installing anaerobic digesters, such as providing renewable energy [15], increasing economic profitability [16], reducing greenhouse gas emissions [17]–[19], ensuring production sustainability [20], and creating job opportunities [21]. In addition to obtaining renewable energy in the form of biogas, the application of anaerobic digesters also provides another advantage where the effluent coming out of the digester has decreased its organic load and can be used for irrigation. Our calculations reveal that total nitrogen (N) and phosphorus (P) fertilizers in the digester effluent are 1.15 kg and 0.05 kg/ton of cassava tubers, respectively [22].

Biogas production is a function of the amount of tapioca wastewater which is directly affected by the availability of cassava feedstock which fluctuates over time. Fluctuations in the availability of cassava are strongly influenced by cassava prices and its competitors, especially corn. High cassava prices will trigger farmers to cultivate cassava so that the tuber supply will be abundant. On the contrary, when the price of cassava is low or the price of corn is high, farmers are reluctant to plant cassava so the supply decreases. Under this situation, biogas digesters in the tapioca industry are prone to shortages of raw materials (wastewater) which results in decreased biogas production. This condition in turn will disrupt the stability of the biogas production system. If the biogas is used to generate electricity which is sold to the PLN, then this instability is unacceptable. Electricity distribution system is sensitive to fluctuations of voltage and frequency that could result in issues like power outages [23].

The performance of biogas plants can be improved from different aspects [24]. To meet the substrate availability for biogas digesters in the tapioca industry, additional sources of feedstock are needed to ensure the stability of biogas production. One of the solutions to overcome the lack of substrate in tapioca mills is utilise onggok as a co-substrate. Several studies reported co-digestion as a suitable method to improve biogas production [25]–[28]. Onggok is high in organic material, with carbohydrates (starch) as the main component of polysaccharides reaching 60-69% [29]. Mixing cassava pulp into tapioca wastewater will enrich the substrate with additional organic matter and ensure the availability of biogas substrate when the supply of cassava tubers is decreasing. Suitability of cassava pulp as a co-substrate in biogas production have been reported several studies [11], [30]–[32]. Converting onggok into biogas can be considered as the implementation of a circular economy concept to ensure the sustainability of cassava industries. Compared to biogas systems using only wastewater, those using both wastewater and cassava pulp as raw materials offer the highest resource efficiency and water recovery with the least amount of land use and the least amount of potential for global warming. They also produce the highest net present value and the quickest payback period [20]. In term of waste-to-energy conversion, the anaerobic digestion of cassava pulp offers the highest net energy ratio for heat and electricity power recovery with great potential for GHG mitigation [33]. Onggok is, however, a more complex material than wastewater so it will be more difficult to decompose. Therefore, the proportion of onggok added to tapioca wastewater will greatly determine its success. In addition, pretreatment is needed to increase its digestibility. Soluble material in the onggok needs to be increased to be more easily converted anaerobically into biogas.

The biogas formation process includes four phases: hydrolysis, acidogenesis, acetogenesis, and methanogenesis. This process is strongly influenced by several parameters, such as pH, temperature, substrate characteristics, and hydraulic residence time. The hydrolysis-acidogenesis reaction of a waste consisting of organic polymers will decompose it into simple monomers. The delaying time is expected to facilitate the hydrolysis process to increase the solubility of the mixture of wastewater and onggok. Therefore, our current study was conducted to evaluate the effect of adding onggok to wastewater and retention time for hydrolysis on biogas production from the onggok-wastewater mixture. The results of the study are expected to be a solution to overcome the lack of substrate for biogas digesters in cassava mills.

2. Materials and Methods

2.1. Materials

The materials used in the study included fresh tapioca wastewater, onggok, and inoculum in the form of active sludge, each of which was obtained from a tapioca mill having a biogas digester located in Central Lampung, Lampung Province. The materials were characterized to find basic, important parameters such as pH, and total- and soluble COD (chemical oxygen demand).

2.2. Digester Preparation

Erlenmeyer glasses with a volume of 1000 mL were utilized as the digester (Fig. 1). The glass was tightly capped using a holed silicon stopper. To collect biogas, a transparent plastic tube was inserted through the hole and was sealed using synthetic glue to prevent gas leaks. A T-connector was added in the middle of the tube as a sample port to take the gas sample for composition analysis. The biogas yield was measured using a simple method of water displacement with a graduated cylinder inverted in a water bath. The digester stood at the top of a magnetic stirrer plate run at 200 RPM

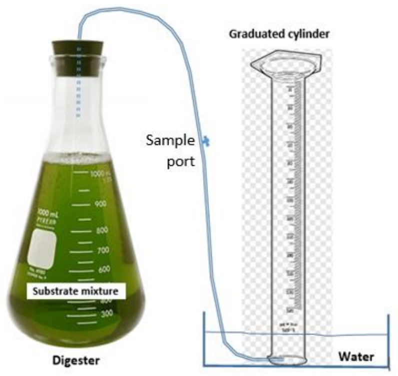

Fig. 1. Digester and gas measurement system.

and the whole rig was kept in a room as presented in Fig. 2. The room temperature was in the narrow range of a minimum of 25-26 °C during the night and 30-32 °C at noon. This temperature range was not expected to affect significantly on anaerobic the digestion process.

2.3. Design of Experiment

Onggok (20 g) was added into tapioca fresh wastewater (180 mL), meaning 10% of the total substrate. The substrate mixture was kept at room temperature for different delaying time (DT), namely 0, 3, 4, and 5 days. This delaying time is purposed to facilitate the hydrolysis step prior to the methanation step. A study on biogas production from sewage sludge reported that hydrolysis-acidogenesis was obtained optimally at a hydraulic residence time of 4 days at a temperature of 55 ºC [34]. Therefore, we extended the delaying time up to 5 days. Additionally, the delaying time of up to 5 days was based on technical considerations, where onggok can reasonably enrich tapioca wastewater for up to 5 days in the event of a substrate shortage brought on by a lack of cassava supply. Following the delaying time, 800 mL sludge collected from the anaerobic digester facility was added as the bacteria seed source. The sludge was characterised by TS (4.82±0.61)%, TVS (1.97±0.24)%, pH (7.93±0.04), T-COD (14,000±400) mg/L, and S-COD (410±71) mg/L. Table 1 shows substrate composition and delaying time for all treatments. The mixture of 1000 mL was then introduced into the prepared digester and the AD process was started. To evaluate the effect of onggok addition, a control treatment using fresh tapioca wastewater (200 mL) and sludge (800 mL) without onggok addition was also performed. The AD was run for 20 days. All treatments were replicated twice to get the average value. The data were compared from average values and their standard deviation.

2.4. Observation and Measurement

The analysis included pH, TS (total solid), TSS (total soluble solid), TVA (Total Volatile Acid), Total COD, soluble COD, biogas yield, and biogas composition. The pH, TS, TSS, COD, and TVA were measured at the initial (day 0) and final (day 20), whereas biogas yield and biogas composition were observed daily.

Table 1. Substrate composition and delaying time treatment applied for the experiment

Treatment code	Wastewater (mL)	Onggok (g)	Sludge (mL)	DT (d)
K	200	0	800	0
A	180	20	800	0
B	180	20	800	3
C	180	20	800	4
D	180	20	800	5

Fig. 2. Digester arrangement to evaluate onggok addition and delaying time in biogas production using tapioca wastewater.

2.4.1. TS, TVS, and pH Measurement

The pH of the substrate mixture was determined by using a pH meter HI 2550 pH/ORP & EC/TDS/NaCl (Hanna Instruments). The total solid (TS) of each substrate component was measured gravimetrically by drying the sample (m_1) using an oven (Memmert D550) at 105 °C for 24 hours. After being cooled in a desiccator for 15 minutes, the oven-dried sample was then weighed (m_2). The TS content of the sample is calculated as the following:

$$TS = (m_2/m_1) \times 100 \tag{1}$$

Total volatile solid (TVS) was analysed using an oven-dry sample (m_2) heated in a furnace (ISUZU EPTR-13K) at 550 °C for 2 hours and allowed to cool down in a desiccator for 15 min and then weighed (m_3). The TVS is calculated as:

$$TVS = [1 - (m_3/m_2)] \times 100 \tag{2}$$

2.4.2. Total Volatile Acid (TVA) Measurement

The pH of the substrate mixture was determined using a pH meter HI 2550 pH/ORP & EC/TDS/NaCl (Hanna Instruments). The TVA was analyzed using an acid solution (0.1 N H_2SO_4) and a base solution (0.1 N NaOH). A substrate sample of 50 mL was introduced into a 250 mL Erlenmeyer and the pH was adjusted to 4 by adding 0.1 N H_2SO_4. The sample solution was boiled for ± 3 minutes using a hotplate and magnetic stirrer (Fisher Scientific). After cooling to room temperature the sample was added 5 drops of 1% PP indicator and was then titrated with 0.1 N NaOH until the color changed to pinky. The TVA was calculated as:

$$TVA\left(\frac{mg}{L}\right) = \frac{\Sigma\, titar\ NaOH\ 0{,}1\ N \times 0{,}1 \times 60}{50} \times 1000 \tag{3}$$

2.4.3. COD Measurement

Total and soluble Chemical Oxygen Demand (T-COD and S-COD) were measured based on the APHA method [35]. A digestion solution and sulfuric acid solution were prepared to make a COD reagent. The digestion solution was made of 10.216 grams of $K_2Cr_2O_7$ (previously dried at 150°C for 2 h), 167 mL of concentrated H_2SO_4, and 33.3 g Ag_2SO_4. After dissolving and cooling to room temperature, the solution was diluted to 1000 mL using aquades. The COD reagent was prepared by adding 10.12 AgSO4 crystals into 1000 mL of concentrated H_2SO_4. The solution was left on a magnetic stirrer for 60 min to dissolve. COD reagent (consist of 1.5 mL of digestion solution and 3.5 mL of acid solution) was put into a COD tube or vial with a capacity of 10 mL and was homogenized by vortexing. To test the COD, a sample of 5 mL was diluted 100 times using distilled water in a 500 mL volumetric flask. After homogenizing, the sample was poured into a 50 mL beaker glass. Another substrate sample of 45 mL was centrifuged at 3000 rpm for 10 minutes to get a supernatant. The T-COD and S-COD were measured using 200 μL of respectively dilute the sample and the supernatant. Each of them was put into a vial containing COD reagent and then heated in a DBR200 reactor at 150 °C for 2 h and cooled to room temperature. The T-COD and S-COD were measured using HACH Spectrophotometry DR4000 at a wavelength of 620 nm.

2.4.4. Biogas Composition

Biogas composition was determined using a GC (gas chromatography, Shimadzu ST 50-80 D-375). The GC was equipped with a shincarbon column with a length of 1-4 meters and a Thermal Conductivity Detector at a temperature of 200 °C with a current of 80 mA. As much as 2.5 mL of biogas sample was injected at the injection port using a syringe sample and the GC was run to obtain data on the biogas composition consisting of CH_4, CO_2, and N_2.

3. Result and Discussion

3.1. Chemical Oxygen Demand (COD)

The effect of onggok addition and the delaying time of the substrate mixture was observed from the changes in the COD, pH, and TVA, as well as biogas production and CH_4 content in the biogas. Table 2 shows the changes in COD, pH, and TVA of the substrate mixture after 20 d of the AD process. It can be seen that there is a decrease in the value of S-COD from day 0 to day 20 which indicates that there is a decrease in the performance of microorganisms along with decomposition time. The decrease in S-COD concentration indicates that the AD process can reduce the value of S-COD on the substrate which reduces the contamination load on the substrate in the reactor. Our current work reveals a fairly good S-COD conversion rate.

The solubility of S-COD can be expressed as the ratio of S-COD to T-COD (S-COD/T-COD) which indicates the success rate of the hydrolysis phase during the anaerobic degradation process. Table 2 shows the change in the S-COD/T-COD ratio which is affected by the delaying time of onggok-wastewater mixture. Initially, the S-COD/T-COD ratio varied from 0.041 to 0.065 where the highest value on day 0 occurred in treatment K (control), which was a sample without the addition of onggok so that the decomposition process took place more quickly. The addition of onggok increases the degradation load in the substrate because onggok is a more complex material. Wastewater with a complex mixture (suspended solid 50-60% of T-COD) will produce a relatively low S-COD/T-COD ratio [36].

After 20 days of anaerobic degradation, the S-COD/T-COD ratio increased from 1.0% to 1.1%. Although it is not significantly high, the change in the value of the S-COD/T-COD ratio indicates that the delaying time will increase the value of T-COD in the wastewater. This means that the delaying time increases the biodegradability of the substrate. During this delaying time, organic matter will decompose into simpler components that will affect the digestibility of the substrate in the biogas system [37].

Effects of the delaying time on the onggok-wastewater mixture can also be seen from the change in the value of TVA. The TVA production illustrates the potential for volatile organic materials which can then be converted into methane gas. TVA affects the anaerobic degradation process,

Table 2. Changes of COD, pH, and TVA (average ± deviation of two measurements)

Parameters	Unit	K	A	B	C	D
S-COD (day 0)	mg/L	1040 ± 50	1050 ± 70	905 ± 60	985 ± 15	1040 ± 60
S-COD (day 20)	mg/L	665 ± 85	880 ± 100	865 ± 55	765 ± 15	800 ± 10
T-COD (day 0)	mg/L	16,000 ± 200	21,500 ± 250	21,000 ± 400	24,500 ± 350	25,000 ± 300
T-COD (day 20)	mg/L	13,000 ± 300	19,000 ± 800	19,300 ± 400	17,600 ± 400	17,150 ± 550
T-COD removal (%)	%	18.75 ± 8.84	12.34 ± 8.61	8.1 ± 5.79	26.90 ± 12.46	30.14 ± 14.97
S-COD/T-COD (day 0)	mg/L	0.065 ± 0.004	0.049 ± 0.013	0.043 ± 0.017	0.040 ± 0.007	0.042 ± 0.011
S-COD/T-COD (day 20)	mg/L	0.051 ± 0.003	0.046 ± 0.016	0.045 ± 0.005	0.043 ± 0.003	0.047 ± 0.001
pH (day 0)		7.15 ± 0.007	7.22 ± 0.007	7.23 ± 0.092	7.18 ± 0.035	7.18 ± 0.035
pH (day 20)		7.54 ± 0.014	7.46 ± 0.014	7.48 ± 0.014	7.55 ± 0.042	7.48 ± 0.021
TVA (day 0)	mg/L	846 ± 25.46	744 ± 101.82	930 ± 42.43	690 ± 42.43	708 ± 50.91
TVA (day 20)	mg/L	558 ± 25.46	720 ± 0.00	576 ± 0.00	702 ± 8.49	696 ± 16.97

due to the inhibition brought on by the accumulation of volatile acids may account for the low biogas production [38]. From Table 2 we can observe a decrease in the value of TVA from day 0 to day 20. The highest change in TVA value occurred in treatment B (3 days delaying time) where the TVA value decreased from 930 mg/L (day 0) to slightly lower than 600 mg/L. The magnitude of the decrease in the value of TVA indicates the success rate of the acidification process. In this study, the best acidogenesis reaction was at the delaying time of 3 days in which the changes in volatile acids were higher than in the control sample and other treatments. Reference [39] recently reported stability indicator parameter values of TVA to be 520 ± 19 mg/L on average for AD using slaughterhouse wastewater. During the decomposition process, volatile acids can be formed in the acetogenesis process and can be subsequently converted during the methanogenesis process, because both processes occur in the same space. A decrease in the value of TVA on the 20th day indicates that most of the volatile acids have been converted to methane gas. Reducing the substrate concentration will decrease the TVA concentration. This result is in accordance with reference [40], where the greater the concentration of the reduced substrate, the greater the dissolved organic matter that is degraded into organic acids. The decrease in TVA value in this study is indicated by the greater TVA conversion rate than the TVA production rate.

Another important parameter in the anaerobic decomposition process is pH. The use of high concentration sludge will increase the pH value to 6.8 – 7.2 [34]. The delaying time of the onggok-wastewater mixture has resulted in a distinct increase in pH during the anaerobic process (Table 2). On day 0 the pH values ranged from 7.15 (control) to 7.23 (B, 3 day delay). Based on the pH value, all treatments had a good pH for biogas production. During the methanogenesis process the pH should be in the interval of 6.5 – 7.5 [41]. The decrease in pH will inhibit the formation of biogas. On the other hand, too high a pH value should also be avoided, because it will decrease methane content in the biogas [42].

3.2. Biogas and Methane Production

Biogas production will be a determining parameter for the success of the anaerobic decomposition system. Daily and cumulative biogas production are presented in Fig. 3 and 4. Figure 3 shows the increase in biogas volume on day 2 and a significant decrease in biogas volume on day 3 until day 5 and a relatively constant decrease until day 10. After that, biogas production was stable until the 20th day in the range below 25 mL/day. The addition of onggok followed by the delaying time treatment can increase biogas production higher than the control treatment K (without adding onggok).

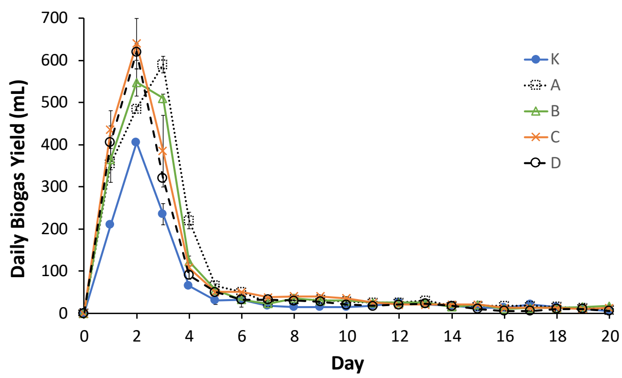

Fig. 3. Daily biogas production for 20 days (Error bars are standard deviation from 2 measurements. K = Control; A = DT 0 d; B = DT 3 d; C = DT 4 d; and D = DT 5 d).

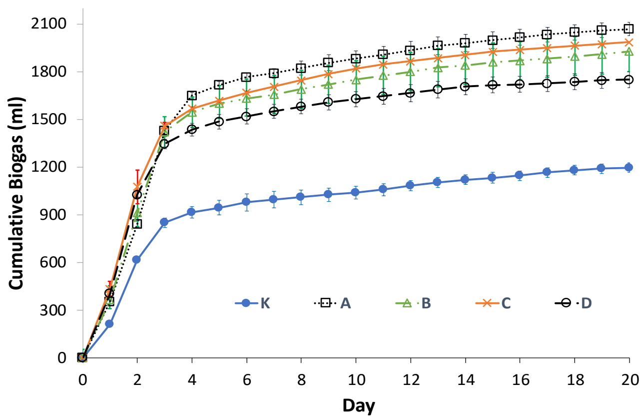

Fig. 4. Accumulation of biogas yield for 20 d (legends are same as in Fig. 3).

This happens because the delaying time provides an opportunity for bacteria during the process of hydrolysis and acidogenesis to decompose the waste in fresh tapioca waste water. This decomposition increases the value of S-COD which then produces volatile acids to be further converted into CH_4 and CO_2 gases.

According to [43], the increase in organic load causes the system to produce higher volatile fatty acids and therefore decrease biogas specific yield. The decrease in biogas production from day 4 to day 20 is not in line with the T-COD value which is still quite high on day 20. This is because the T-COD value consists of COD particulate and S-COD. By inspecting the ratio of S-COD/T-COD (Table 2), it can be seen that the dissolved organic matter that can be consumed by colonizing methanogenic bacteria is only about 4 – 6%. This means that the substrate that can be converted into methane gas (CH_4) during biogas production is 4% to 6%, whereas a high S-COD value is expected to result in higher production as well. The removal of very low T-COD values strengthens the value of the S-COD/T-COD ratio which indicates that the sample consists of COD particulate which cannot be consumed or degraded during the biogas formation process. Therefore, in a short period, most of the dissolved organic matter is consumed and the remaining particulate matter is calculated as the T-COD value.

The cumulative biogas volume obtained for 20 days was 1,195 mL, 2,067.5 mL, 1,927.5 mL, 1,985 mL, and 1,750 mL, respectively for treatments K, A, B, C, and D. Delaying time delay treatment of 0, 3, 4, and 5 days on the onggok-wastewater mixture increased biogas yield by respectively 73.01%, 61.29%, 66.10%, and 46.44% as compared to the control treatment (without onggok addition). This shows that the addition of onggok with the provision of a delaying time provides an increase in biogas production.

3.3. Specific Yield of Biogas and Methane

Biogas mainly consists of methane (CH_4) and carbon dioxide (CO_2). The quality of biogas is evaluated by the methane content (the higher, the better). Figure 5 shows the concentration of methane gas (CH_4) that is quite low on day 1 but shows an increase on day 2 and on. The low concentration of CH_4 on the first day indicates that methanogenic bacteria are still in adaptation to the new environment so the decomposition process into methane has not to occur optimally. That is, the first day of gas formation occurs from the process of acidogenesis which forms volatile acids, H_2, and CO_2. Most of the H_2 and CO_2 are mainly produced because the rate of consumption of S-COD by the activity of acidogenic bacteria is more dominant [44]. During the 20-day anaerobic process, it was seen that treatment C showed a fairly constant CH_4 concentration in the range of 57.2 – 58.6%, followed by treatment A (57.4 – 59.2%), D (56.8 – 59, 4 %), and B (55.2 – 57.2). The process of methanogenesis will produce CH_4 as the main product. A process using acetic acid or substrates that have undergone an acidogenesis-acetogenesis process will be easier and faster to be used by methanogenic bacteria to produce methane (CH_4) [45].

The energy potential of biogas can be seen from the total methane obtained during anaerobic decomposition. The methane yield is obtained by multiplying the methane concentration by the volume of biogas obtained on a respective day. Figure 6 shows the cumulative methane yield for 20 days of anaerobic decomposition. The highest total methane was obtained from treatment C, which was 1083.1 mL CH4 followed by treatment A (1074 mL) and the lowest total methane was obtained from control K, which was 641.5 mL. Figure 6 also implies that the addition of onggok and the delaying time treatment to the mixture of onggok and fresh wastewater can increase the total methane yield by 67.42, 58.73, 68.83, and 48.01% respectively for the delaying time of 0, 3, 4, and 5 days when compared to the control treatment (without onggok addition). With the highest increase in methane yield (68.83%), treatment C (with 4 days delaying time) is a good treatment because the total methane obtained during 20 days of anaerobic decomposition was the largest so it has the potential to be applied to increase biogas production in cassava mills. It is important to note that this result is similar to that reported by Ponsá (2008) where the hydrolysis-acidogenesis process of sludge at a higher temperature (55 °C) was optimal with a hydraulic retention time of 4 days [34], whereas our research was conducted at room temperature (25-32 °C). This can be caused by our sludge that was in a high portion (80% volume) with higher

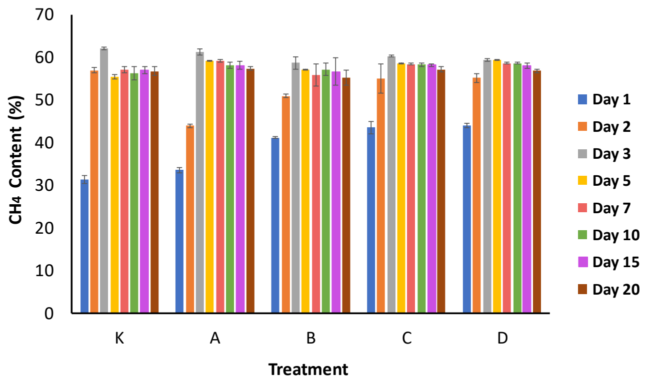

Fig. 5. Methane content in biogas during 20 d (legends are same as in Fig. 3).

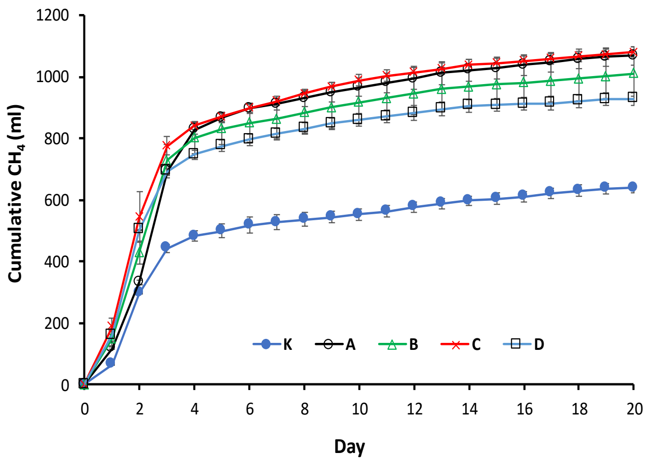

Fig. 6. Accumulation of methane yield for 20 d (legends are same as in Fig. 3).

TS content (4.82%) as compared to 2.252% in the case of [25]. Our sludge was collected from an anaerobic digester facility using the same substrate (tapioca wastewater) so that it is more adaptive. In addition, we also used substrate with T-COD of around 20,000 mg/L for 20 days, equivalent to daily organic loading of around 0.2 kgCOD/m^3, which is relatively low.

Methane productivity is calculated from total methane production divided by T-COD removed or S-COD removed. Methane productivity shows the yield per unit gram of T-COD or S-COD removed. Figures 7 and 8 show the methane productivity over T-COD removed and S-COD removed. The highest methane productivity was in treatment B for 20 days of anaerobic decomposition, which was 0.60 L/g T-COD removed and 25.5 L/g S-COD removed. Sample K showed the lowest methane productivity at 0.21 L/g T-COD removed or 1.7 L/g S-COD removed. The high productivity of methane in sample B is categorized as very good because it is accompanied by a fairly high concentration of methane gas with an average methane concentration of 55.83%. Methane productivity is strongly influenced by a total biogas production and the concentration of methane gas. According to [46], biogas productivity is influenced by the total biogas production and the amount of organic matter degraded by bacteria during the anaerobic digestion process.

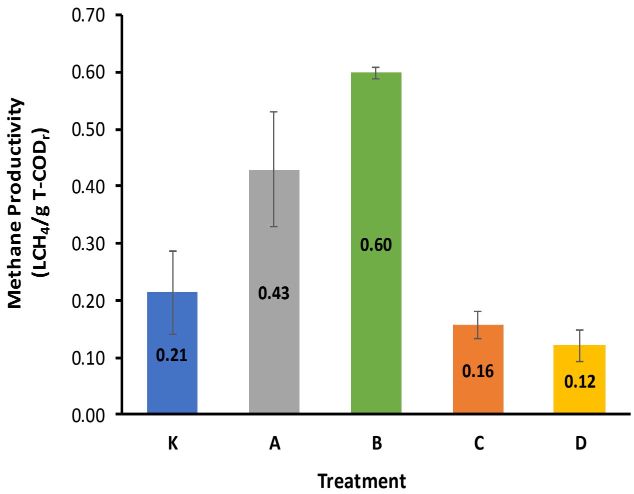

Fig. 7. Methane productivity based on T-COD removed (legends are same as in Fig. 3)

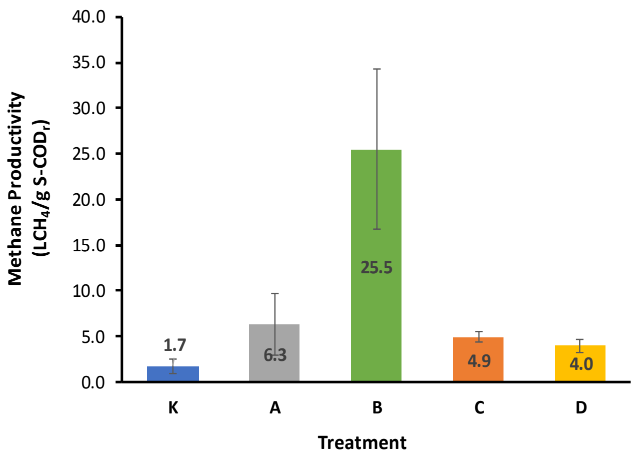

Fig. 8. Methane productivity based on S-COD removed (legends are same as in Fig. 3)

The results of this lab-scale research are very promising. However, the success of this work needs a real implementation in the cassava starch industries. Furthermore, the performance of the digester due to the addition of onggok can be monitored in real applications.

4. Conclusion

The addition of onggok increased biogas production by 73.01 %; 61.29%; 66.10%; and 46.44% for delaying time of 0, 3, 4, and 5 days, respectively, compared to the control treatment (without the addition of onggok). The best delay time for the mixture of onggok and fresh tapioca wastewater is 4 days which gives an increase in biogas production by 66.10% with a cumulative production of 1985 mL biogas and an increase in methane gas amounted to 68.83% with a cumulative total methane of 1083.1 mL of methane gas, and the average concentration of methane gas during the 20-day decomposition process was 57.58%. The results of this study provide motivation to be followed up in the real field through cooperation with tapioca industries having biogas digester installation and/or with biogas-based electricity developers.

Acknowledgements

The funding of this work was provided by The University of Lampung through Applied Research scheme under contract number of 758/UN26.21/PN/2022 dated on 17 May 2022.

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