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Comparison of Biogas Production from Oil Palm Empty Fruit Bunches of Post-Mushroom Cultivation Media (EFBMM) from Semi Wet and Dry Fermentation

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Abstarct
The high content of organic substances (25.56%) in solid waste post-mushroom cultivation (EFBMM) has the potential to be processed into biogas**.** Comparative research of biogas production from EFBMM with semi wet and dry fermentation aims to know the potential of biogas using 20% cow dung solution (inoculum) which is mixed by way of circulation. Semi-wet anaerobic digestion is performed on WC/TS ratio (4.0 - 5.7) and dry digestion is performed on the WC/TS ratio (1.5 - 3.5)**.** Anaerobic fermentation method was developed using a circulation system by observing the physical-chemical characteristics of raw materials and products produced. The results showed that the fermentation of dry and semi-wet fermentation for 65 days decreased the C/N ratio by 5.27% and 19.31%, respectively. Biogas production in semi-wet fermentation produces 18.60 L/kg of EFBMM biogas with CH_4 131.85 L/kgVSr gas productivity with biogas composition 40.69% CH_4, 49.96% CO_2 and 7.58% nitrogen. In dry fermentation, biogas produced 5.98 L/kg EFBMM with CH_4 38.71 L/kgVSr gas productivity and biogas composition 35.58% CH_4, 46.12% CO_2 and 17.31% nitrogen. Semi-wet and dry fermentation process produces carbon (released as biogas) respectively 3.90 kgC (26.88%) and 3.40 kgC (23.44%). The result of lignocellulose analysis showed that dry fermentation of EFB using fungus media was able to degrade 6.00% hemicellulose, 10.60% cellulose and 6.74% lignin. Where as semi-wet fermentation was able to degrade 9.26% hemicellulose, 13.02% cellulose and 9.28% lignin. Imaging results with SEM show the fermentation process alters the EFBMM lignocellulosic morphology structure into more open, hollow and fragile textures.
Keywords: biogas, EFBMM, WC/TS ratio

1. Introductions

The palm oil industry continues to increase with increasing demand for palm oil worldwide. Indonesia and Malaysia are the main producers (85-90%) of the world's palm oil (Choong *et al*. 2015). Within 5 years, the area of oil palm plantation Indonesia has grown by 28.63%. From 9.57 million hectares in 2012 to 12.31 million hectares in 2017 (Directorate General of Estate Crops. 2016).

The palm oil mill produces large amounts of solid wastes, such as 23% empty palm oil bunches (EFB), 12% mesocarp fibers and 5% palm kernels for each ton of fresh fruit bunches (FFB). EFB is a problem in the production process of palm oil (Saelor *et al*. 2017). High moisture content (60-70%) and high organic materials have the potential for biogas production although they contain lignocellulosic biomass. The methane biochemical potential of EFB was reported 0.15-0.2 LCH_4/gVS under thermophilic conditions (55^oC) (Kim *et al*. 2013).

The results of previous research showed that EFB used in mushroom media (EFBMM) still contains moisture content (68.05%) and 25.56% organic material. It still have the potential to be used as raw material for biogas production. Co-digestion is a solid and liquid waste treatment technology that is carried out simultaneously with the aim of increasing biogas production (Saelor *et al*. 2017). Also by controlling the ratio of CN (Jha *et al*. 2011; Dioha *et al*. 2013), improving efficiency, nutrient balance and minimize the effects of toxic compounds on the fermentation process so that existing bacteria can synergize positively (Choong *et al*. 2018, Saelor *et al*. 2017; Jha *et al*. 2011).

Anaerobic digestion (AD) technology is suitable for raw materials with high solids content and can operate with total solids (TS)> 15%. According to Saelor *et al.* (2017) there are 3 types of AD, in example wet digestion, if TS <10%, semi-dry digestion if TS levels are 10-20%, and modern dry digestion if TS> 20%. Meanwhile, according to Chiumenti *et al.* (2018) AD is grouped into 3 parts of wet digestion when TS levels <20%, semi-dry digestion if TS content is 20% and dry digestion if TS> 20%.

Comparative research of biogas production from EFBMM with semi wet and dry fermentation aims to know the potential of biogas using 20% cow dung solution (inoculum) which is mixed by way of circulation.

Semi-wet anaerobic digestion is performed on WC/TS ratio (4.0 - 5.7) and dry digestion is performed on the WC/TS ratio (1.5 - 3.5). In this research, carbon balance analysis, observation of lignocellulose change and morphological changes of microstructure was analyzed using scanning electron microscope (SEM).

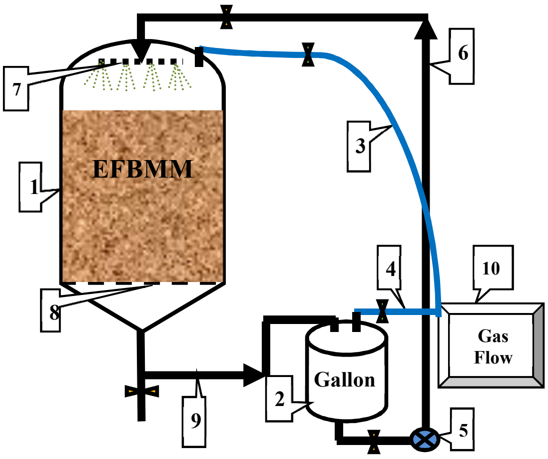
2. Methodology

2.1. Materials Research

The raw materials used in this research are: Oil Palm Bunches used as mushroom media medium (EFBMM) as substrate, derived from mushroom farmer and 20% cow dung (1 kg cow dung: 5 liters of water) as inoculum.

2.2. Research Tools

In detail, the digester images used in the study are presented in Figure 1



Information :
1 = anaerobic digester
2 = gallon container inoculum
3 and 4 = biogas sampling hose
5 = circulating engine inoculum
6 = inoculum circulating pipeline
7 = hollow sprayer pipe
8 = screen the base of the digester
9 = pipe backflow leachate water
10 = gas flow meter appliance

Figure 1. Biogas digester circuit with circulating system

2.3. Implementation of Research

Biogas production was done using digester with 2 treatments and 2 replications, ie at optimum condition (semi wet fermentation) with WC/TS ratio = 4.0-5.7 and as a comparator was also done on dry fermentation condition with WC/TS ratio = 1.5 - <3.5. The fermentation condition of each digester is determined by adjusting the volume of inoculum which is added/circulated using the comparison equation between water content (substrate + inoculum) with total solid content (substrate + inoculum) using the following equation:

$$Ratio\,\frac{WC}{TS} = \frac{(WC\ \ EFBMM\ \ x\,Weight\ \ EFBMM\,) + (WC\ inoculum\ \ x\,Volume\ inoculum)}{(TS\ EFBMM\ \ x\,Weight\ \ EFBMM\,) + (TS\ inoculum\ \ x\,Volume\,inoculum)} \quad (1)$$

This experiment begins by inserting EFBMM into the digester, followed by closing the digester and ensuring its airtightness/no leakage. Once ready, each digester was then added the inoculum using a circulating pump with volume as presented in Table 1, in so the anaerobic fermentation process begins to run. During the fermentation process, measuring the volume of biogas takes place every morning using gas flowmeter and followed by recirculation of the inoculum into the digester. The anaerobic fermentation process lasts for 65 days.

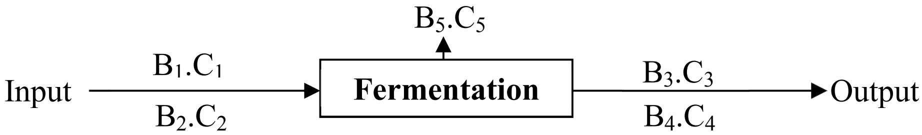
Table 1. Characteristics of EFBMM raw materials in each digester

Code	Digester	Weight-EFBMM (kg)	WC (%)	TS (%)	VS (%)	VI (L/h)	(WC/TS) Ratio	Fermentation
U-1	R-1	45.0	72.00	28.0	24.63	**10**	3.29	dry
	R-2	45.0	72.00	28.0	24.63	**20**	4.00	semi-wet
U-2	R-1	32.0	68.88	31.12	26.88	**10**	3.11	dry
	R-2	32.0	68.88	31.12	26.88	**30**	4.92	semi-wet

Information : U = repeat; R = reactor; WC = water content; TS = total solid, VS = volatile solid, VI = volume of inoculum that is circulated daily

Every week (7 days), biogas composition on each digester was measured once. Analysis of its biogas composition (CH_4, CO_2 and N_2) was measured by Gas Chromatography (Shimadzu GC 2014) with thermal conductivity detector at 200^{o}C and 100^{o}C injection temperature. GC analysis uses a Shincarbon column of 4.0 m long, 3 mm inner diameter with Helium gas as a gas carrier and a flow rate of 40 ml/min.

To determine the ratio of carbon and nitrogen (C/N ratio) an analysis was performed using Elementer Analyzer Vario El Cube tool with thermal conductivity detector. The analysis was carried out at a temperature of 1200^{o}C for 30 seconds. Furthermore, to know the change of lignocellulosic composition, to know the content of cellulose, hemicellulose and lignin, Chesson analysis method was used. In this research, carbon mass balance analysis is done to determine total carbon in each raw material (Input) and anaerobic fermentation product (Output).



$$B_1.C_1 + B_2.C_2 = B_3.C_3 + B_4.C_4 + B_5C_5$$

Information:

B_1 = Weight of EFBMM used (kg) — C_1 = Carbon concentration at EFBMM (%)
B_2 = Weight of inoculum used (kg) — C_2 = Carbon concentration at inoculum (%)
B_3 = Weight of compost generated (kg) — C_3 = Carbon concentration at compost (%)
B_4 = Weight of leachate generated (kg) — C_4 = Carbon concentration at leachate (%)
B_5 = Weight of biogas generated (kg) — C_5 = Carbon concentration at biogas (%)

At the end of the research to find out the physical change of surface morphology from EFB of fungal media before and after fermentation process, imaging analysis using Scanning Electron Microscope [series SEM ZEISS EVO MA 10, with 1800 times magnification and 5000 times magnification] was used.

3. Results And Discussion

3.1. Characteristics of EFBMM and inoculums

The data in Table 2 shows that the average carbon content is still high (32.24%) and (1.88%) Nitrogen in EFBMM raw materials indicates that EFBMM has the potential to produce biogas. High water content (60-70%) and high organic content are potentially used for biogas production (Saelor *et al.* 2017). The ratio of C/N of EFBMM and inoculum raw materials is 17.09 and 19.29. It suits a suitable C/N ratio for the anaerobic fermentation process (between 20-30), beyond that range AD fermentation will have a negative effect. A high C/N ratio can slow the fermentation process due to the formation of simple fatty acids (VFA), otherwise a low C/N ratio will form inhibitors such as ammonia (NH_3) (Choong *et al.* 2018).

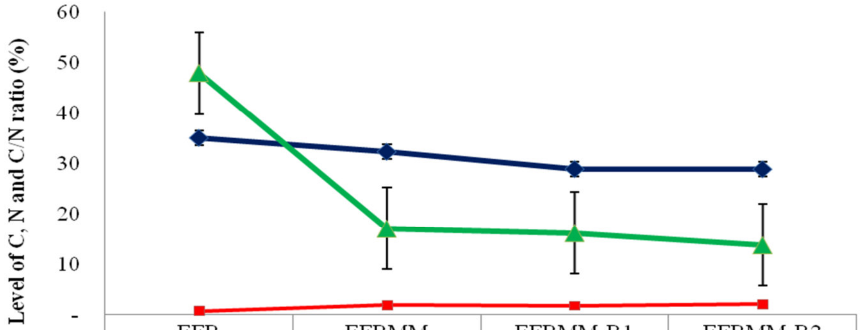
The results showed that during 65 days semi-wet fermentation process was able to reduce the vaporized solid (VS) from 25.56% to 10.03% (25.55%) and dry fermentation process reduced VS from 25.56% to 19.31% (24.45%). High degradation rates will produce high methane gas (Saelor *et al.* 2017). Other research conducted by Saaddy and Masse (2015) in Chiumenti *et al.* (2018) stated that, dry cow dung anaerobic fermentation process at temperature 20^{o}C can reduce VS 34-35%. Kusch et al. (2008) in Chiumenti *et al.* (2017) stated that fermented cow dung on mesophilic conditions was capable of reducing 46% VS. Dry fermentation yield (TS> 20%) agricultural waste with animal waste at plant scale conducted by Chiumenti *et al.* (2018) was capable of reducing 42.8% VS. VS degradation depends on the type of organic raw materials used. The fiber content affects the amount of VS because it is difficult to degrade compared to other organic materials (Chiumenti *et al.* 2018).

Table 2. Characteristics of EFBMM and inoculum before and after fermentation

Parameter	Unit	Raw material		Dry Fermentation WC/TS ratio (3.20 ± 0.13)		Semi-wet Fermentation WC/TS ratio (4.46 ± 0.65)	
		EFBMM	Inoculum	Compost	Leachate	Compost	Leachate
Carbon	%	32,24±0,85	25,61±0,18	28,83±2,42	31,40±1,86	28,81±1,31	31,58±0,59
Nitrogen	%	1,88±0,04	1,50±0,02	1,79±0,13	2,24±1,39	2,09±0,08	1,88±0,88
C/N ratio	-	17,09±0,12	19,29±0,33	16,19±0,13	13,04±0,31	13,79±0,04	12,66±0,28
Fosfor	%	1,21±0,04	0,23±0,04	1,86±0,08	0,03±0,03	1,38±0,13	0,08±0,03
Kalium	%	1,88±0,34	0,14±0,02	0,72±0,07	4,26±0,09	0,77±0,07	3,58±0,52
Water content	%	68,05±1,34	91,30±0,85	78,46±1,73	98,45±0,21	79,87±3,31	98,85±0,07
VS	%	25,56±1,31	25,86±1,74	19,31±1,35	1,50±0,26	19,03±1,79	1,73±0,13
TS	%	31,95±1,34	8,70±0,85	21,54±1,73	1,55±0,21	20,13±3,31	1,15±0,07

Information : EFBMM = EFB after being used as a medium of mushroom cultivation
Inoculum = 20% cow dung solution dissolved with water (1 : 5)
Compost = Solids EFBMM result of anaerobic fermentation process
Leachate = Residual fluid from the inoculums circulation process

The data in Table 2 show that the semi-wet fermentation yields good quality compost which has macro elements (C, N, P and K). In addition to carbon elements, compost by semi-wet fermentation meets the requirements of SNI No. 19-7030-2004, in example; Carbon 9.8-32%; minimum Nitrogen content 0.10%, C/N ratio 10-20, phosforus (P_2O_5) minimum 0.10% and potassium (K_2O) content of minimum 0.2%.



	EFB	EFBMM	EFBMM-R1	EFBMM-R2
Carbon	34.97	32.24	28.83	28.81
Nitrogen	0.73	1.88	1.79	2.09
C/N ratio	47.83	17.09	16.19	13.79

Figure 2. Carbon, Nitrogen and C/N ratio curves

Information: EFB = Empty fruit bunches
EFBMM = EFB after being used as a medium of mushroom cultivation
EFBMM-R1 = EFBMM after dry fermentation process
EFBMM-R2 = EFBMM after semi-wet fermentation process

Figure 2 shows that the use of EFB as a mushroom media can reduce the C/N ratio from 47.83 to 17.09 (64.27%), while the utilization of EFBMM in biogas production by dry fermentation process can reduce the C/N ratio from 17.09 to 16.19 (5.27%) and the semi-wet fermentation process was able to reduce the C/N ratio from 17.09 to 13.79 (19.31%).

3.2. Biogas production

Biogas production has been formed on the first day (Figure 3) and fluctuates daily (up/down). Observed per week, the accumulation of biogas production in the semi-wet fermentation process showed maximum production of biogas between the third and fourth weeks.

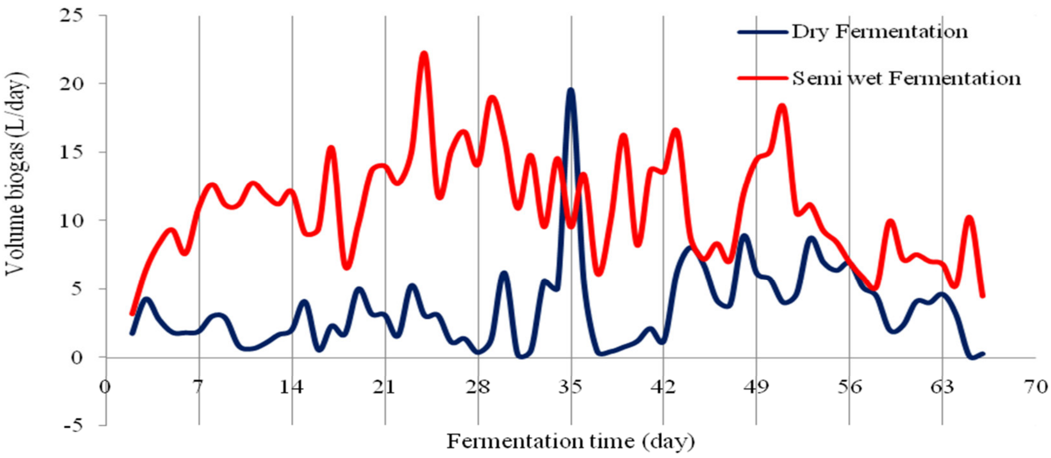


Figure 3. Daily volume of biogas from 65 days EFBMM fermentation (38.5 kg)

The dry fermentation process shows maximum gas production occurring in the fifth week. The accumulative biogas production in the semi-wet fermentation process (average WC/TS = 4.46) is higher than dry fermentation production (average WC/TS = 3.20). According to Hyaric *et al* (2011) in Chiumenti *et al*. (2018), on the dry anaerobic fermentation process there is a linear relationship between methanogenic activity and moisture content. Maximum yield will be obtained at 82% water content or TS 18%. If calculated using the method in this study, then the maximum results in the research was obtained at the ratio of WC/TS = 4.56.

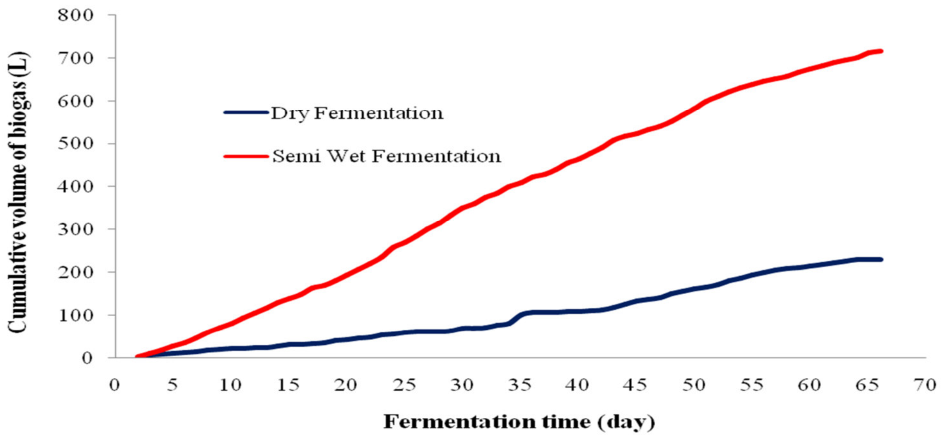
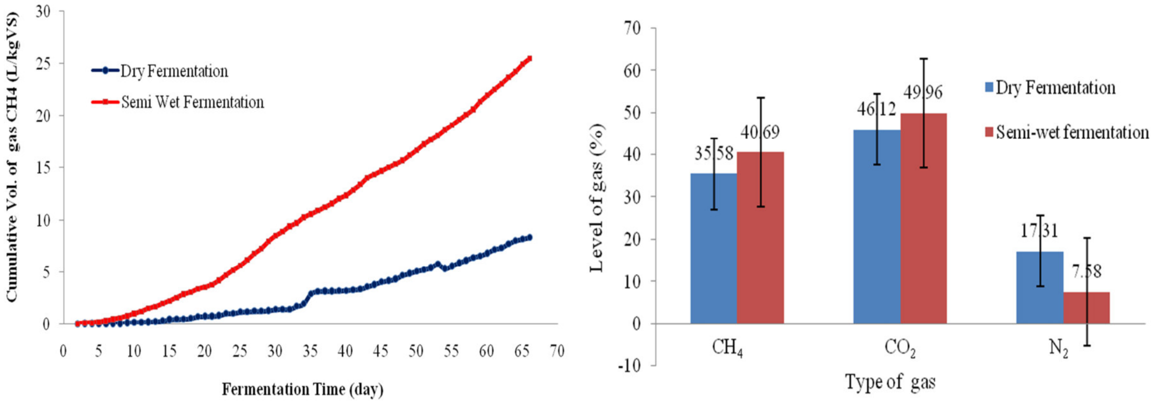


Figure 4. Volume of biogas accumulation of 65 days EFBMM fermentation (38.5 kg)

Figure 4 shows the biogas production from semi-wet fermentation process of 38.5 kg of EFBMM for 65 days resulting in biogas 716.21 L (18.60 L/kg) or equal to 25.49 L/kgVS gas CH_4 (Figure 5(a)) with composition of biogas 40.69% gas CH_4, 49.96% CO_2 gas and 7.58% N_2 gas (Figure 5(b)). The treatment of dried fermentation produces biogas 230.20 L (5.98 L/kg) or equal to 8.32 L/kgVS gas CH_4, with biogas composition 35.58% gas CH_4, 46.12% CO_2 gas and 17.31% gas N_2. Low methane yields can occur at high substrate concentrations, it was because low moisture content and high TS can inhibit microbial activity (Suksong *et al.* 2017)



(a) (b)

Figure 5. Accumulated gas volumes CH_4/kgVS and respective gas concentrations

The results of anaerobic fermentation of EFB mixture and organic sludge with variation ratio performed by Suksong *et al.* (2017) obtained CH_4 gas production that decreased significantly with TS increase. At a 95:5 ratio, the highest CH_4 gas was 18.1 L/kgVS. Hasanudin *et al.* (2015) carried out wet anaerobic fermentation (EFB) using inoculum of oil palm factory liquid waste (POME) produced biogas at 77.18 L/kgEFB or 17.75 L/kgFFB with biogas composition 40.1% CH_4 gas 46.7% CO_2 gas and 13.1% N_2 gas. The results from Amelia *et al* (2017) showed that anaerobic composting EFB with effluent treatment 15 L/day fresh POME, produces biogas as much as 19.12 L/kgFFB.

Figure 6 (a) shows the gas productivity of the removed organic solids (VS-removal). In dry fermentation process, biogas produced was 110.84 L/kgVSr or equal to 38.71 L/kgVSr CH_4 gas and in semi wet fermentation process biogas produced was 327.81 L/kgVSr (131.85 L/kgVSr gas CH_4). When compared with research reported by Amelia *et al.* (2017), the percentage of carbon that forms biogas in dry and semi-wet fermentation is greater than in EFB fermentation with POME (Figure 6 (b)). This shows that the fermentation of EFBMM raw material is more easily degraded than the raw material of EFB.

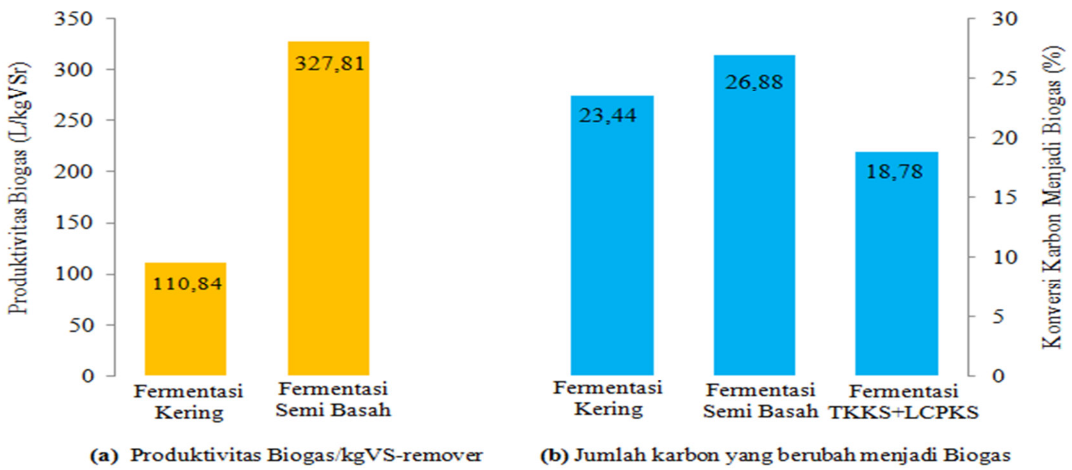


Figure 6. Productivity of CH_4 gas to $VS_{Removal}$ and Percentage C transformed into biogas

3.3. Carbon Balance Analysis

The carbon balance analysis of the dry and semi-wet fermentation processes is the total carbon from the raw materials of inoculum and inoculum used (inlet) and total carbon from leachate, compost and biogas (outlet). The results of the analysis presented in Figure 7 showed that in the dry fermentation and semi-wet fermentation process with 100 kg of EFBMM (equivalent to 9.98 kgC) with 40 kg of cow dung (equivalent to 4.52 kgC), the resulting carbon was released as biogas, respectively 3.40 kgC or 23.44% of total raw material carbon and 3.90 kgC (26.88%). If calculated from the initial carbon stock of raw materials then the utilization of EFB (100 kg) for mushroom cultivation media followed by dry fermentation process can reduce free carbon by 19.79% and wet fermentation process can reduce the free carbon by 22.33%. It means that the utilization of EFBMM for biogas production can reduce the free carbon released to the environment.

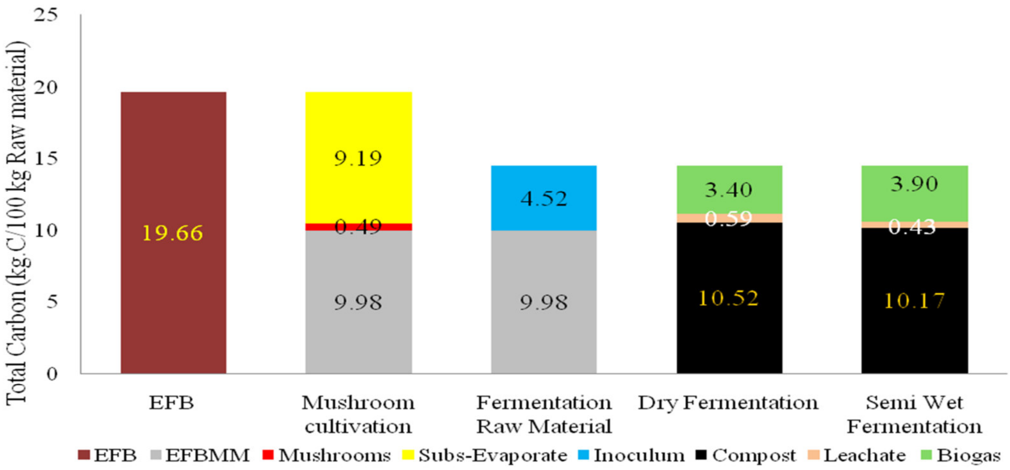
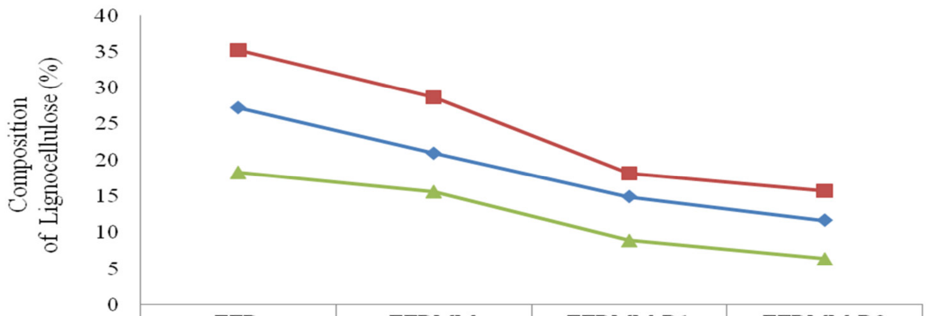


Figure 7. Changes in the Carbon Composition of Each Process

3.4. Lignocellulosic composition

The main components in EFB microfibrils are lignocelluloses, consisting of cellulose (42.7-65%), lignin (13.2 - 25.31%) and hemicellulose (17.1 - 33.5%) (Rahmasita *et al*. 2017). Figure 8 showed a continuously decreasing lignocellulose content after treatment as a fungus medium both in semi-wet fermentation process and dry fermentation process.



	EFB	EFBMM	EFBMM-R1	EFBMM-R2
Hemicellulose	27.23	20.9	14.9	11.64
Cellulose	35.26	28.71	18.11	15.69
Lignin	18.31	15.64	8.9	6.36

Figure 8. Curve of Lignocellulose composition

Information: EFB = Empty fruit bunches
EFBMM = EFB after being used as a medium of mushroom cultivation
EFBMM-R1 = EFBMM after dry fermentation process
EFBMM-R2 = EFBMM after semi-wet fermentation process

The process of mushroom cultivation using fresh EFB as mushroom media was able to degrade hemicellulose 6.33% (from 27.23% to 20.9%), 6.55% cellulose and 2.67% lignin. While in dry fermentation process EFBMM, was able to degrade 6.00% hemicellulose, 10.60% cellulose and 6.74% lignin and semi wet fermentation was able to degrade 9.26% hemicellulose, 13.02% cellulose and 9.28% lignin.

Lignocellulose is a carbohydrate that has a hard structure (difficult to degrade) because it has a strong chemical bond, so lignocellulosic materials generally require pretreatment or be used as an anaerobic fermentation mixture to produce better biogas production (Choong *et al*. 2018; Jha *et al*. 2011). The existence of decreasing lignin levels in EFB which was used as mushroom cultivation media can be used as one of pretreatment method. Utilization of EFB as a mushroom media in addition to damaging the structure of lignocellulosic morphology (Figure 8) can also increase the economic value of EFB. During this time lignocellulosic pretreatment was done mechanically (cut, crushed, milled), physically; hydrothermally; microwave; pyrolysis etc.), biologically (using microorganisms or enzymes) and chemically (addition of alkali and various types of acids) (Choong *et al*. 2018, Jha *et al*. 2011, Anindyawati 2010), all of which requires considerable time, technology and cost (Cotana *et al*. 2015).

3.5. Morphological analysis using scanning electron microscope (SEM)

Figure 9 shows the results of EFBMM fiber observations before and after the fermentation process with 1800 magnification times and 5000 times. The SEM imaging results show differences in microstructure appearance. EFBMM before it had fermented has a lignocellulosic microstructure that was still dense and slightly brittle. The lignin structure in EFBMM was still in a form of a compact surface.

After experiencing the dry or semi-wet fermentation process, at 1800 times magnification it can been seen clearly that the appearance of the surface microstructure was more open and there was a wider cavity. At 5000 times magnification it was clearly visible that tissues on the outer surface has been damaged and fragile with a larger and open cavity. Morphology of post-fermentation EFBMM showed that the lignin structure was no longer intact and fragmented, it was then that post-fermentation with enough drying immediately can be used as a compost.

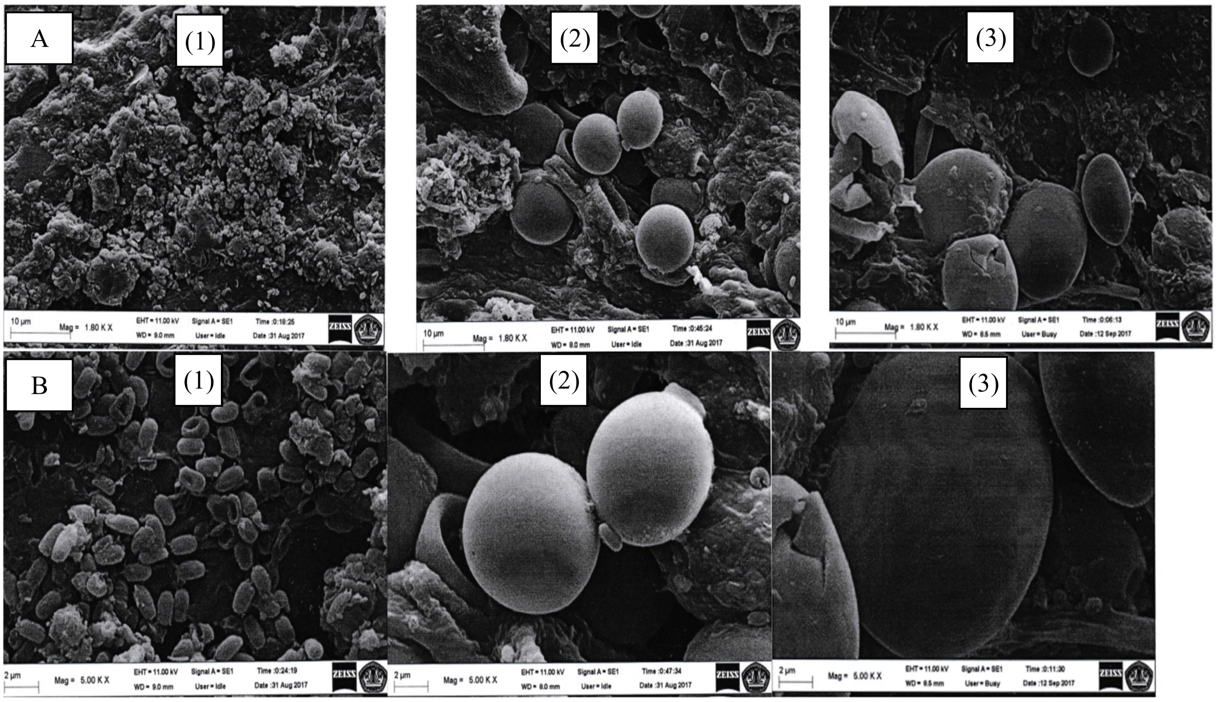


Figure 9. SEM image result with 1800 times (A) dan 5000 times (B) magnification
Information: (1) Raw material EFBMM before fermentation process
(2) EFBMM after dry fermentation process
(3) EFBMM after semi-wet fermentation process

4. Conclusion

Utilization of EFB as a mushroom media can reduce the C/N ratio up to 64.27%. Utilization of EFBMM on biogas production with dry fermentation can reduce the C/N ratio of 5.27% and in semi-wet fermentation reduces the C/N ratio of 19.31%. Semi-wet fermentation process produces biogas with higher productivity than dry fermentation process. Production of biogas in semi-wet fermentation 18.60 L/kg EFBMM with CH_4 131.85 L/kgVSr gas productivity. The composition of biogas was 40.69% CH_4, 49.96% CO_2 and 7.58% of Nitrogen. In dry fermentation biogas produced was 5.98 L/kg EFBMM with CH_4 38.71 L/kgVSr gas productivity. Biogas composition was 35.58% CH_4, 46.12% CO_2 and 17.31% of Nitrogen. The semi-wet and dry fermentation process for 65 days resulted in carbon released as biogases each 3.90 kgC (26.88% of total raw material carbon) and 3.40 kgC (23.44%).

The process of mushroom cultivation with the use of fresh EFB as the medium was capable of degrading hemicellulose 6.33%, cellulose 6.55% and lignin 2.67%. EFBMM dry fermentation process with inoculum of cow dung solution was able to degrade hemicellulose 6.00%, cellulose 10.60% and lignin 6.74%. Semi-wet fermentation process EFBMM was able to degrade hemicellulose 9.26%, 13.02% cellulose and lignin 9.28%. Imaging results with SEM show the fermentation process alters the EFBMM lignocellulosic morphology structure into more open, hollow and fragile textures.

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