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The Dietary Effects on Manure Characteristics and Biogas Production from Dairy Cows Feeding with Pineapple Peel

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Abstract

This study explored the dietary effect on manure characteristics and potential of biogas production from the manure of dairy cows feeding with pineapple peel as a roughage source. Three mid-lactation primiparous crossbred Holstein dairy cows, which had an average body weight of 443.5±10.6 kg and average milk production of 9.6±0.3 kg/d were assigned with three different diet types including T1, T2 and T3. T1 was a control diet, which consisted of a mixture of dry Pangola grass and commercial pellet (CL). Moreover, T2 was a mixture of dry Pangola grass, pineapple peel and CL, while T3 was a mixture of pineapple peel and CL. Dairy cow manure was collected on the day 10th after feeding and anaerobic digestion of the dairy cow manure was operated with an HRT of 30 days. Results showed that all diet types gave similar manure characteristics of high organic matter and nitrogen. Average concentrations of TS and COD ranged from 82.59 to 85.78 g/L and 85.47 to 91.47 g/L, respectively, whereas TAN ranged from 1.54 to 1.67 g/L. However, a higher pH of 7.50 was found for the manure of dairy cow fed with T1, while a lower pH of 6.50 was obtained with T3. Besides, the highest methane yield of 0.20 m^3 CH_4/kg VS_{added} was obtained when using the manure of dairy cow fed with T1 as a substrate, followed by T2 and T3 which found at 0.14 and 0.11 m^3 CH_4/kg VS_{added}, respectively. This indicated the efficient potential of biogas production from the manure of dairy cows fed with pineapple peel, which will improve sustainable utilization of agricultural wastes and waste produced from dairy cow farm in the future.

Keywords : Pineapple Peel; Dairy Cow; Manure Characteristics; Biogas

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1. Introduction

In 2019, the total cow milk produces around 522 million tons and it is expected to rise every year [1], [2]. Such a high dairy cow population will lead to a huge quantity of feed resources needed. Thailand is also one of predominantly agricultural countries with having nearly 0.7 million dairy cows in 2019 [3]. However, feed shortage becomes a major constraint to dairy production, including the dairy cow farm in Thailand. A lack of natural grasslands limits a large-scale dairy cow production in Thailand, especially during the dry season months [4]. Therefore, several local feed resources and agricultural by-products have been investigated to use as feed source for dairy cows such as pineapple peel, rice straw, sugarcane molasses and corn husk, as these contain high fiber for maintaining optimal rumen function of dairy cows [5]-[7]. Among the different alternative feed sources suggested by the researchers, pineapple peel becomes a promising feed sources for dairy cows, as pineapple has become one of the world majority commercial crops, which it grows best in the tropical areas [8]. Pineapple peel is a cannery by-product waste of pineapple (*Ananas comosus*) which can cause environmental pollutions, because this is highly fermentable and perishable [8], [9]. However, pineapple peel can be used as a potential roughage source for dairy cows due to high amount of effective fiber and sugars [5], [7]. Recently, the study of Wittayakun et al. [7] has successfully showed that pineapple peel could be used as the main roughage for lactating dairy cows without affecting milk production.

Additionally, as the value of global manufacturing has continually increased both for industrial and agricultural sectors, which leading to a significant amount of energy usage and requires efficient waste management [10]. One of the renewable energy resources that has become very important is biogas. Biogas is produced through anaerobic digestion consisting of four subsequent steps, which are hydrolysis, acidogenesis, acetogenesis and methanogenesis. Biogas production technology is important for comprehensive utilization of biomass such as livestock manures. Especially, cow manure becomes a promising alternative as it generally contains high organic matter and biogas slurry can also be used as nutrients-rich organic fertilizer [11], [12]. Thus, the challenges in the future biogas production from dairy cow manure have changed to the development of a combined efficient feed source and potential resource recovery from the manure. However, limited information can be found in the literature on the effect of manure characteristics and biogas production from the manure of lactating dairy cows fed with pineapple peel as the roughage source. Therefore, the objective of this study was to explore the dietary effect on manure characteristics and potential of biogas production from the manure of dairy cows feeding with pineapple peel as the roughage source. The results obtained from this study can be further used for utilizing agricultural wastes to reduce environmental impacts and improving sustainability of waste treatment for biogas production from dairy cow farm in the future.

2. Research Methodology

2.1 Animals and Diet Types

Three primiparous, mid-lactation (84±18 days in milk) crossbred Holstein dairy cows, which had an average body weight of 443.5±10.6 kg and average milk production of 9.6±0.3 kg/d, were assigned with three different diet types including T1, T2 and T3. Each diet type was a mixture of different compositions, as suggested by Wittayakun et al. [7]. T1 was a control diet, which consisted of dry Pangola grass to commercial pellet (CL) containing 16% protein (Charoen Pokphand PCL, Thailand) with a ratio of 70:30 on dry matter basis. Moreover, T2 consisted of dry Pangola grass to pineapple peel to CL with a ratio of 35:35:30 and T3 consisted of pineapple peel to CL with a ratio of 70:30. In this study, the pineapple peel was collected from a cannery factory located in Lampang province, the Northern region of Thailand. For transportation, the pineapple peel was stored approximately 30 kg each in a sealed double layer polyethylene plastic bag without any preservative agents. Moreover, the Pangola grass was harvested on the day 50th after planting from the grassland located in the Faculty of Science and Agricultural Technology, Rajamagala University of Technology Lanna in Lampang province and the dry Pangola grass was chopped before used. This Pangola grass (*Digitaria eriantha*) is a high-quality tropical grass, which is popularly grown in Thailand as a pasture and widely utilized as a livestock feed [13].

Feed for each lactating dairy cow was balanced depending on its body weight, milk yield and milk fat, which following the nutrients requirement recommended by the National Research Council (NRC) [14]. Each diet composition was weighted individually before distribution as a mixed feed. Moreover, each lactating dairy cow was house individually in a 3x6 m^2 pen with available drinking water and mineral blocks. Moreover, all dairy cows were fed twice daily at 7 AM and 5 PM at 110% of expected intake throughout the experiments [7]. Animal management and experimental protocol was performed with respect to animal care and welfare.

2.2 Anaerobic Digestion Setup

In this study, an anaerobic digestion was used to explore the potential of biogas production under anaerobic conditions from the manure of dairy cow as a substrate. Three different manure sources from the dairy cows fed with three diet types of T1, T2 and T3 were used. The anaerobic digestion reactors with a working volume of 5 L were operated in a complete randomized design with a hydraulic retention time (HRT) of 30 days [11], [15]. All experiments were conducted in triplicate. Daily anaerobic digester temperature was measured using a digital thermometer (SCT-lilliput, Scichem Tech). The temperatures of all anaerobic digesters were observed in a range of 32 to 34°C, which implied that the operating digestion process was performed by mesophilic bacteria that had temperature ranged between 30 and 38°C [15].

2.3 Sample Collection and Analysis

Grab samples of dairy cow manure were collected on the day 10th after feeding and stored in a refrigerator (4°C) until used. Before start-up an anaerobic digestion, the manure was diluted with tap water in a ratio of 1:1 (dairy cow manure: tap water) to achieve a Total Solids (TS) content of approximately 5% [16]. The mixed liquid samples of undiluted manure from the dairy cows fed with different diet types of T1, T2 and T3, as well as samples of the end anaerobic digestion process were collected. The stored undiluted manure samples and digested samples were first measured pH using pH electrode (OHAUS Starter ST5000-B Bench pH Meter, USA). Then, the measurements of TS, Volatile Solids (VS), Chemical Oxygen Demand (COD), Total Organic Carbon (TOC), Total Ammonia Nitrogen (TAN), and Total Phosphorus (TP) were determined in triplicate for the undiluted manure according to standard methods [17]. Moreover, the concentrations of VS and COD were measured for the samples at the end of anaerobic digestion process. The amount of gas produced was also measured daily in the gas collection unit using volume displacement. Besides, the CH_4 and CO_2 content of biogas were measured at the end of system performance to examine the quality of biogas production by using a gas chromatography (Model 7890, Agilent, USA). The removal efficiencies of VS and COD were calculated using equation (1) and the methane yield was calculated using equation (2) as follows [18], [19].

$$\eta_x = \frac{(C_{x,in} - C_{x,out})*100}{C_{x,in}} \quad (1)$$

When

η_x = Removal efficiencies of x (%), as this study refers to VS and COD

$C_{x,in}$ = Concentrations of x at the beginning (mg/L)

$C_{x,out}$ = Concentrations of x at the end of system performance (mg/L)

$$Y_{CH_4} = \frac{V_{CH_4}}{VS_{in}} \quad (2)$$

When

Y_{CH_4} = Methane yield (m^3 CH_4/kg VS_{added})

V_{CH_4} = Cumulative volume of methane production at the end of system performance (m^3 CH_4)

VS_{in} = Mass of original VS content of the substrate (kg VS_{added})

3. Results and Discussion

3.1 Characteristics of the Manure from Dairy Cows Feeding with Different diets

Table 1 gives a summary of the most important characteristics of the undiluted manure from the dairy cows feeding with three different diet types of T1, T2 and T3, which were used as a substrate to anaerobic digestion for biogas production in this study.

Table 1 Characteristics of the undiluted manure from the dairy cows feeding with different diet types, which used as a substrate to anaerobic digestion for biogas production. (pH and concentrations are average values and standard deviations are shown between brackets, which calculated from the results of 3 samples.)

Parameters	Unit	Cow manure from dairy cows feeding with different diets[a]		
		T1	T2	T3
pH	-	7.50 (0.09)	7.10 (0.10)	6.50 (0.06)
Total Solids (TS)	g/L	85.78 (2.12)	83.46 (2.50)	82.59 (2.51)
Volatile Solids (VS)	g/L	70.40 (2.05)	65.87 (1.65)	63.56 (1.85)
Chemical Oxygen Demand (COD)	g/L	91.47 (3.25)	87.60 (2.67)	85.47 (2.75)
Total Organic Carbon (TOC)	%	33.79 (1.05)	33.59 (1.75)	33.02 (1.85)
Total Ammonia Nitrogen (TAN)	g/L	1.54 (0.09)	1.59 (0.08)	1.67 (0.09)
Total Phosphorus (TP)	g/L	0.40 (0.02)	0.43 (0.02)	0.44 (0.03)

[a] T1: Control diet, dry Pangola grass to commercial pellet (CL) with a ratio of 70:30 on dry matter basis,
T2: Dry Pangola grass to pineapple peel to CL with a ratio of 35:35:30, and
T3: Pineapple peel to CL with a ratio of 70:30.

As shown in **Table 1**, the manure from the dairy cows was characterized mainly by high organic matter and nutrients especially nitrogen as compared to the average characteristics of human waste [15]. The dairy cow manure revealed average concentrations of TS and COD with a range of 82.59 to 85.78 g/L and 85.47 to 91.47 g/L, respectively. These results are in agreement with the previous studies, which also reported high concentrations of TS and COD ranged from approximately 51 to 107 g/L and 55 to 124 g/L, respectively [20]-[22]. This clearly showed that the dairy cow manure requires significant treatment for a sustainable and safe treated effluent before discharge to the environment. As the dairy cow manure contained such a high concentration of organic matter content, consequently, it becomes an excellent substrate for the production of biogas. Moreover, another advantage of ruminants manure especially cows is that the manure is readily utilized for the fermentation phase and it already has the necessary methanogenic bacteria [23]. However, it is important to note that the differences in diet types resulted in different characteristics of the manure, especially pH values. An average pH for the manure of dairy cow fed with T1 was found at 7.50, while lower pH values of 7.10 and 6.50 were found for the manure of dairy cow fed with T2 and T3, respectively. The low pH for the dairy cow manure fed with T3 could be explained by the chemical properties of pineapple peel, which has rather low pH values of 3.47-3.84 [24]. In the literature, information about the biogas production from the manure of dairy cow feeding with pineapple peel as a roughage source, which resulting in a lower pH than using dry Pangola grass, is still limited and needs to be further investigated.

Moreover, the nutrients nitrogen (N) and phosphorus (P) in terms of TAN and

TP were also determined in the manure used as a substrate for the biogas production. The results clearly showed that the manure of dairy cows fed with T1, T2 and T3 contained high N. The average TAN concentrations ranged from 1.54 to 1.67 g/L and these results were in agreement with the studies of Frear et al. [22] and Liu et al. [25], who also reported the high TAN concentrations of 1.72 and 2.17 g/L, respectively. For this study, similar average concentrations for TOC, TAN and TP in the manure of dairy cows fed with T1, T2 and T3 were observed. This may cause by the similar organic carbon, N and P fractions in both dry Pangola grass and pineapple peel, resulting in the similar organic carbon and nutrients excretion [26]-[29]. Moreover, it is also important to note that ammonia inhibition in anaerobic digestion of the dairy cow manure feeding with T1, T2 and T3 is not expected to become a limiting factor, as Frear et al. [22] showed that TAN concentrations of 1.87 g/L (at pH 6.87) and 2.65 g/L (at pH 7.88) had no adverse inhibition on methane-forming bacteria.

3.2 System Performance of Biogas Production from the Dairy Cow Manure

Fig. 1 shows the cumulative biogas production from the dairy cow manure feeding with three different diet types of T1, T2 and T3 throughout the whole experiment.

As shown in **Fig. 1**, the dairy cow manure feeding with all three diets were possible to use as a substrate for biogas production. The cumulative biogas production from the manure of dairy cow fed with T3 increased significantly in the first 8 days and reached the highest amount of 40 L after 16 days of digestion process. Whereas when using the manure of dairy cows fed with T1 and T2, the cumulative biogas production increased significantly in the first 20 and 12 days, respectively, and reach the highest amount of 58 L after 25 days and 44 L after 18 days of digestion process, respectively. These results clearly showed that the manure of dairy cows fed with different diet types would lead to different potential of biogas production. Moreover, a rapid increase in biogas production in the first 8 days from the manure of dairy cow fed with T3 could be explained by a low pH in the manure used, as acidic condition could increase the rates of particle disruption, hydrolysis and acidogenesis steps [30].

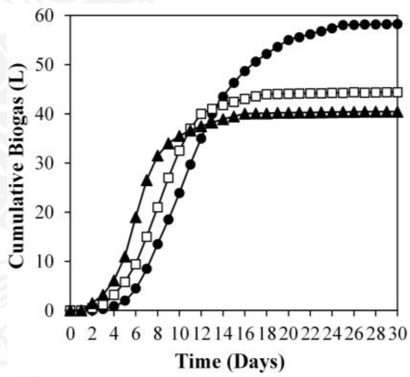

Fig. 1 Cumulative biogas production from the manure of dairy cows feeding with 3 different diets; (●) T1: Control diet consisted of dry Pangola grass to commercial pellet (CL) with a ratio of 70:30, (□) T2: Dry Pangola grass to pineapple peel to CL with a ratio of 35:35:30, and (▲) T3: Pineapple peel to CL with a ratio of 70:30.

Table 2 System performance of biogas production from the manure of dairy cows feeding with different diet types on pH in the effluent (pH_{eff}), biogas compositions of CH_4 and CO_2, removal efficiencies of VS and COD, and methane yield. (pH and biogas compositions are average values. Standard deviations are shown between brackets, which calculated from the results of 3 samples).

Parameters[a]	**Unit**	**System performance of biogas production from dairy cow manure feeding with different diets**[b]		
		T1	**T2**	**T3**
pH_{eff}	-	7.07 (0.05)	6.58 (0.03)	6.18 (0.03)
CH_4 in biogas	%	60.33 (1.95)	50.95 (1.36)	41.75 (1.62)
CO_2 in biogas	%	38.55 (1.15)	46.79 (1.50)	51.33 (1.48)
VS removal efficiency	%	40.32	36.72	34.36
COD removal efficiency	%	45.67	41.45	38.10
Methane yield	m^3 CH_4/kg VS_{added}	0.20	0.14	0.11

[a] Volatile Solids (VS) and Chemical Oxygen Demand (COD).
[b] T1: Control diet, dry Pangola grass to commercial pellet (CL) with a ratio of 70:30 on dry matter basis, T2: Dry Pangola grass to pineapple peel to CL with a ratio of 35:35:30, and T3: Pineapple peel to CL with a ratio of 70:30.

In addition, **Table 2** summarizes the system performance of biogas production from the dairy cow manure feeding with different diet types on pH values in the effluent, compositions of biogas, removal efficiencies of VS and COD, and methane yield. Generally, the anaerobic digestion process is sensitive to various processing conditions including pH values, in which optimum pH for acidogens ranged from 5.5 to 6.5 and for methanogens ranged from 6.8 to 7.2 [15], [31]. Based on the data shown in **Table 2**, the average pH values at the end of the system were decreased in all three anaerobic digesters of the dairy cow manure and reached down to pH values of 7.07, 6.58 and 6.18 when using the manure of dairy cows fed with T1, T2, and T3, respectively. These results indicated that only the anaerobic digester of the dairy cow manure feeding with T1 could give the optimal system performance of biogas production and biogas quality. This confirmed by the results of pH value at the end of the system when using the manure of dairy cow fed with T1 that was in the optimum pH range for methanogens and therefore the highest cumulative biogas production was observed. In addition, as expected, the biogas quality in term of CH_4 and CO_2 contents, in which identified the quality of biogas, showed that the anaerobic digestion of the manure of dairy cow fed with T1 resulted in a higher average CH_4 content of 60.33%, followed by T2 (50.95%) and T3 (41.75%). This high CH_4 content of the biogas production also confirmed that methanogenesis was performed optimally in the anaerobic digestion of the manure of dairy cow fed with T1 and this is in agreement with the review study of Nasir et al. [11] that was reported the CH_4 content as between 50 and 70%. Besides, in the anaerobic digestion of the manure of dairy cows fed with T2 and T3, biogas contained rather high amount of CO_2 content. This high amount of CO_2 most likely produced during the hydrolysis and acidogenesis steps as the methanogenic activity was not fully developed at low pH [30].

Moreover, the removal of organic matter in the forms of VS and COD degradation was also shown in **Table 2**. The results revealed poor biodegradable fraction of the dairy cow manure VS as compared to other livestock manure [11]. This is mainly due to the high amount of inorganic compounds and fibers in the diets that could not digest in the digestive system of dairy cow and therefore the dairy cow manure will be hardly degraded during the anaerobic digestion [11]. In this study, the average VS removal efficiencies ranged from 34.36 to 40.32%, which were comparable to an ultimate biodegradable fraction of the dairy cow manure VS of approximately 40% [32].

With a high total cumulative biogas production (**Fig. 1**) and CH_4 content obtained from the anaerobic digestion of the manure of dairy cow fed with T1, the methane yield of as high as 0.20 m^3 CH_4/kg VS_{added} was achieved and this would translate to the methane yield of 0.49 m^3 CH_4/kg $VS_{degraded}$. This result is in agreement with the review study of Nasir et al. [11] and the guidelines of Shelford et al. [33], which reported the methane yield from anaerobic digestion of the dairy cow manure as between 0.16-0.26 m^3 CH_4/kg VS_{added} and the appropriate estimation of methane production based on VS degradation of 0.50 m^3 CH_4/kg $VS_{degraded}$. Besides, lower methane yields of 0.14 and 0.11 m^3 CH_4/kg VS_{added} were found when using the manure of dairy cows fed with T2 and T3, respectively. The low methane yield in anaerobic digestion of the manure of dairy cow fed with T3 could be explained by (1) an inhibition of methanogenic activity at low pH value and (2) a higher lignin content in pineapple peel than dry Pangola grass as this expected to increase in lignin excretion in the manure [27], [30], [34]. The studies of Amon et al. [35] and Li et al. [36] showed that high lignin content in the manure could significantly reduce the methane yield. In order to make the use of pineapple peel as a substitute roughage source more attractive, several methods can be used to enhance methane yield such as anaerobic co-digestion with other organic wastes and pH adjustment in anaerobic digester. The anaerobic co-digestion would help to optimize feed compositions, macro and micronutrients, pH, and toxic compounds [11], [23], [30], [37]. For example, the review study of Nasir et al. [11] reported that anaerobic co-digestion of the dairy cow manure with other organic wastes could enhance the methane yield up to 0.31 m^3 CH_4/kg VS_{added} when using anaerobic co-digestion of the dairy cow manure with kitchen waste. However, the anaerobic co-digestion process of the dairy cow manure still needs to be further investigated with respect to types of organic wastes used and mixing ratios. Additionally, pH adjustment in anaerobic digester can also be considered by using a base solution to the optimum pH range for methanogenic activity. This would help to enrich methanogens as well as to prevent acid accumulation in the anaerobic digester, resulting in a higher methane yield [30].

4. Conclusion

In this study, it was found that all diet types of T1, T2 and T3 resulted in similar manure characteristics of high organic matter and high nutrient nitrogen. However, a higher pH was found for the manure of dairy cow fed with T1, while lower pH values were obtained with T2 and T3. Moreover, it was found that the highest methane yield was obtained from the manure of dairy cow fed with T1, followed by T2 and T3, respectively. The low methane yield from the manure of dairy cow fed with T3 is the most likely can be explained by an inhibition of methanogenic activity at low pH value and a higher lignin content in pineapple peel. However, the anaerobic co-digestion process with other organic wastes and pH adjustment in anaerobic digester could be used to further enhance the methane yield. Based on the results obtained from this study, it can be concluded that the manure of dairy cows fed with pineapple peel as a substitute roughage source was an effective potential substrate for biogas production. This study not only offers the opportunity to develop sustainable utilization of agricultural wastes for feedstock, but also improve the sustainability of waste management for biogas production from dairy cow farm in the future.

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