Songklanakarin J. Sci. Technol.
40 (2), 418-423, Mar. - Apr. 2018

http://www.sjst.psu.ac.th

Original Article

An initial assessment of factors affecting biogas production by the fermentation of oil palm wood in homestead conditions

Nitas Proukaew[1, 2*], Suchada Inpan[1], and Atita Phetphirun[1]

[1] *Faculty of Science and Industrial Technology, Prince of Songkla University,*
Surattani Campus, Mueang, Surat Thani, 84000 Thailand

[2] *Department of Applied Chemistry, Faculty of Science and Industrial Technology,*
Prince of Songkla University, Surattani Campus, Mueang, Surat Thani, 84000 Thailand

Received: 4 April 2015; Revised: 21 July 2016; Accepted: 13 January 2017

Abstract

Wood from a dead palm tree was studied for its suitability to methane production. Ground wood samples of 3 kg were processed in fermentation tanks (plain sample in tank A). The gas was accumulated and measured over 30 days. Similar ground wood sample was put in another tank, also inoculating this with methanogen microbes (tank B), and the fermentation was compared to similar with cow dung as the substrate (tank C). The dependence of methane production on environmental conditions was also examined. The varied fermentation parameters were temperature, pretreatment of the substrate, and C/N ratio. It was found that tank C produced the largest amount of gas (4,125 cm^3) followed by tank B (3,345 cm^3), and finally tank A (2,010 cm^3). Varying the fermentation temperature from high (outdoors) to medium (room temperature) and low (air conditioned room) gave about similar accumulated gas amounts in the range 1,865-2,010 cm^3. Pre-treatment of the substrate with alkaline (NaOH) produced more methane, about 2,412 cm^3, while pre-treatment with acid (1% HCl) gave about 1,936 cm^3 produced gas, which was equal to fermentation without pretreatment. The gas production further increased to about 2,702 cm^3 when nitrogen (ammonium phosphate) was added to the system, and was only about 1,314 cm^3 when the C/N ratio was raised by adding molasses. The use of palm wood waste as substrate for biogas production is thus possible, but it should be fermented with inoculated methanogens, pre-treated with alkali, and the C/N ratio should be adjusted by adding nitrogen.

Keywords:palm oil tree, biogas production, methanogen, temperature, C/N ratio

1. Introduction

Palm oil is an important crop in Thailand, which is globally only behind Indonesia and Malaysia as a producer of palm oil. It is cultivated on about 1.6 million acres in Thailand and yields around 12.24 million tons of oil annually (Prasertsan *et al*., 1996). Oil palm is mainly planted in southern Thailand and it grows well in the tropics, but the cultivation has expanded also to other regions of Thailand, thus becoming increasingly important to the national economy. Most parts of the palm oil plant are used productively. The palm fruit are used to extract oil, palm kernel is used to extract palm kernel oil, and kernel meal is used as animal feed (Almaguer *et al.,* 2014; Santos *et al*., 2014; Zahari *et al*., 2012). Oil cake and palm fiber are used as fuel in boilers (Chin *et al*., 2013) and for mushroom production, as well as to cover soil around palm trees so as to retain moisture and to fertilize (Yoon *et al*., 2013). Palm leaves are used as fodder and they are a source of fiber and vitamin E for animals (Thongprajukaew *et al.*, 2015). Even the waste from palm oil industry can be utilized. For example, decanter cake is used as fertilizer because of its high nitrogen content. Industry wastewater with high organic residues will be applied to

---

*Corresponding author
Email address: nproukaew@gmail.com

produce electricity in the near future (Pattanapongchai *et al*., 2014). Almost all other parts except for the palm tree wood are thus used for benefit. At about 25 years of age a cultivated palm tree becomes unproductive, so farmers will use cutting, landfill disposal, incineration, or chemical injection to the stem, to kill such palm trees and let them rot. The cost of removing palm wood exceeds the potential revenue from such material for the farmers. Several published studies examine how oil palm wood could be utilized. However, this type of wood performs poorly both as timber and as burning fuel.

An important feature in the chemical composition of palm wood is its soluble sugars in the forms of sucrose, glucose, fructose, and starch, making it potential raw material for methane biogas production (Gutierrez *et al*., 2009). This research studied the potential of palm wood as raw material substrate for the production of methane gas, which might add value to an otherwise waste stream on oil palm plantations. Naturally, the farmers would benefit from the extra value and income generated, or alternatively they could produce biogas for their own household use.

The main fuel component in biogas from natural substrates is methane. Biogas can also be viewed as an alternative energy source that can reduce dependency on fossil fuels. Typically the conversion of sugar into methane happens in four stages (Suntikunaporn *et al*., 2014). The first stage is hydrolysis that breaks into smaller molecules compounds with large molecules, such ascarbohydrates, proteins, and lipids. The second stage is acidogenesis and acetogenesis by acid forming bacteria. This converts the small-molecule organic compounds into small-molecule organic acids, such as propionic acid, valeric acid, and lactic acid. The third stage is acetogenesis: the organic acids are converted to acetic acid, which is the precursor of methane; and the last step is methanogenesis by methanogens that convert acetic acid to methane. The important microorganisms are the acid forming bacteria and the methanogens. Methanogens can be found in anaerobic environments, such as in mud and in the stomachs of ruminants (Kumar *et al*., 2012; Sirohi *et al*., 2010; St-Pierre *et al*., 2013). The study by Dhamodharan *et al*. (2015) shows that crow dung and pig dung that contain methanogens were more suitable as inoculums for the anaerobic digestion of food waste than other livestock dungs. Important raw materials for biogas fermentation include food wastes, agricultural wastes, livestock dung, and municipal solid wastes (Ghasimi*et al*., 2009; Suntikunaporn*et al*., 2014; Zhang *et al*., 2007). Livestock dung, especially of cow or buffalo, is the best raw material for methane production, due to the types and amounts of organic matter, the pH conditions, and the optimal C/N ratio for growth of methanogens (Obiukwu *et al*., 2016; Prabha *et al*., 2014; Salam *et al*., 2015). Important factors affecting fermentation include temperature, pH of the medium (alkalinity), carbon to nitrogen ratio (C/N ratio), inhibiting or toxic substances, and mixing (Ghasimi *et al*., 2009; Jeong *et al*., 2014; Nieves *et al*., 2011).

This research focused on the potential of dead palm wood in the production of biogas. Various process parameters like temperature, acid vs. alkaline conditions, and C/N ratio, were also assessed for maximal biogas yield. This study strived to generate such findings that could practically be used by farmers, so it focused on readily available materials and chemicals already in agriculture use, and on wastes from agriculture. The goal was to provide convenient low-cost opportunities for farmers to gain benefits from their waste materials.

2. Materials and Methods

1) Palm wood raw material samples for producing biogas were taken from a dead palm tree in Suratthani. The samples were ground with backhoe and cut to fine fragments (Figure 1 and 2).

Figure 1. Dead palm tree was ground by backhoe

Figure 2. Mechanically ground wood

2) Inoculums of methane producing bacteria. The inoculums of methanogenic bacteria were obtained from cow dung, which naturally contains methane-producing bacteria. This mixture was allowed to ferment for two weeks.

The normal flora strains of indigenous microbes in the soil and the palm wood raw material samples were used in cases without actual inoculum, i.e. in all other cases except for B and C. This is consistent with the idea that the farmers will have to produce biogas without seeking such methanogens that are difficult to acquire/culture in practice.

3) Experiments comparing fermentation parameters. Each bucket with 3 kg of raw material (ground palm wood or cow dung) was fermented with specified parameters, namely with normal flora or with inoculums of methanogens, at a specified temperature range, and from initially adjusted acidic

or basic pH, or C/N ratio. The parameters used in the experimental design are summarized in Table 1, and Figure 3 presents the design graphically. The digestion system is shown in the photo of Figure 4

Table 1. Experimental design to find good fermentation parameters for ground palm wood.

Tank label	Raw material (3 kg)	Microbe	Pretreatment with acid or base	Temperature	Molasses or Ammonium phosphate
A	Ground palm wood	Normal flora	None	Room temp	None
B	Ground palm wood	Inoculum of methanogen	None	Room temp	None
C	Cow dung	Inoculum of methanogen	None	Room temp	None
D	Ground palm wood	Normal flora	None	under the sunshine	None
E	Ground palm wood	Normal flora	None	20-25^{0}C	None
F	Ground palm wood	Normal flora	1% of NaOH	Room temp	None
G	Ground palm wood	Normal flora	1% of HCl	Room temp	None
H	Ground palm wood	Normal flora	None	Room temp	Molasses
I	Ground palm wood	Normal flora	None	Room temp	Ammonium phosphate

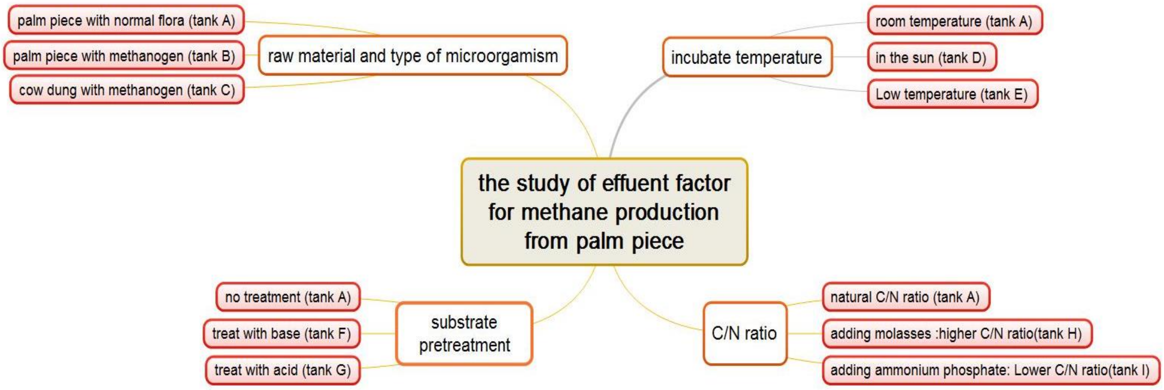

Figure 3. Graphical view of the experimental design

Figure 4. Digestion and gas trapping system

The experiments were designed to compare parameter choices for four aspects (Figure 3). First, palm wood fermentation with natural microorganisms was compared with use of methanogen bacteria (10% of inoculum), along with comparison to cow dung as the raw material substrate (tanks A, B, and C). Second, fermentation temperatures were compared (tanks A, D, and E). Third, pretreatment of substrate with acid or base was compared (tanks A, F, and G). To pretreat the substrate, it was soaked in 1% NaOH or 1% HCl for 3 days, after which the pH was adjusted before digestion to 7.0 using HCl or NaOH, respectively. Finally, the effects of C/N ratio were assessed (tanks A, H, and I). So, tank A is the control in all these comparisons. It had 3 kg of palm ground wood with normal flora, no pretreatment, natural C/N ratio, and was fermented at ambient room temperature (30–35 °C). Each fermentation experiment was run for 30 days, and the gas volume produced was measured from water displacement. At the final day, gas samples were collected in plastic bags and analyzed for the percentages of CH_4, CO_2, and other components, using a portable gas analyzer. For the statistical analysis, all experiments and analytical measurements were carried out in duplicates. The results presented are average values.

3. Results

The total accumulated biogas in each experimental case was recorded on days 5, 10, 15, 20, and 30. The production of biogas was observed to continue until the end of the experiment. A comparison of biogas production from the palm wood and the cow dung substrates, with an inoculum of methanogens, is shown in Figure 5. The accumulation of biogas at day 30 for tank C (cow dung substrate) was the higher one at about 4,125 cm^3, while the palm wood substrate (tank B) produced about 3,345 cm^3, and the control case of palm wood without inoculum (tank A) produced about 2,010 cm^3.The results show that cow dung generated more biogas than palm wood, expectedly because cow dung consists of degradable organic compounds, whereas most of the palm wood is fiber. TheC/N ratio of cow dung (21:1) is nearly the ideal one (23:1) for biogas production, whereas palm wood has too highC/N ratio (38:1). The results indicate that palm wood fermentation with normal flora may not provide enough gas to be economically feasible. However, the inoculation of methanogens noticeably increased gas production by fermentation.

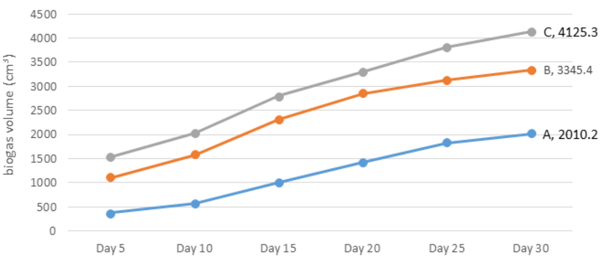

Figure 5. Time traces of biogas production. Tank A had ground palm wood with its normal flora, tank B had ground palm wood with a methanogen inoculum, and tank C had cow dung with methanogens.

Effects of temperature on the accumulated quantity of biogas are shown in Figure 6. The control tank A, which was fermented at room temperature (30-33 °C), and tank D fermented under the sun (38-40 °C) produced similar amounts of biogas, and slightly more than fermentation at a lower temperature in tank E (20-25 °C). The methanogens may be divided into two types. There are mesophilic methanogens that produce their highest biogas yields at temperatures from 20 to 45 °C, while the thermophilic methanogens have their highest biogas yields at about 50 °C. Studies of both mesophilic and thermophilic digestion can produce conflicting results that may depend on the substrate raw material. Gannoun *et al*. (2007) examined the anaerobic digestion of combined olive mill and abattoir waste at 37 °C and 55 °C, and found that the thermophilic reactor produced a higher biogas yield than the mesophilic reactor. Hegde and Pullammanappallil (2007) observed that during the batch digestion of vegetable waste and wood chips, more rapid degradation of fatty acids was found at 55 °C than at 38 °C, and that 95% of the methane yield had realized within 11 days under thermophilic conditions, while under mesophilic conditions this took 27 days. However, Parawira *et al.* (2007) studied the digestion of potato waste and found evidence that the mesophilic temperature digesters had better degradation rates than the thermophilic digesters. In a study comparing palm oil mill effluent digestion between mesophilics and thermophilics found similar production levels of biogas (Jeong *et al*., 2014). In the current study, the temperature effects were clearly minor.

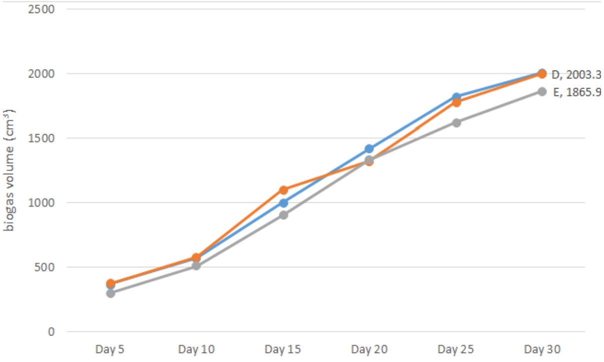

Figure 6. Effects of fermentation temperature on biogas yield. Tank A (blue line) was fermented at room temperature. Tank D (orange line) was fermented under sunlight (at elevated temperature) and tank E (gray line) was fermented at comparatively low temperature. The biogas amounts produced in tanks A, D and E by day 30 were 2,010.2, 2,003.3 and 1,865.9 cm^3, respectively.

On comparing the pre-treatments with 1% acid and 1% base for three days, the gas production after NaOH treatment was the highest (2,412 cm^3), while pre-treatment with acid gave about similar production as the untreated case (about 1,936 cm^3 and 2010 cm^3, respectively, Figure 7). An alkali treatment can be particularly advantageous when using plant materials in anaerobic digestion. This is consistent with the reports of Fahad *et al.* (2014) and of Nieves *et al*. (2011). Gunaseelan (1994) compared the anaerobic digestion of *Parthenium*, an invasive weed with high lignin content, with and without alkali pre-treatment, and found that methane production and cellulose reduction were significantly enhanced by the alkali treatment. Clarkson and Xiao (2000) reported that the degradation rate of paper waste increased when NaOH was added at 10%. The mechanism by which alkali pretreatment improves digestion is the opening of compact structures that facilitates biodegradation (Taherzaded & Karimi, 2008). The base pretreatment gave the higher biogas production, because in the early stage of fermentation the microbes convert organic matter to highly volatile acids byabiogenesis, and too high acidity (too low pH) can kill the methanogens. The effects of C/N ratio are shown in Figure 8. Tank I with added ammonium phosphate gave the highest about 2,702 cm^3 biogas production. Tank H with added molasses gave only about 1,314 cm^3 biogas, which is worse than the 2,010 cm^3 achieved at baseline conditions by tank A (Figure 8). The ideal C/N ratio for biogas production is about 23 (Ghasimi *et al.*, 2009; Jain *et al.*, 2014), whereas the C/N ratio of palm wood itself is about 38. Reducing the C/N ratio towards its ideal value should increase biogas production, and this can be done by adding ammonium phosphate that has high nitrogen content (C/N ratio 15.9). The addition amount used here decreased the C/N ratio to 33.6. Molasses on the other hand is high in carbon (C/N ratio 64), so adding it further increased the C/N ratio to 43.2, and decreased the gas production. In the gas analysis roughly 50 %methane was found, while the CO_2 content was approximately 30 %by volume.

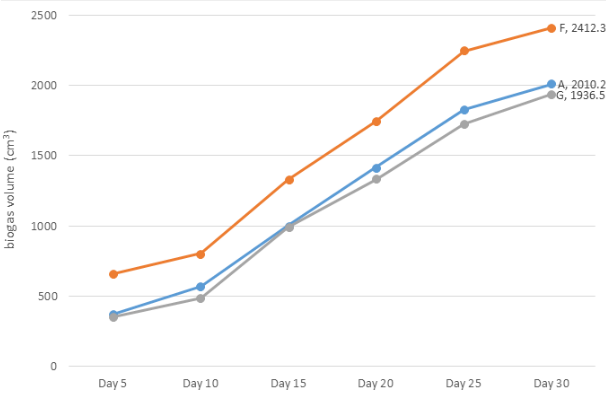

Figure 7. Biogas production from ground palm wood with alkaline or acid pretreatment. Tank F had alkaline pretreatment, tank A had no pretreatment, and tank G was acid pretreated.

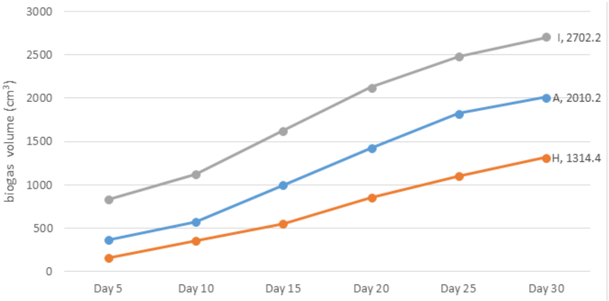

Figure 8. Effects of adjusting the C/N ratio by adding ammonium phosphate: tank A had nothing added, and tank H had added molasses.

4. Conclusions

We assessed ground palm wood as a substrate for methane biogas production. Baseline fermentation of this substrate with normal flora gave comparatively low biogas production. However, inoculation with methanogens increased the biogas production to nearly that of cow manure. Within the easily accessible range of temperatures in Thailand's homestead conditions, the fermentation temperature had no appreciable effects on biogas production. Pre-treatment of the substrate with alkali was significantly better than none and better than pre-treatment with acid. Also, the baseline C/N ratio of ground palm wood was clearly too high and got worse with added molasses, but decreasing it with ammonium phosphate improved biogas production.The results indicate that dead palm wood may be used as a substrate for biogas production, if pretreated with alkali and the C/N ratio is reduced by adding some low C/N ratio substance (i.e., high nitrogen content material). However, fermenting with the indigenous normal flora only may give poor gas production; instead inoculation with methanogens helps improve biogas production. In future work the maximal gas production may be sought by response surface methods. In this current study the palm wood was manually ground, but in pilot or commercial scale this would be mechanized and automated, and the cost of processing energy would also need to be accounted for on evaluating economic feasibility.

Acknowledgements

Partial funding for this research was provided by the Faculty of Science and Industrial Technology, Prince of Songkla University, Surat Thani Campus.

References

Almaguer, B. L., Sulabo, R. C., & Liu, Y. (2014). Standardized total trarct digestibility of phosphorus in copra meal, palm kernel expellers, palm kernel meal, and soybean meal fed to growing pigs. *Journal of Animal Science, 92*, 2473-2480.

Chin, M. J., Poh, P. E., Tey, B. T., & Chin, K. L. (2013). Biogas from palm oil mill effluent (POME): Opportunities and challenges from Malaysia's perspective. *Renewable and Sustainable Energy Reviews, 26*, 717-726.

Clarkson, W. W., & Xiao, W. (2000). Bench-scale anaerobic bioconversion of newsprint and office paper. *Water Science and Technology, 41*, 93-100.

Dhamodharan, K., Kumar, V., & Kalamdhad, A. S. (2015). Effect of different livestock dungs as inoculum on food waste anaerobic digestion and its kinetics. *Bioresource Technology, 180*, 237-241.

Fahad, Y. A., Siddig, H. H., Ibraheem, S., & Otaibi, A. M. M. (2014). Biogas Production through the Anaerobic Digestion of Date Palm Tree Wastes-Process Optimization. *BioResources, 9*(2), 3323-3333.

Gannoun, H., Ben, O. N., Bouallagui, H., & Moktar, H. (2007). Mesophilic and thermophilic anaerobic co-digestion of olive mill wastewaters and abattoir wastewaters in an upflow anaerobic filter. *Industrial and Engineering Chemistry Research, 46*, 6737-6743.

Ghasimi, S., Idris, A., Chuah, T., & Tey, B. (2009). The Effect of C:N:P ratio, volatile fatty acids and Na+ levels on the performance of an anaerobic treatment of fresh leachate from municipal solid waste transfer station. *African Journal of Biotechnology, 8*, 4572-4581.

Gunaseelan, V. N. (1994). Methane production from Partheniumhysterophorus L., a terrestrial weed in semi-continuous fermenters. *Biomass and Bioenergy, 6*, 391-398.

Gutierrez, L. F., Sanchez, O. J., & Cardon, C. A. (2009). Process integration possibilities for biodiesel production palm oil using ethanol obtained from lignocellulosic residues of oil palm industry. *Bioresource and Technology, 100*, 1227-1237.

Hegde, G., & Pullammanappallil, P. (2007). Comparison of thermophilic and mesophilic one-stage, batch, high-solids anaerobic digestion. *Environmental Technology, 28*, 361-369.

Jain, S., Wolf, I. T., & Wah, T. Y. (2014). Anerobic digestion of food waste using artificially cultured and natural anaerobes under Mesophilic conditions. *Journal of Materials and Environmental Science, 5*(6), 1709-1714.

Jeong, J. Y., Son, S. M., Pyon, J. H., & Park, J. Y. (2013). Performance comparison between mesophilic and thermophilic anaerobic reactors for treatment of palm oil mill effluent. *Bioresource Technology, 165,* 122-128.

Kumar, S., Dager, S. S., &Puniya, A. K. (2012). Isolation and characterization of methanogens from rumen of Murrah buffalo. *Annals of Microbiology, 61*(1), 345-350.

Nieves, D. C., Karimi, K., & Horvath, I. S. (2011). Improvement of biogas production from oil palm empty fruit bunches (OPEFB). *Industrial Crops and Products, 34*, 1097-1101.

Obiukwu, O. O., & Nwafor, M. O. (2016). Comparative evaluation of batch and continuous process biogas production from animal wastes. *International Journal of Ambient Energy, 37*(1), 29-35.

Pattanapongchai, A., & Limmeechokchai, B. (2014). The Co-benefits of Biogas from the palm oil industry in long-term energy planning: A least-cost biogas upgrade in Thailand. *Energy Sources Part B-Economics Planning and Policy, 9*, 360-373.

Prabha, C., Lakshmi, P. M., & Madham, S. D. (2014). Bio-methanation using water hyacinth with cow dung and performance evaluation of high speed diesel engine using gas and diesel. *International Journal of ChemTech Research, 6*(2), 1524-1530.

Prasertsan, S., & Prasertsan, P. (1996). Biomass residues from palm oil mills in Thailand: An overview on quantity and potential usage. *Biomass and Bioenergy, 11*, 387-395.

Qasaimeh, A., Abhallah, R. M., & Hani, F. B. (2016). A review on biogas interception process in municipal landfill. *Journal of Environmental Science and Technology, 9*(1), 1-25.

Salam, B., Biswas, S., & Rabbi, M. S. (2015). Biogas from mesophilic anaerobic digestion of cow dung using silica gel as catalyt. *Procedia Engineering, 105*, 652-657.

Santos, A. X., Kahwage, P. R., Faturi, C., & Neto, T. Q. (2014). Feed supplementation with palm kernel cake-based concentrate increase the quality of water buffalo semen. *Animal Reproduction, 11*, 85-95.

Sirohi, S. K., Pandey, N., Singh, B., & Puniya, A. K. (2010). Rumen methanogens: A review. *Indian Journal of Microbiology, 50*(3), 253-262.

St-Pierre, B., & Wright, A. D. G. (2013). Diversity of gut methanogens in herbivorous animal. *Animal, 7*(1), 49-56.

Suntikunaporn, M., Echaroj, S., & Rimpikul, W. (2014). Evaluation of agricultural wastes for biogas production. *Thammasat International Journal of Science and Technology, 19*(1), 1-8.

Thongprajukaew, K., Rodjaoen, S., & Yoonram, K. (2015). Effect of dietary modified palm kernel meal on growth feed utilization, radical scavenging activity, carcass composition and muscle quality in sex reversed Nile tilapia (Oreochromis niloticus). *Aquaculture, 439*, 45-52.

Yoon, L. C., & Sohei, S. (2013). Current state and environmental impact assessment for utilizing oil palm empty fruit bunches for fuel, fiber and fertilizer- A case study of Malaysia. *Biomass and Bioenergy, 51*, 109-124.

Zahari, M. W., Alimon, A. R., & Wong, H. K. (2012). Utilization of oil palm co-products as feeds for liverstock in Malaysia. In H. P. S. Makkar (Ed.), *Biofuel Co-products as Liverstock Feed-Opportunities and Challenges* (pp. 243-262). Rome, Italy: Food and Agriculture Organization.