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Seasonal Variations in Biogas Production from Excreta of Monogastric Farm Animals under Tropical Climate

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ABSTRACT

The present study analysed the changes in the quantity and composition of biogas produced from the excreta of swine, rabbit and poultry during monsoon and summer seasons. The highest volume of biogas production was observed in rabbit excreta (0.0813 ± 0.0007m^3), followed by poultry excreta (0.0778 ± 0.0005 m^3) and swine excreta (0.0738 ± 0.0004 m^3). Methane concentration was higher in biogas produced from rabbit excreta (70.96 ± 0.19) followed by that from poultry excreta (66.87 ± 0.21) and swine excreta (62.41 ± 0.20), whereas carbon dioxide concentration was highest in swine excreta (28.07 ± 0 .32) followed by rabbit excreta (24.54 ± 0.15) and poultry excreta (22.14 ± 0.14). The biogas production was significantly higher (P<0.01) in the summer season compared to monsoon in all three substrates. It was observed that daily mean temperature had a significant positive relationship and relative humidity had a negative relationship with the quantity of biogas produced (P<0.01). The gas production also had a significant positive correlation with the temperature and pH of the digesta.

Key words: Farmyard manure, Methane, Renewable energy, Waste management.

Highlights

- Biogas production from the excreta of swine, rabbit and poultry during monsoon and summer seasons were compared.
- Biogas production was significantly higher (P<0.01) in the summer season.
- Methane concentration was higher in biogas produced from rabbit excreta, whereas carbon dioxide concentration was highest in biogas from swine excreta.

INTRODUCTION

The global energy demand is growing rapidly and most of it is met by fossil fuels. Fossil fuel derived carbon dioxide emission leads to the accumulation of greenhouse gases in the atmosphere. To conserve the depleting reserves of fossil-based energy sources and to resist climate change, it is necessary to switch to renewable energies. Biogas is a versatile renewable energy source and a carbon-neutral fuel that utilizes methane from organic waste and help in reducing global warming. In the last few decades, biogas has assumed considerable importance as an alternative to conventional energy sources throughout the world, particularly in developing countries like India and China. In India, about 693.12 million tonnes of animal excreta is available per year (Khoiyangbam *et al*., 2004). Under the National Biogas Programme implemented by the Ministry of New and Renewable Energy, Government of India, over 4.75 million biogas plants in the capacity range of 1-6 m^3 have been installed in the country (MNRE, 2019). But there is a high percentage of non-functioning plants, which may endanger further development in this field (Raha *et al*., 2014). To overcome this, there is a need to understand the different factors affecting anaerobic digestion and to find out the most suitable substrates, digesters and operating conditions for the sustainability of biogas production in different agro-climatic conditions.

It is reported that the excreta of monogastric animals have a comparatively higher efficiency of biodegradation than that of ruminants due to the high presence of lignin in the excreta of ruminants (VanSoest, 1994). Many studies reported that pig manure, rabbit manure (Babatola, 2008) and poultry manure (Costa *et al*., 2012) are excellent substrates for biogas production and the efficiency is higher than cattle dung. It is well known that the process of anaerobic digestion is influenced by factors such as biogas potential of feedstock, design of digester, pH, temperature, Hydraulic retention time (HRT) and loading rate (Nagamani and Ramasamy, 1999; Thy, 2003; Divya *et al*., 2014).

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Preliminary studies showed that biogas production efficiency was higher in summer than in winter (Khoiyangbam *et al*., 2004; Divya *et al*., 2014) due to an increase in atmospheric temperature.

The present study was designed to evaluate the efficiency of biogas production from substrates *viz.* excreta of swine, rabbit and poultry under hot and humid conditions climatic conditions prevailing in Kerala. The physicochemical characters of substrates, quantity and quality of biogas production and seasonal variations were analysed.

MATERIALS AND METHODS

Study location and experimental design

The study was conducted at University Livestock Farm and Fodder Research and Development Station, College of Veterinary and Animal Sciences, Mannuthy, Thrissur which is situated 22.25 m above mean sea level at 10°53″ N latitude and 76°26″ E longitude.

The experiment was performed using three floating drum biogas plants of 0.5 m^3 capacity designed by the Agro-Biotechnology Agency for Rural Employment Development (ABARD), Kerala Agricultural University, using excreta of Swine, Rabbit (monogastric farm animals) and Poultry. The units were operated for a period of 60 days during the rainy season (S1; June - September) and summer (S2; February - May). The plants were operated for 30 days so that gas production stabilized. Subsequently volume and composition of the gas produced were observed for 10 days (Paudel, 2012; Parajuli, 2011). The substrates were analysed for dry matter (DM), ash, crude protein (CP), crude fat (ether extract) and crude fibre (CF) according to procedures stipulated by AOAC, (1990).

The temperatures of the substrates were recorded daily at 8.00, Indian standard time (IST) using a mercury bulb thermometer (Khoiyangbam *et al*. 2004). The pH of the substrates was recorded using a digital tester (Eutech PC Stestr 35, Thermo Scientific, China). The maximum and minimum temperatures of the experimental area were recorded daily using Zeal's maximum and minimum thermometer. The relative humidity was recorded daily using HTC-1 digital hygrometer. The meteorological data over a period from July 2013 to April 2014 were obtained from the meteorological observatory unit, Department of Meteorology, College of Horticulture, KAU, Vellanikkara.

Hydraulic retention time (HRT) is the average time spent by the input slurry inside the digester before it comes out. HRT was calculated by dividing the digester volume by the feed volume.

Biogas pressure was recorded daily at 8.00, IST using U - tube Manometer as 'centimetre water column (WC) (Mondal and Biswas, 2012). The volume of biogas produced was calculated using the formula

$$V = \pi \text{ r2h}$$

Where

'r' is the radius of the gas holder and 'h' is the elevation of the gas holder due to gas production. Biogas samples were collected in gas collection bladders (Hans Seamless Latex Valve Bladders) for 10 days. The composition of liberated biogas was determined by gas chromatography (Parajuli, 2011), using Thermo Scientific Trace GC 600 with Packed Column injector, Flame Ionization Detector (FID) and methanizer.

RESULTS AND DISCUSSION

Properties and composition of the substrates

The physicochemical properties of the substrates (excreta of swine, rabbit and poultry) used for the study are presented in Table 1. The study compared the quantity and composition of biogas produced from the excreta of swine, rabbit and poultry in summer and monsoon seasons. Among the three substrates, higher dry matter content was observed in poultry excreta, followed by swine and rabbit. Previously, Thy (2003) obtained similar results in the case of DM contents of poultry and swine excreta. The CF content was highest in swine excreta followed by rabbit and poultry excreta. The high CF content in swine excreta may be due to the concentrate fed to the animals (Ferreira *et al*., 2012). The mean temperatures of the substrates were higher in the summer season than in the monsoon. This might be due to the effect of atmospheric temperature on the substrates. The pH of the substrate was highest for rabbit excreta followed by poultry and swine excreta.

The hydraulic retention time was calculated for each substrate in S1 and S2. The retention time of the substrates, in general, was longer in the rainy season than in summer. In the rainy season, (S1) HRT decreased in the order as rabbit excreta (25 days) followed by swine excreta (24 days) and poultry excreta (23 days), with an overall mean of 24 days. In summer (S2), HRT was highest for swine excreta (20 days), followed by rabbit (19 days) and poultry excreta (18 days), with an average of 19 days. The observed HRT was highest for swine manure (25-30 days), followed by rabbit manure and least for poultry manure, as reported earlier by Babatola (2008). But, Aubart *et al*. (1983) stated that the HRT was highest for poultry manure among the three. In tropical countries like India, HRT varies from 30-50 days (Yadvika *et al*., 2004). Because of the uniform experimental conditions such as loading rate, dilution, size and make of the digester, HRT was almost similar among

Table 1: Physicochemical characters of substrates.

Parameter	Excreta		
	Swine	Rabbit	Poultry
Moisture (%)[#]	65.39±1.18	72.44±0.37	55.48±1.75
Dry matter (%)[#]	34.61±1.18	27.56±0.37	44.52±1.75
pH[#]	6.85±0.11	7.35±0.19	7.15±0.12
Crude fiber (%)[##]	24.82±0.04	23.08±0.23	19.15±0.05
Nitrogen (%)[##]	2.10±0.03	2.48±0.02	2.85±0.04
Phosphorous (%)[##]	1.20±0.02	1.96±0.03	1.62±0.02
Potassium (%)[##]	0.86±0.03	0.94±0.02	1.23±0.02

[#]on fresh basis; [##]on dry matter basis.

the substrates. The HRT of all the substrates were under 30 days, as reported by Tomar (1995). HRT was found to be lower in summer. Similar observations were reported by Khoiyangbam *et al*. (2004) and Weiland (2010). This might be due to the increased atmospheric temperature in summer within a mesophilic temperature range, which accelerated the rate of gas production.

Mean biogas production (m^3) per day observed in the study with seasonal variations is presented in Table 2. The biogas production was observed to be significantly different among the substrates with rabbit excreta having the highest production followed by poultry and swine excreta. Similar results were reported by Itodo and Awulu (1999) and Callaghan *et al*. (1999). The result of Aubart *et al*. (1983) was in contrast with the observed results. According to them, gas production was higher with swine excreta than rabbit excreta. This may be due to the effect of the batch digesters used for his study. The microflora and fauna specific to the rabbit excreta may be a reason for the increased gas production.

Gas composition varied significantly among species ($p<0.01$) and between seasons ($p<0.01$). Gas production was significantly higher in summer in all three groups. This was supported by the findings of Khoiyangbam *et al*. (2004) and could be related to the findings of Divya *et al.* (2014), who reported that biogas production dropped in winter months due to the decrease in atmospheric temperature.

Seasonal variations in Methane and Carbon dioxide content of biogas produced while using different substrates are presented in Table 3. There was a significant difference among the substrates concerning methane and carbon dioxide composition of the biogas. Weiland (2010), stated that biogas production and composition depended upon the composition and biodegradability of the substrate. Since the substrate compositions were different, there was a significant difference in the methane and carbon dioxide composition of released biogas. Biogas from rabbit excreta had the highest methane content followed by that of poultry and swine. Carbon dioxide content was highest in biogas produced from swine excreta, followed by that from rabbit and poultry excreta. Deshmukh (2012) stated that the nature and composition of the substrate material dictated the microbial regime present inside the digester. Rabbit excreta might be having favourable indigenous methanogens and this might be the reason for the increased methane concentration.

The composition of biogas produced was different in monsoon and summer seasons. The methane concentration was higher and carbon dioxide concentration was lower in the biogas produced from all the substrates in summer compared to monsoon. Khoiyangbam *et al*. (2004) reported that methane emission increased with the elevation in monthly temperature and the methane release rate from the slurry displacement chambers of biogas plants were higher during these months. According to Adelekan and Bamgboye (2009), biogas production was greatest when the digester temperature was in the range of 32 to 40°C. Khalid *et al*. (2011) reported that temperature had significant effects on the microbial community, process kinetics, stability and methane yield. Therefore increased methane concentration in summer could be due to the influence of atmospheric temperature, which enhanced methanogenic activity.

Environmental parameters such as daily mean temperature, maximum temperature and daily mean RH were recorded and correlated with gas production. Observations in this regard are presented in Table 4. Correlation with micro-environment variables like daily mean temperature and daily mean RH were also computed. Highly significant positive correlations ($p<0.01$) were observed between biogas production and mean daily temperature as well as maximum temperature. Negative correlations were noted between relative humidity and biogas production. Similar findings were reported by Khoiyangbam *et al*. (2004) while contrasting observations were reported by Khalid *et al*. (2011). According to them, high temperatures lowered biogas

Table 2: Daily biogas production with respect to substrate and season.

Substrate	Gas production (m^3)		
	Monsoon	Summer	Overall mean
Swine excreta	0.0715±0.0002^{a}	0.0762±0.0002^{b}	0.0738^{c}±0.0004
Rabbit excreta	0.0773±0.0005^{c}	0.0854±0.0004^{d}	0.0813^{a}±0.0007
Poultry excreta	0.0747±0.0002^{e}	0.0810±0.0003^{f}	0.0778^{b}±0.0005

Means with different superscripts between rows and columns differed significantly ($p<0.01$).

Table 3: Seasonal variations in biogas production (m^3).

Type of	Methane (Mean ± SE)			Carbon dioxide (Mean ± SE)		
excreta	Season 1	Season 2	Overall mean	Season 1	Season 2	Overall mean
Swine	61.44±0.19^{a}	63.38±0.18^{b}	62.41±0.20**	29.86±0.19^{a}	26.28±0.24^{b}	28.07±0.32**
Rabbit	70.21±0.21^{c}	71.70±0.24^{d}	70.96 ±0.19**	25.31±0.14^{a}	23.78±0.14^{b}	24.54±0.15**
Poultry	65.81±0.20^{e}	67.94±0.16^{f}	66.87±0.21**	22.68±0.22^{a}	21.60±0.20^{b}	22.14±0.14**

Means bearing different superscripts between rows and columns differed significantly ($p<0.01$).

Table 4: Correlation of biogas production from different substrates with temperature and humidity.

Parameter	Correlation with weather variables			Correlation with Micro-environment variables		
	Swine	Rabbit	Poultry	Swine	Rabbit	Poultry
Daily mean temperature	0.822**	0.779**	0.862**	0.832**	0.788**	0.869**
Maximum temperature	0.864**	0.816**	0.890**	-	-	-
Daily mean RH	-0.856**	-0.830**	-0.877**	-0.852**	-0.829**	-0.869**

**Significant at 0.01 level; (-) shows negative correlation.

Table 5: Seasonal variations in temperature and pH of substrate and digesta.

Parameter	Swine excreta		Rabbit excreta		Poultry excreta	
	Monsoon	Summer	Monsoon	Summer	Monsoon	Summer
Temperature of substrate	26.77±0.28	31.23±0.51	27.09±0.28	32.28±0.49	26.4±0.27	31.70±0.49
pH of substrate	6.83±0.016	6.76±0.026	7.33±.033	7.31±0.022	7.08±0.038	6.96±0.042
Temperature of digesta	31.7±1.02	33.88±1.05	31.96±0.99	35.08±1.07	31.75±1.02	34.28±1.03
pH of digesta	7.0±0.12	6.86±0.11	7.18±0.16	7.14±0.10	7.16±0.16	6.98±0.11

Table 6: Correlation of temperature and pH of substrate and digesta with biogas production.

Parameter	Gas production from excreta of		
	Swine	Rabbit	Poultry
Substrate temperature	0.421^{ns}	0.457^{ns}	0.388^{ns}
Substrate pH	0.108^{ns}	0.015^{ns}	-0.211^{ns}
Digesta temperature	0.887**	0.868**	0.898**
Digesta pH	0.777**	0.531**	0.626**

**Significant at 0.01 level; ^{ns}Non-significant.

yield due to the production of volatile gases such as ammonia which suppressed methanogenic activity. However, during the present study, the atmospheric temperature remained within the mesophilic range (32 to 40°C), which favoured methanogenesis (Adelekan and Bamgboye, 2009). So, there was increased methane production with an increase in atmospheric temperature.

The correlations observed between substrate temperature, digesta temperature, substrate pH and digesta pH are presented in Table 6. The temperature and pH of the digesta had a significant positive correlation with gas production ($p<0.01$) but the substrate temperature and pH were not significantly correlated with gas volumes.

The results were similar to the reports by Yadvika *et al*. (2004), Yasin and Wasim (2011) and Rajendran *et al*. (2012). They observed that a neutral pH favoured biogas production since most of the methanogens grew at a pH range of 6.7 to 7.5. The pH of the digesta in the present study was in this range. In general, the elevation of pH resulted in increased biogas production, since the methanogens consumed volatile fatty acids produced in earlier stages and create alkalinity, (Ahn *et al*. 2010) resulting in higher gas production.

CONCLUSION

Based on the results, it can be concluded that rabbit excreta had the highest biogas production and methane concentration among the substrates. The biogas production was highest in the summer season with all the substrates. Gas production had a positive relation with atmospheric temperature, digesta temperature and digesta pH, whereas gas production had a negative relation with RH. The exact reason for significantly high biogas production from rabbit excreta is yet to be investigated.

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