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# Comparative Study on Biogas Production Between Certain Fecal Materials from Farm Animals

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**Abstract:** *The use of faecal materials from selected farm animals for the production of biogas was investigated. The considered farm animals were chicken (Gallus gallus domesticus), cattle (Bos taurus) and goat (Capra aegagrus hircus) hence, fresh poultry droppings (PD), cow dung (CD) and goat droppings (GD) were mixed in different PD:CD:GD ratios as 1:0:0, 1:1:1 and 0:1:0 and stored in an anaerobic digester for a retention period of 40days under mesophilic condition. The ratios were denoted as A, B and C, representing mono-digestion of poultry droppings, co-digestion of poultry droppings, cow dung with goat droppings, and mono-digestion of cow dung respectively. Results revealed that the daily biogas yield for samples A, B and C were 0.081, 0.0904 and 0.079mL per gram of feedstock respectively. Hence it was concluded that poultry droppings have higher biogas potential or yield than cow dung when digested individually while the co-digestion of all materials produce higher biogas yield than either of them. Necessary recommendation drawn from the research as well as those for further related studies were made.*

**Keywords:** Biogas, farm animals (Gallus gallus domesticus, Bos Taurus, Capra aegagrus hircus), Biomass, Hydrolysis, Optimal pH range, Alkalinity and pH.

## INTRODUCTION

The estimated number of cattle, gots and chicken in Nigeria as at the year 2021 were 21.16million, 76.29million and 180million respectively (FAOSTAT, 2021). Excessive amounts of feces from these huge number of farm animals may produce nitrate and ammonia gases, which can pollute the water supply, cause unpleasant odors, and harm people's health. Utilizing these feces as a source of raw materials for the production of biogas is an alternate strategy to tackle this issue. Methane, hydrogen, carbon dioxide, and other gases that are produced during the bacterial decomposition of organic materials without the presence of oxygen (anaerobic) make up biogas. According to Manyi-Loh *et al.* (2013), biomass is defined as ecologically dried components from living organisms that were present for a specific amount of time on the earth's surface. Among the various biomasses that can be turned into energy to provide more affordable and renewable energy sources are animal excrement and agricultural waste (Zheng *et al.*, 2011). Biogas majorly consists of 55 – 75% of methane ($CH_4$) and 25 – 45% of carbon dioxide ($CO_2$) with few proportions of other gases, particularly nitrogen (Ayhan *et al.*, 2016). During biogas production, the organic substance or biomass undergoes various stages of decomposition, including hydrolysis, acidogenesis, acetogenesis, and methanogenesis with each stage requiring different anaerobic microbes for the decomposition or conversion process. Nevertheless, co-digestion of different biomasseshas proven to enhance the production of biogas compared to mono-digestion of the same biomasses (Mroso *et al.*, 2023). Since animal excrement or fecal materials have been established to be useful biomass for biogas production, it is important to investigate the potential of the excrements of the said farm animals in producing biogas when co-digested to make necessary recommend. ations

## Experimental Procedures

## Materials and Methods

### Biogas as a Source of Renewable Energy

For a man to be comfortable and meet his basic demands in daily life, energy is a key necessity. Most developing nations are experiencing energy crises due to an overreliance on fossil fuels (Mohammad *et al.,* 2021; Gursan 2021). The need for alternative energy sources arises from predictions that fossil fuels like coal, gas, and oil will run out within the next 10 decades (Azam *et al.,* 2021). Due to the significant greenhouse gas emissions produced by fossil fuels and the resulting climate change, international treaties especially the Kyoto Protocol support the switch to renewable and low-carbon energy sources (Sahota *et al.,* 2018; Moreau 2022). Biogas has demonstrated considerable potential as a source of clean energy for home and commercial applications, as well as an effective response to the world's energy dilemma (Kumar *et al.*, 2018; Achinas *et al* 2017). There is growing interest in biogas as a substitute for renewable energy sources because of the rising usage of fossil fuels and environmental worries about greenhouse gas emissions and climate change (Pasterenak, 2021). Beyond providing sustenance for the whole human race, agriculture serves as the primary economic activity for almost two-thirds of the world's population (Sarkar *et al.,* 2020). Smallholder agriculture and related industries also make up the majority of the economies in many developing nations, directly or indirectly supporting 82% of the world's population (Sarkar *et al.,* 2020). The majority of developing nations struggle to provide their citizens with access to contemporary energy services. For instance, in India alone, 836 million people did not have access to modern energy in 2012 (Kabayi, 2013). The most effective tools and strategies for sustainable food and energy production are the creation and use of technology that conserves resources and income in agriculture (Sarkar *et al.,* 2020). Around 60% of the world's power is produced using fossil fuels including coal, oil, and gas, but in the first quarter of 2020, the share of renewable sources climbed from 26% to 28%, and the share of variable renewables increased from 8% to 9% (International Energy, 2020)

### Poultry Droppings as Biogas Feedstock

Poultry droppings have a great potential for bioenergy production through the anaerobic digestion process due to their high amount of total and volatile solids as well as highly biodegradable compounds (Elsamadony *et al*., 2015). The anaerobic digestion of poultry droppings is nevertheless constrained by several issues (Jurgutis *et al*., 2020). One such restriction is the high levels of ammonia and volatile fatty acids in poultry droppings, as well as the addition of antibiotics and heavy metals to poultry feed which consequently appear in the poultry droppings and hurt the anaerobic bacteria (Mahdy *et al*., 2020). Numerous methods have been documented to improve the anaerobic digestion of poultry droppings to get over these restrictions. Anaerobic co-digestion technology is one such method, which entails mixing the poultry droppings with additional feedstocks thus, reducing the amount of ammonia in the substrate and increasing the nutrients available to the anaerobes. It has been discovered that the addition of alternative feedstocks can improve biogas productivity and reduce inhibitory factors (Magbanua *et al.*, 2001; Wang *et al*,. 2022).

### Goat Droppings as Biogas Feedstock

Goat droppings are an ideal biomass for anaerobic digestion due to its high nitrogen content and fermentation stability (Wang *et al.*, 2006). It is significantly drier and more pH-balanced than poultry droppings and consequently composts faster (Tessa, 2016). It has been found by Wang *et al.* (2006) that fresh goat droppings have greater total nitrogen content than cow dung and swine manure, and it is resistant to the acidity that occurs during anaerobic fermentation.

Numerous researches have Goat feces has been found to be potential biomass of generating sizable quantity of biogas when applied properly. For instance, Usman *et al.* (2013) discovered that goat manure generated 0.18 $m^3$/kg of biogas.

### Co-Digestion in Biogas Production

The process of co-digestion involves combining two or more distinct feedstocks for anaerobic digestion, which yields biogas (Azaric *et al*., 2023). It has been earlier reported by Kangle *et al.* (2012) that co-digestion of wastes produces higher methane gas yields, which has a beneficial effect on the quality ($CH_4$ concentration) and quantity of biogas produced. Also, Aragaw *et al.* (2013) reported that co-digestion can significantly increase the biogas yields by 24 to 47% over their control (organic kitchen waste and dairy manure only). A wide range of organic materials can be used in co-digestion, including agricultural residues, municipal solid waste, and industrial waste (Azaric *et al*., 2023). Agricultural waste feedstocks include cow dung, poultry droppings, pig manure, crop residues, and food waste. Municipal solid waste feedstocks include organic fractions of municipal solid waste, such as food waste, yard waste, and paper. Industrial waste feedstocks include organic wastes from industrial processes, such as wastewater from food processing and paper manufacturing.

## Factors Affecting Biogas Production

An ideal fermentation process depends on a variety of factors, such as pH level, temperature, solids concentration, hydraulic retention time, volatile solids, organic loading rate, inoculum, carbon–nitrogen ratio, toxicity, ammonium ($NH_4$), and water content. These factors need to be controlled in the design and operation of anaerobic digestion reactors to maintain good treatment efficiency (Alastair *et al.*, 2008).

### Operating temperature

Operating at low temperatures slows down biological and chemical reactions as well as the growth of germs. When organic material degradation and suspended solids hydrolysis occur at low temperatures, the anaerobic digestion system's performance is severely constrained (El-Mashad and Zhang, 2010). Anaerobic microbes will stop growing at a minimal temperature. The entire internal microbe processes, including chemical and biological reactions as well as the growth rate of the bacteria, peak at elevated temperatures. Within the ideal range, the anaerobic degradation and treatment efficiency can produce the greatest outcomes. However, when temperatures rise above the ideal range, proteins, nucleic acids, and other cellular constituents will suffer irreversible damage, and the system will shut down as a result of the microorganisms ceasing to function (Luostarinen *et al.*, 2009). The reports of Chae *et al.* (2017) as well as Poh *et al.* (2009) suggested that a greater temperature may increase the rate of reaction, which in turn may encourage the use of more organic loading rate without compromising the effectiveness of organic removal. Furthermore, if the thermophilic temperature cannot be regulated, biomass washout might result in the accumulation of volatile fatty acids and the suppression of methanogenesis could also happen (Poh and Chong, 2009).

### Alkalinity and pH

The capacity of a solution to neutralise acids is measured by its alkalinity. It is necessary to keep the pH environment in the digester steady, which is necessary for the methanogenic bacteria to function at their best. The main bacteria that produce biogas, known as methanogens, prefer a high pH range, usually between 6.5 and 8.0 (Karthikeyan *et al.*, 2018). A pH decrease brought on by insufficient alkalinity might result in an acidic environment that prevents methanogen growth and activity. Process instability and a reduction in biogas production may follow from this. However, high alkalinity can also have a detrimental effect on the production of biogas since it can lead to an accumulation of ammonia, which is poisonous to methanogens (Rocha *et al.,* 2022).

The concentration of hydrogen ions ($H^+$) in a solution (i.e. pH), has a direct impact on how methanogens metabolise carbon. As was previously established, 6.5 to 8.0 is the ideal pH range for methanogenesis. Lower pH levels cause methanogen activity to decline, which in turn reduces the amount of biogas produced. On the other hand, pH levels higher than the ideal range can also hinder methanogenesis since ammonia is poisonous (Karthikeyan *et al*., 2018; Jayasinghe *et al*., 2021). Hence, to maximise the generation of biogas, a pH that is stable and within the ideal range must be monitored and maintained. The best digester conditions can be achieved with routine pH checks and modifications using the proper alkaline or acidic buffers (Rocha *et al.*, 2022). The ideal pH range for certain bacteria are shown in Table 1.

Table 1: Optimal pH range for specific methanogens

| Organism | pH Range | Reference |
|---|---|---|
| *Methanobacterium thermautotrophicum* | 6.0-7.0 | Ma *et al*., 2023 |
| *Methanosarcina barkeri* | 6.5-7.5 | Jayasinghe *et al*., 2021 |
| *Methanogenium candidum* | 6.8-7.2 | Jones *et al*., 2023 |
| *Methanosaeta concilii* | 6.8-7.3 | Karthikeyan *et al*., 2018 |
| *Methanomethylophilus alticus* | 6.2-7.2 | Shen *et al*., 2022 |

## Organic loading rate

The quantity of raw materials fed daily per unit volume of digester capacity is known as the loading rate. This resulted from the buildup of chemicals that caused impedance such as fatty acids, in the digester slurry (Arsova, 2010). Over feeding the digester will cause acids to build up and hinder the synthesis of methane since micro-bacteria cannot exist in an acidic environment. Anaerobic digester loading rates a critical factor that affects digester stability and biogas generation efficiency. According to Mata-Alvarez *et al.* (2011), organic loading rate is commonly stated in grams of volatile solids (VS) per liter per day.

To maximize biogas output and maintain digester stability, an ideal organic loading rate must be maintained. High organic loading rates have the potential to overwhelm the microbial community, which could result in reduced biogas generation, incomplete organic matter breakdown, and even digester collapse. Conversely, an extremely low organic loading rate may lead to digester capacity being underutilized, which would lower biogas output and raise operating expenses (Rocha *et al.*, 2022).

## Hydraulic retention time

Anaerobic digestion relies heavily on hydraulic retention time (HRT), which affects digester stability and biogas generation efficiency. It shows how long organic matter stays in the digester on average, enabling organic matter to break down and produce biogas (Jayasinghe *et al.*, 2021). The units used to express HRT are usually days or hours while the formula shown in equation above can be used to get the retention time in anaerobic digester

$$Retention\ time\ (days) = \frac{Operating\ volume\ V\ (m^3)}{Flow\ rate\ Q\ (\ m^3\ /day)}$$

The type of feedstock, the surrounding environment, and the planned use of the digested material all influence the hydraulic retention time (Ostrem and Themelis, 2004).

For digester stability and maximum biogas generation, an ideal hydraulic retention time must be maintained. A short hydraulic retention time may result in insufficient organic matter breakdown, which could lead to a reduction in biogas generation and the possible release of hazardous intermediates. On the other hand, a lengthy hydraulic retention time may result in less digester capacity being used efficiently, which would decrease biogas output and raise operational expenses (Rocha *et al.*, 2022).

## Preparation of substrates

Fresh cow dung (CD), poultry droppings (PD) and goat droppings of 2kg each, were separately collected in pristine polyethylene bags at Integrated Farm in Azikoro town (4.9429$^0$N, 6.3238$^0$E) and at a farm in Otuoke town (4.7944$^0$N, 6.3146$^0$E)), Bayelsa state. Prior to this, a pilot study was conducted on the mono-digestions of cow dung, poultry droppings and goat droppings and was found that the mono-digestion of the later was not performing well in terms of biogas yield hence, goat droppings was not mono-digested but rather co-digested. The collected faecal materials (biomasses) were mixed in different ratios of CD:PD:GD as 1:0:0, 0:1:0 and 1:1:1 thereafter, mixed with equal weight of water and denoted as samples A, B and C respectively. However, the exact quantity of the various biomasses used in mixing for each of the sample or experimental assay are given in Table 2.

Table 2: Proportion of feedstock components in bio-digester

| Assay ID | Ratio of Biomass (CD:PD:GD) | Quantity of Biomass (g) | | | Quantity of Water (g) |
|---|---|---|---|---|---|
| | | CD | PD | GD | |
| A | 1:0:0 | 750 | 0 | 0 | 750 |
| B | 0:1:0 | 0 | 750 | 0 | 750 |
| C | 1:1:1 | 250 | 250 | 250 | 750 |

Note: CD, GD and PD represent cow dung, goat droppings and poultry droppings respectively.

Each of the various biomass ratios shown in Table 3.1 together with the equal weight of water added were thoroughly mixed to form slurry then poured into a 1000mL plastic bottle (i.e. bio-digester) which occupies 80% of the volume. Thus, 20% free space in the bio-digester was kept to account for the formation biogas as well as rise of slurry during fermentation.

## Experimental set-up and data collection

The three bio-digesters containing different proportions of feedstocks (i.e. Assay A, B and C) were corked to maintain anaerobic condition, and kept outdoor (to ensure mesophilic condition) for 40days retention period. The daily quantity of biogas generated in the bio-digesters were determined using the downward water displacement method based on the report of Ogbozige (2023). It involves filling 500mL beaker and 100mL measuring cylinder with water, then submerging the filled measuring cylinder in an inverted form inside the filled beaker. The inverted submerged measuring cylinder was kept in vertical position by means of a retort stand and clamps. Thereafter, an IV infusion set was connected from the bio-digester to the inverted measuring cylinder as shown in Figure 3.1. This served as a channel for the flow of biogas from bio-digester to the measuring cylinders as the control valve of the flow channel in each experimental assay was opened. Thus, the flow of biogas into the measuring cylinder displaced equal volume of water out of the cylinder. Hence, the daily quantity of biogas produced was known by recording the volume of water displaced in the measuring cylinder for each day. However, while recording the daily quantity of biogas, it was ensured that the water in the measuring cylinder did not completely displaced hence, the measuring cylinder was constantly refilled after taking the reading for each day. The daily biogas production alongside the ambient temperature (at 12noon) was recorded throughout the 40days retention period.

Figure 1: Experimental set-up

## Analysis of data

The average daily biogas produced in each of the experimental assay was known by dividing the volume of the overall cumulative biogas (mL) by number of retention days. Thereafter, the quotient obtained was divided by the quantity of substrate (gram) introduced into the bio-digester, which gives the daily biogas yield or potential in mL per gram of substrate. The biogas yields for the various experimental assays (i.e. mono-digestion and co-digestion) were thereafter compared.

## RESULTS

The results of the cumulative biogas production from the various experimental assays are shown in Figure 2 while the biogas yield or potentials are presented in Table 3.

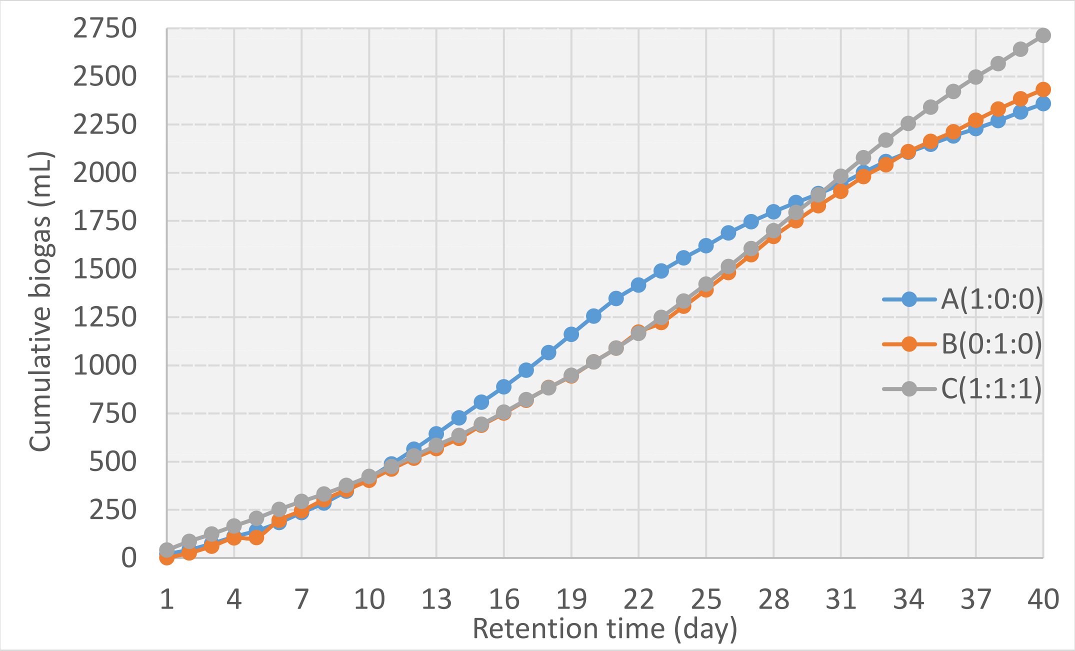

Figure 2: Cumulative biogas production

Table 3: Biogas potentials of considered experimental assays

| Assay ID | CD:PD:GD Ratio | Total quantity of Feedstock (gram) | Final cum. Biogas (mL) | Average daily biogas (mL) | Average daily biogas potential (mL per gram of feedstock) |
|---|---|---|---|---|---|
| A | 1:0:0 | 750 | 2358 | 58.95 | 0.0786 |
| B | 0:1:0 | 750 | 2431 | 60.78 | 0.0810 |
| C | 1:1:1 | 750 | 2712 | 67.80 | 0.0904 |

Note: PD, CD, GD and cum. represent poultry droppings, cow dung, goat droppings and cumulative respectively.

## DISCUSSION

The information in Table 4.1 clearly informed that the biogas yield for sample C being co-digestion of poultry droppings, cow dung and goat droppings was 0.0904mL per gram of feedstock used, while those for sample A and B being their respective mono-digestions were 0.0786 and 0.0810mL per gram of feedstock, in that order. In other words, the biogas yield for the co-digestion was higher than either of the mono-digestion processes. This buttressed the assertions of other related researchers on co-digestion including Fares and Rahul (2020), Nkodi *et al.* (2020) as well as Spyridon and Gerrit (2019). Notwithstanding, the biogas yield for mono-digestion of poultry droppings was higher than that of cow dung thus, affirming the reports of Imologie *et al.* (2017), Abdullahi *et al.* (2015) and Alfa *et al.* (2014) but negating the claim of Dankawu *et al.* (2022).

## CONCLUSION

The research has successfully investigated the biogas yields of selected fecal materials using simplified methodology that can serve as a guide to prospective related researchers. Hence, poultry droppings produced more biogas than cow dung when mono-digested since their daily biogas yield are respectively 0.081 and 0.079mL per gram of feedstock and the co-digestion of poultry droppings, cow dung and goat droppings produced more biogas than either of their mono-digestions as the biogas yield for the co-digestion is 0.0904mL per gram of feedstock, unlike their mono-digestions that were 0.079 and 0.081mL per gram of feedstock respectively.

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