OPEN ACCESS

Scholars International Journal of Chemistry and Material Sciences

Abbreviated Key Title: Sch Int J Chem Mater Sci
ISSN 2616-8669 (Print) | ISSN 2617-6556 (Online)
Scholars Middle East Publishers, Dubai, United Arab Emirates
Journal homepage: http://saudijournals.com

Original Research Article

Assessing the Suitability of Animal and Food Waste Samples for Biogas Production and Fertilizer Evaluation

Akinyemi Olufemi Ogunkeyede[1*], Adedoyin Olubunmi Bankole[1*], Uchenna Augusta Isinwa[1], Sunday Jonathan Raphael[2], Benjamin Chinedu Odoh[3], Efe Jeffery Isukuru[1], Rim-Rukeh Akpofure[1]

[1]Department of Environmental Management and Toxicology, College of Science, Federal University of Petroleum Resources, P.M.B., 1221, Effurun, Delta State, Nigeria
[2]Department of Mechanical Engineering, Cross River University of Technology, Calabar, P.M.B. 1123, Calabar, Cross River State, Nigeria
[3]Department of Biology and Environmental Sciences, University of New Haven, West Haven, 300 Boston Post Road West Haven, CT 06516, US

DOI: 10.36348/sijcms.2024.v07i06.001 | **Received:** 03.05.2024 | **Accepted:** 08.06.2024 | **Published:** 24.06.2024

***Corresponding author:** Akinyemi Olufemi Ogunkeyede & Adedoyin Olubunmi Bankole
Department of Environmental Management and Toxicology, College of Science, Federal University of Petroleum Resources, P.M.B., 1221, Effurun, Delta State, Nigeria Emails: ogunkeyede.akinyemi@fupre.edu.ng & adebayo.adedoyin@fupre.edu.ng

Abstract

With increasing concerns over fossil fuel depletion and environmental pollution, research into alternative energy sources has gained significant momentum. Organic wastes, particularly from animals and food, offer a promising substrate for biogas production, providing dual benefits of energy generation and waste reduction. This study evaluates the suitability of food waste, cow regurgitates, and cow dung for biogas production through biodigestion. The objectives were to design a lab-scale biodigester, compare biomethane yields from each waste, and evaluate their effectiveness as fertilizers. The results indicate that all three samples have properties within the acceptable range for digestion. Food waste exhibited the highest methane yield with a daily biogas production of 0.4979 m^3/day, corresponding to an energy content of 27,699.45 KJ/day. Cow regurgitates produced 0.2656 m^3/day of biogas, yielding an energy content of 14,739.6 KJ/day. Cow dung yielded 0.3213 m^3/day of biogas, translating to an energy content of 17,723.65 KJ/day. Microbial analysis indicated the presence of beneficial bacteria and fungi, such as *Staphylococcus spp, Proteus vulgaris, Escherichia coli, Enterobacter aerogens, Aspergillus spp,* and *Mucor spp,* which are advantageous for soil conditioning and nutrient cycling. The study highlights the importance of assessing physicochemical properties, nutrient content, and microbial composition to optimise biogas production and explore the potential of organic waste as a sustainable energy source and soil conditioner.

Keywords: Biogas production, Organic waste, Animal and food waste, soil conditioning, Biomethane yield.

1.0 INTRODUCTION

The escalating environmental concerns associated with food waste and cow dung require urgent attention due to their profound impact on the environment and human health. Food waste significantly contributes to greenhouse gas emissions, while cow dung is a prominent source of surface water pollution and eutrophication (DeMartini, 2017; Li *et al.*, 2021). Effective strategies are needed to mitigate these adverse effects, including source reduction of food waste, composting practices, and best management techniques for cow dung. Implementing these measures reduces greenhouse gas emissions, safeguards water quality, and enhances soil health, fostering a more sustainable future. However, the quantity of food losses and waste has surged, driven by the rapid expansion of the global economy and population (Sheahan *et al.*, 2017; Grote *et al.*, 2020). According to the Food and Agriculture Organization (FAO, 2013), approximately 33.3% of the food produced globally for human consumption—equivalent to 1.6 gigatons annually and valued at $750 billion—is lost or wasted throughout the food supply chain. This wastage inefficiently utilizes limited resources, exacerbating environmental degradation (Seberini, 2020; Barrera and Hertel, 2021). Urgent actions are required to address these challenges, develop sustainable practices, and meet the growing demands for food production while minimising the detrimental effects of food waste and cow dung on the environment.

Food waste is pervasive across the food supply chain, leading to significant losses in developed and developing countries (Sheahan *et al*., 2017; Mokrane *et al*., 2023). This waste contributes to greenhouse gas emissions, particularly methane and carbon dioxide released during landfill disposal, exacerbating global warming (Pucker *et al*., 2013; Gautam and Agrawal, 2021; Chen *et al*., 2023). Furthermore, food waste disrupts vital biogenic cycles, such as phosphorus and nitrogen, essential for agricultural fertilisation (Jama-Rodzeńska *et al*., 2021; Sutton *et al*., 2022). Anaerobic digestion (AD) has emerged as a promising technology for treating food waste and organic wastes, breaking down organic matter into biogas, predominantly composed of methane and carbon dioxide, with the potential for renewable energy and reduced emissions (Ma and Liu, 2019; Hoang *et al*., 2022). Anaerobic digestion holds significant potential in mitigating environmental impacts and offers a sustainable solution for energy recovery.

Despite its benefits, such as decreased greenhouse gas emissions and the production of valuable digestate for agricultural applications, the widespread implementation of anaerobic digestion faces challenges including high capital costs, extended retention times, and the need for precise control of operational parameters (Wang *et al.*, 2023). Nevertheless, AD holds great promise for energy recovery from organic wastes in Nigeria, including food waste, cow dung, and cow regurgitates. Biogas production from organic waste has gained significant attention due to its efficiency in mitigating greenhouse gas emissions (Atelge *et al.*, 2020; Perin *et al*., 2020; Shamurad *et al*., 2020; Obileke *et al*., 2022). In Nigeria, abundant organic wastes can be utilised as substrates for biogas production, with cow dung showing an average methane composition of 50% and co-digestion of food waste with cow dung enhancing methane yield and quality (Awasthi *et al*., 2018; Obileke *et al*., 2022).

Exploring the use of cow regurgitates as a substrate for biogas production is a relatively new research area with the potential to improve process efficiency. Harnessing the energy potential of food waste, cow regurgitates, and cow dung offers numerous advantages, including the mitigation of greenhouse gas emissions, reduced dependence on fossil fuels, and the potential for job creation and cost savings in waste disposal (Schmidt and Mohr, 2018; USEPA, 2021). This work uses food waste, cow dung, and cow regurgitates as renewable energy sources. The objectives are to design a lab-scale biodigester, compare biomethane yields from each waste, and evaluate their effectiveness as energy sources and fertilizers.

2.0 MATERIALS AND METHODS

2.1 Sample Collection

Fresh food waste (comprising mainly carbohydrates and proteins), cattle dung, and cattle regurgitation were collected for the study. The food waste was collected from Tutu's canteen on PTI Road, while the fresh cattle dung and regurgitation were collected from the major abattoir in the Osubi metropolis. The waste materials were hand-picked and kept in black synthetic polymers before they were transported to the laboratory for further preparation. To achieve a uniform size of particles measuring approximately 5 mm, the food waste underwent homogenization for 1 minute using a kitchen blender. The food waste, cow dung, and cow regurgitation were each weighed using a manual measuring scale to obtain 8 kg of each waste substrate.

2.2 Preparation of Digester

In this experiment, a 20-litre Polyethylene Terephthalate (PET) container was used as the digester. Three sets of 20-litre PET digesters were used, with each digester labelled according to the substrate it contained. The three samples were grouped as follows: Sample A contained food wastes, Sample B contained cow regurgitates, and Sample C contained cow dung.

To allow gas flow from the digester to the storage chamber, hoses were provided. The digester was covered with black synthetic polymers to prevent algae growth in the presence of light. The setup used in this experiment was a batch digester, and each digester was completely sealed with adhesives to close leakages. Delivery tubes were also connected to the digesters to transport the gas from the biodigester tank to the gas receiver.

The digesters were allowed to undergo anaerobic digestion for a retention period of 30 days, operating at a temperature between 28 -30ºC. See Figure 1 below for a visual representation of the black synthetic polymer covering used in this experiment.

Figure 1: Experimental biodigester setup

2.3 Preparation of Slurry

Different slurries were formed from the weighed samples using an electronic blender to aid the decomposition of the feedstock. Each 8 kg of the blended food wastes, cow dung, and cow dung were mixed thoroughly with 8 liters of water (1:1) in a 20L plastic bucket and mixed properly to obtain a homogeneous mixture before feeding into the biodigester to about 70% of the biodigester capacity. The water was added to dilute the organic substances and to increase the breeding of microorganisms (Prakash and Singh, 2013).

2.4 Physicochemical Analysis

The following parameters were checked for the fresh slurry and the digested slurry.

2.4.1 Determination of pH and Temperature in Sample

The pH and temperature of the sample were determined using an electrometric method (APHA 4500-H+ B). The electrode of the pH meter was rinsed copiously with distilled water. The equipment was calibrated with different buffers (Buffer 7.0, 4.0, and 11.0). About 100 ml of the substrate was poured into a clean 100-mL capacity beaker, and the electrode end of the meter was inserted into the sample. The READ button was pressed and the pH reading was recorded when the value stabilized. The MODE of the meter was then switched to Temperature, and the value was recorded. This method was repeated in triplicates.

2.5 Analysis of the Digestate

2.5.2 Procedure of Total Nitrogen (NH_4-N) using regular Macro-Kjeldahl method

Total nitrogen was determined using the Macro-Kjeldahl method (APHA, 2017). The sample (5 g) was mixed with distilled water (20 mL) in a 500 mL Macro Kjeldahl flask, and 1 g of K_2SO_4-HgO and 10 g of K_2SO_4 were added, followed by 30 mL of concentrated H_2SO_4. The mixture was digested for 5 hours on a digesting stand. After cooling, the digested sample was transferred to a clean Macro Kjeldahl flask (750 mL), retaining all sand particles in the original digestion flask. The distillate was collected, and the NH_4-N was determined by titration with 0.01N standard HCl (or H_2SO_4) using a 25 mL burette. The percentage of Nitrogen (% N) in the sample was calculated.

2.5.3 Determination of Moisture Content

Moisture content was determined for the sample by the gravimetric method (APHA, 2017). The sample was spread evenly in a pan and weighed as Wt. of Wet

Sample (A). The pan was heated in an oven at 110°C ± 5°C until the sample achieved a fixed weight. Weights were taken every hour until two successive weights were the same, confirming the drying process. The weight of the water removed (D) was calculated, and the weight of the dry sample (E) was obtained. The moisture content of the sample was then calculated using the formula:

$$Moisture\ Content\ (\%) = (\frac{\text{Weight of Water}}{\text{Weight of Sample}})x\ 100\%$$

2.5.4 Total Solids Determination

The total solids (TS %) were determined by weighing approximately 10 g of the sample and pouring it into a foil plate. The sample was then dried to a constant weight at about 105°C in a furnace. The TS % was calculated using the formula:

TS % = (Final weight/Initial weight) x 100

2.5.5 Volatile Solids Determination

The volatile solids (VS %) were determined by weighing the dried residue from.

2.6 Analysis of Carbon Dioxide, Nitrogen and Methane Gas Generated in the Biodigester

The analysis of carbon dioxide, nitrogen, and methane gas was carried out, and after a period, specific equipment was used to measure the concentrations of methane gas and total nitrogen. The methane gas, nitrogen, and carbon dioxide concentrations were analysed through a gas chromatograph that incorporated a flame ionization detector manufactured by Hewlett Packard's HP 68050 series. On the other hand, photometric kits produced by Merck in the USA were employed to measure the total nitrogen levels. These analytical techniques were crucial in determining the precise concentrations of the gases under investigation.

2.7 Biogas Production and Energy Calculation from Different Feedstocks

Electricity generation from biogas is a multi-faceted process that hinges on harnessing the methane gas produced through the biogas production system. To assess the potential for energy production and methane content, the biogas yield can be calculated. This calculation is expressed through the following formula:

$$Biogas\ yield, G\ (m^3) = \frac{Y\ x\ V_d\ x\ V_s}{1000}$$

G = Biogas yield (m^3)
Y = Biogas production rate (m^3/ton)
V_d = Volume of digester (m^3)
V_s = Volatile solids content (kg)

Table 1 shows the biogas production rates at various retention times and temperatures, showing the optimal conditions for maximizing biogas yield.

Table 1: Biogas Production Rates at Various Retention Times and Temperatures

Feedstock retention time (in days)	**Temperature (°C)**					
	16-18	**19-21**	**22-24**	**25-27**	**28-30**	**31-33**
06 -10	5.41	7.98	10.8	13.6	15.9	18.3
11 -15	4.73	6.79	8.99	11.1	12.9	14.7
16-20	4.21	5.9	7.68	9.37	10.8	12.3
21-25	3.79	5.22	6.7	8.11	9.33	10.6
26-30	3.44	4.69	5.95	7.15	8.2	9.28
31-35	3.16	4.25	5.35	6.39	7.32	8.26
36-40	2.91	3.88	4.86	5.78	6.6	7.44
41-45	2.71	3.58	4.45	5.27	6.02	6.77
46-50	2.53	3.32	4.1	4.85	5.53	6.21
51-55	2.37	3.09	3.81	4.49	5.11	5.74
56-60	2.23	2.89	3.55	4.18	4.75	5.33
61-65	2.1	2.72	3.33	3.91	4.44	4.98
66-70	1.99	2.57	3.13	3.67	4.17	4.67
71-75	1.89	2.43	2.95	3.46	3.93	4.4
76-80	1.8	2.3	2.8	3.27	3.71	4.15
81-85	1.72	2.19	2.66	3.1	3.52	3.94
86-90	1.65	2.09	2.53	2.95	3.34	3.74
91-95	1.58	2	2.41	2.81	3.19	3.56
96-100	1.52	1.92	2.31	2.69	3.04	3.4

The important parameter for the yield factor (S), which is determined as follows:

$$Yield\ factor, S\ = \frac{V_s}{V_f}$$

In this context, Vs stands for the volatile solids per day (measured in kg/day), and V_f represents the feedstock volume per day (measured in m^3/day). Utilizing this formula allows for the accurate estimation of daily biogas production potential from each biodigester setup, a crucial step in efficient electricity generation.

The subsequent stage involves converting the methane gas into energy, measured in joules. This is achieved by considering the concept of calorific values, which denote the quantities of heat energy released during the complete combustion of a substance. For methane gas, the calorific value is approximately 55.5 megajoules per cubic meter (MJ/m³) or 55,500 kilojoules per cubic meter (KJ/m³).

The formula for this conversion is as follows:

$$\text{Energy (Joules)} = \text{Value of Methane (in cubic meters)} \times \text{Calorific Values}$$

In this equation, the "Value of Methane" represents the amount of methane gas produced, typically measured in cubic meters. By multiplying this value by the calorific values and conversion factor of 0.65 m^3 of methane to biogas, one can determine the energy content of the biogas in joules.

2.8 Statistical Analysis

All the experiments were conducted in triplicate, and the results were expressed as mean ± standard deviation which was processed using Microsoft Excel version 16.

3.0 RESULTS AND DISCUSSIONS

3.1 Physicochemical Properties of Animal and Food Waste Samples before Biodigestion

The physicochemical properties of animal and food waste samples before bio digestion for biogas production are shown in Figure 2. Three samples, namely sample A (food waste), sample B (cow regurgitates), and sample C (cow dung), were collected, and their properties were analysed. The following parameters were determined for each sample: pH, temperature, total organic carbon (TOC), total nitrogen, C: N ratio, moisture content, total solids (TS), and volatile solids (VS).

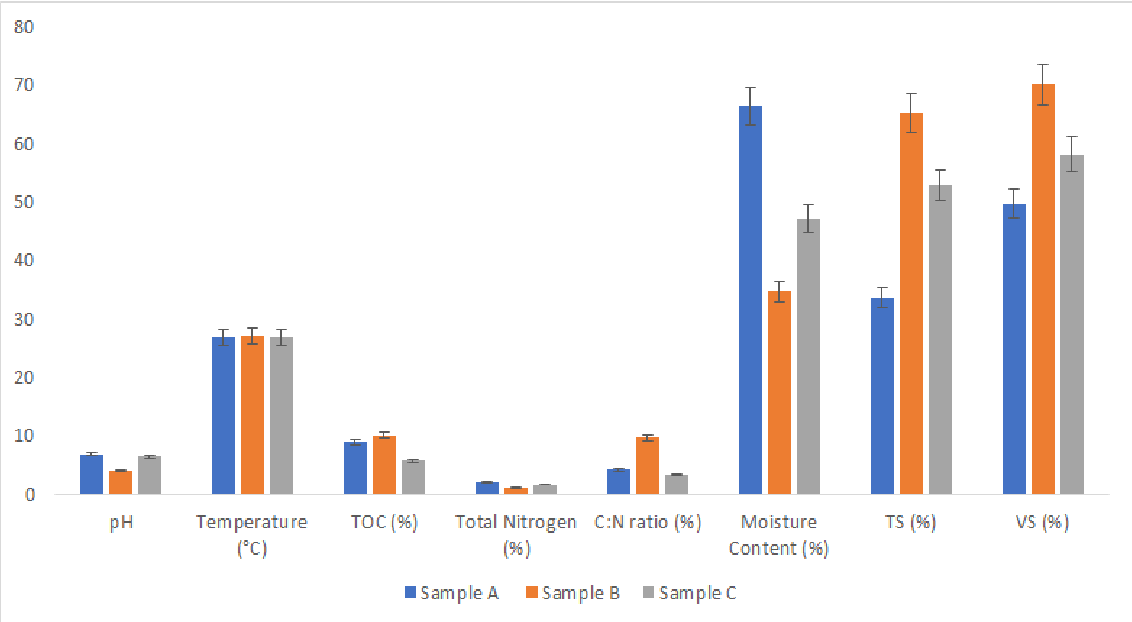

Figure 2: Physicochemical Properties of Animal and Food Waste Samples

3.1.1 pH and Temperature

The pH and temperature of the samples were determined to assess their suitability for biodigestion. The results show that sample A has a pH of 6.89, which is slightly acidic but still within the acceptable range for biodigestion. Sample B has a pH of 4.08, which is more acidic and may require pH adjustment before biodigestion. Sample C has a pH of 6.41, which is also within the acceptable range. The temperature of the samples was found to be similar, with samples A, B, and C having temperatures of 26.9 °C, 27.1 °C, and 26.8 °C, respectively.

3.1.2 Total Organic Carbon (TOC) and Total Nitrogen

Total Organic Carbon (TOC) and total nitrogen were analyzed to determine the nutrient content of the samples. The results show that sample A has a TOC of 8.94%, which indicates that it contains a relatively high amount of organic matter. Sample B has a TOC of 10.01%, which is higher than sample A, indicating that cow regurgitates are rich in organic matter. Sample C has a TOC of 5.67%, which is the lowest among the three samples. Total nitrogen analysis shows that sample A has the highest total nitrogen content of 2.11%, followed by sample C with 1.68%, and sample B with the lowest total nitrogen content of 1.04%.

3.1.3 Carbon: Nitrogen (C: N) Ratio

The C: N ratio of the samples was calculated to assess their suitability for biogas production. The results showed that sample A has a C: N ratio of 4.24, which is within the optimum range for biogas production. Sample B has a C: N ratio of 9.63, which is higher than the recommended range and may require the addition of nitrogen-rich substrates to enhance biogas production. Sample C has the lowest C: N ratio of 3.38, which indicates that it contains a higher amount of nitrogen than carbon.

3.1.4 Moisture Content, Total Solids (TS), and Volatile Solids (VS)

Moisture content, TS, and VS were determined to assess the water-holding capacity and the organic matter content of the samples. The results show that sample A has the highest moisture content of 66.4%, followed by sample C with 47.2%, and sample B with the lowest moisture content of 34.7%. Sample B has the highest TS and VS content of 65.3% and 70.1%, respectively, indicating that cow regurgitates have a high organic matter content. Sample A has the lowest TS and VS content of 33.6% and 49.7%, respectively, while sample C has TS and VS content of 52.8% and 58.2%, respectively. The results of all samples before being kept in the PET bottles for biogas production suggest that the samples are suitable for biogas production, although sample B (cow regurgitates) may require additional nitrogen-rich substrates to optimize biogas production.

3.2 Comparing Biogas Production from Different Substrates

The biogas production was observed from the fourth day in all three digesters, indicating the breakdown of organic matter in the feedstock. Figure 3 shows the quantity of biogas from the three different waste samples used in this study for 30 days. The quantity of gas generated suggests that food waste is the most efficient substrate for biogas production in terms of methane yield, as it produced the highest amount of methane (116.8 ppm) followed by cow regurgitates (4.11 ppm) and cow dung (1.57 ppm). In terms of nitrogen content, cow dung had the highest amount (76.2 ppm) followed by cow regurgitates (72.3 ppm) and food waste (7.27 ppm). Biogas is a renewable energy source that can be generated by anaerobically digesting organic Methane is the main component of biogas and can be used as a fuel for heating, electricity generation, or transportation.

Nitrogen is a crucial component in the growth of microorganisms that break down organic material during anaerobic digestion, indicating that samples with higher nitrogen content may be more effective in biogas production. Lastly, cow regurgitates produced the highest amount of carbon dioxide (12.6 ppm) followed by cow dung (7.99 ppm) and food waste (0 ppm). Although carbon dioxide is not the primary component of biogas, it is a by-product of the anaerobic digestion process and can be harnessed for various applications.

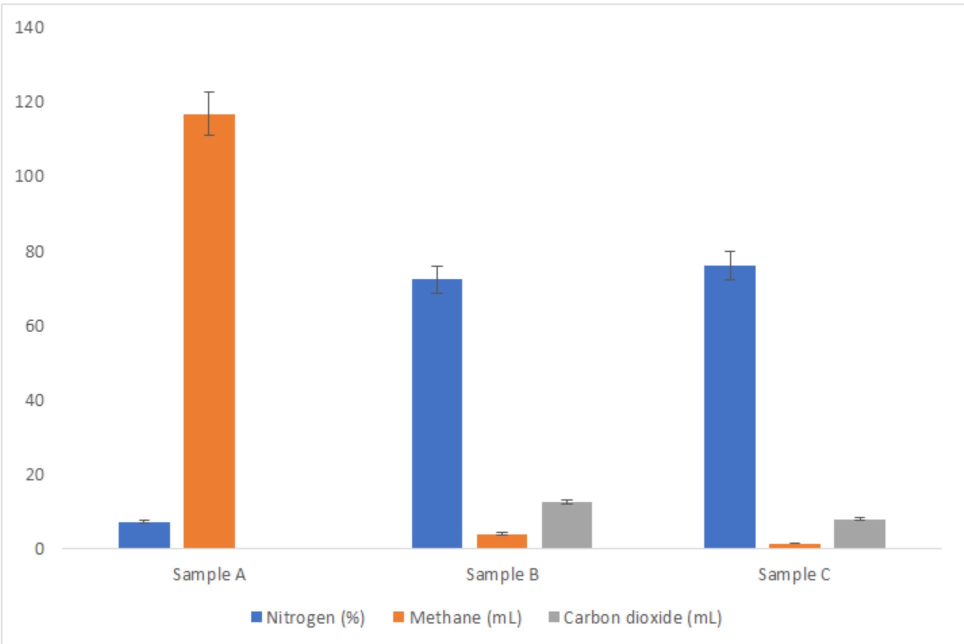

Figure 3: Comparison of Biogas Production from Food Waste, Cow Regurgitates, and Cow Dung

The amount of methane produced from each substrate varied, with the waste from food-producing the highest amount of 116.8 mL due to its high volatile solid content of 49.7%. On the other hand, cow dung and cow regurgitation produced 1925 mL and 1650 mL, respectively. It can be inferred that the digestion of the organic waste substrate progressed faster than the other substrates. This could be attributed to the presence of unused energy in the food waste, which provides the necessary nutrients for the microbes to survive and facilitate an effective digestion process. Additionally, the volume of each feedstock did not correspond to the same mass, and the amount of volatile solid per kilogram varied. As a result, variations in the amount of gas generated were inevitable. The amount of biogas generated in this study was similar to what was generated in a biodigester system containing food waste that was kept for 30 days (Mohan and Jagadeesan, 2013).

3.3 Microbial Analysis and pH Evaluation of Organic Waste Materials for Anaerobic Digestion

The microbial population isolated from the digestate of the biodigester is shown in Table 2 below. The pH values from the study are an important indicator of the acidity or alkalinity of the waste material. Anaerobic digestion is most effective at a pH of around 7.0 to 8.0 (Wang *et al*., 2021). The pH values in this study were below this range, with the lowest value of 3.49 found in food waste. This suggests that the waste material may need to be adjusted to a more neutral pH before anaerobic digestion can take place. The microbial population isolated from the digestates after biogas generation in this study includes *Staphylococcus spp*, *Proteus vulgaris*, *Escherichia coli*, *Enterobacter aerogens*, *Aspergillus spp*, and *Mucor spp*. The presence of these organisms in the organic waste materials makes it an excellent soil conditioner and fertilizer, as evidenced by the fertilization test on cow dung. This statement is supported by the fact that the microbial analysis shows high counts of bacteria and fungi in the samples, which are essential for plant growth and nutrient cycling in the soil.

Table 2: Microbial Analysis Results of Food Waste, Cow Dung, and Cow Regurgitation Used for Anaerobic Digestion

Components	Unit	Food Waste	Cow Dung	Cow Regurgitation
pH		3.49	5.21	4.86
Total Bacteria Count	cfu/ml	19.61×10^8	21.27×10^8	15.48×10^8
Total Fungi Count	cfu/ml	6.3×10^3	4.9×10^3	4.1×10^3
Bacteria Isolates		*Staphylococcus spp., Proteus vulgaris*	*Escherichia coli, Staphylococcus spp., Enterobacter aerogens*	*Enterobacter aerogens, Staphylococcus spp.*
Fungi Isolates		*Aspergillus spp., Mucor spp*	*Aspergillus spp*	*Aspergillus spp*

The total bacteria count, and total fungi count are also important factors to consider in anaerobic digestion. These microorganisms play a crucial role in the breakdown of organic matter and the production of biogas (Koniuszewska *et al*., 2020; Xu *et al*., 2022). The high bacterial and fungal counts in cow dung and cow regurgitation could indicate that these materials are good candidates for anaerobic digestion. However, some of the bacterial isolates identified in the samples, such as *Escherichia coli* and *Staphylococcus spp.*, can cause health problems in humans and animals (Alzaben *et al*., 2022). It is important to ensure that these pathogens are properly cautious is ensured during the anaerobic digestion process.

3.4 Evaluation of the Fertilization Potential of Digested Slurry

Digestion wastes were used as fertilizers for the growing of *Phaseolus vulgaris* plant species after being dried and blended. Three forms of fertilizers—waste food, cow dung, and cow regurgitation—were successfully used to fertilise all the plants, except for the organic kitchen waste. Three plants were given treatments with each type of fertilizer to study their effects, while a neutral plant served as the control. Plate 1 to 3 shows the four plants' starting levels as they were recorded. The four plants were similar in height and had about the same number of branches.

Plate 1: Food waste slurry

Plate 2: Cow dung slurry

Plate 3: Cow regurgitation slurry

The experimental findings indicate that the plant treated with cow regurgitation exhibited the highest growth, attaining a height of 9 cm. Subsequently, the cow dung fertilizer resulted in the second-highest plant growth, measuring 7 cm. In contrast, the control plant recorded a growth of 5 cm. According to Olowolafe (2008), plants mainly absorb three primary nutrients, namely, nitrogen, phosphorus, and potassium. Secondary nutrients, including calcium, magnesium, and sulfur, are also essential in significant quantities. Additionally, micronutrients, such as manganese, iron, zinc, and boron, are necessary in moderate amounts. Cow dung is an effective organic fertilizer because it contains high levels of nitrogen (N), phosphorus (P), and potassium (K), which enhance plant growth. In a comparative study by Abidemi (2011), cow dung demonstrated the highest levels of nitrogen, phosphate, and potassium in contrast to chicken, sheep, or goat dung.

3.5 Calculating Daily Biogas Production and Energy Content for Different Feedstocks

We applied the formula for biogas generation earlier mentioned in the methodology section to calculate the daily biogas production (G) and the energy content for three different feedstocks: food waste, cow regurgitation, and cow dung.

For Food Waste:
First, adjust the daily biogas production:

$$G = 0.65 \times 0.7654\mathrm{m^3/day} = 0.4979\mathrm{m^3/day}$$

Now, calculate the energy content using the adjusted biogas value and the given calorific value of methane:

$$\text{Energy (in joules)} = 0.4979\mathrm{m^3/day} \times 55{,}500\mathrm{KJ/m^3} = 27{,}699.45\mathrm{KJ/day}$$

For Cow Regurgitation:
First, adjust the daily biogas production:

$$G = 0.65 \times 0.4084\mathrm{m^3/day} = 0.2656\mathrm{m^3/day}$$

Now, calculate the energy content using the adjusted biogas value and the given calorific value of methane:

$$\text{Energy (in joules)} = 0.2656\mathrm{m^3/day} \times 55{,}500\mathrm{KJ/m^3} = 14{,}739.6\mathrm{KJ/day}$$

For Cow Dung:
First, adjust the daily biogas production:

$$G = 0.65 \times 0.4941\mathrm{m^3/day} = 0.3213\mathrm{m^3/day}$$

Now, calculate the energy content using the adjusted biogas value and the given calorific value of methane:

$$\text{Energy (in joules)} = 0.3213\mathrm{m^3/day} \times 55{,}500\mathrm{KJ/m^3} = 17{,}723.65\mathrm{KJ/day}$$

These adjusted calculations take into account a 0.65 factor to convert biogas values to methane values, providing the energy content (in joules) for each of the specified feedstocks when used for biogas generation.

The quantification of daily biogas production and the determination of energy content from different feedstocks are essential aspects in the assessment of biogas generation systems. In this study, we have applied a rigorous methodology to calculate daily biogas production and energy content for three distinct feedstocks: food waste, cow regurgitation, and cow dung. Our calculations have been meticulously adjusted to account for the conversion of biogas values to methane values using a scientifically justified factor of 0.65, thus providing precise estimates of the energy content (in joules) for each specified feedstock.

3.5.1 Food Waste

Our results indicate that, after adjustment, food waste yields a daily biogas production of approximately 0.49 $\mathrm{m^3/day}$, corresponding to an energy content of 27,699.45 KJ/day. These findings are of particular significance in the context of sustainable waste management and energy recovery. Food waste, a prevalent byproduct of human activities, possesses substantial untapped energy potential when subjected to anaerobic digestion. The energy content of food waste-derived biogas underscores its viability as a renewable energy source, capable of reducing environmental pollution and enhancing resource efficiency.

3.5.2 Cow Regurgitation

When considering cow regurgitation as a feedstock for biogas generation, our calculations reveal a daily biogas production of approximately 0.2656 m³/day, with an associated energy content of 14,739.6 KJ/day. It is important to acknowledge that cow regurgitation, although a less conventional feedstock, can serve as a valuable resource for biogas production. The energy content quantified in this study sheds light on the potential for sustainable energy generation in agricultural settings and highlights the need for further research into optimizing the utilization of this resource.

3.5.3 Cow Dung

For cow dung, our adjusted calculations yield a daily biogas production of about 0.3213 m³/day, resulting in an energy content of 17,723.65 KJ/day. Cow dung has long been recognized as a valuable substrate for biogas production due to its widespread availability. The quantified energy content emphasizes the role of cow dung as an environmentally friendly and economically viable source of biogas. This has implications for rural communities and agricultural sectors seeking to harness the energy potential of livestock waste.

The conversion factor of 0.65 applied in our calculations is based on the well-established assumption that biogas primarily consists of methane. While this factor is widely accepted, it is important to acknowledge that the composition of biogas can vary depending on several factors, including the nature of the feedstock, operating conditions, and microbial activity. Further research is warranted to explore the impact of these variables on biogas composition and energy content.

It is crucial to recognize that the potential benefits of biogas production extend beyond energy generation. Biogas systems offer a sustainable approach to waste management, reducing the release of methane—a potent greenhouse gas—from landfills and mitigating environmental pollution. Moreover, the revenue generated from biogas energy can contribute to the economic viability of waste-to-energy projects.

The precise determination of daily biogas production and energy content for different feedstocks is pivotal in evaluating the feasibility and sustainability of biogas systems. The results presented in this study exemplify the untapped potential of organic waste materials in addressing both energy needs and environmental concerns. As we move toward a more sustainable and circular economy, the findings presented here underscore the importance of continued research and development in the field of biogas technology. This knowledge will not only enable the efficient utilization of organic resources but also facilitate the transition to a more environmentally responsible and energy-secure future.

4.0 CONCLUSION

This study demonstrates that food waste, cow regurgitates, and cow dung are viable substrates for biogas production, with food waste yielding the highest methane. Adjustments in pH and additional nitrogen sources may enhance biogas yields from cow regurgitates. Microbial analysis confirms the presence of beneficial organisms for soil health. Future research should explore optimizing digestion conditions and scaling up the process for industrial applications. These findings support the potential of using organic waste for renewable energy and soil conditioning, offering a sustainable solution for waste management.

REFERENCES

- Abidemi, O. O. (2011). An assessment of the nitrogen, phosphorus, and potassium levels of some animal wastes as organic fertilizer source. *Electronic Journal of Environmental, Agricultural & Food Chemistry*, *10*(3).
- Alzaben, F., Fat'hi, S., Elbehiry, A., Alsugair, M., Marzouk, E., Abalkhail, A., & Hamada, M. (2022). Laboratory Diagnostic Methods and Antibiotic Resistance Patterns of Staphylococcus aureus and Escherichia coli Strains: An Evolving Human Health Challenge. *Diagnostics*, *12*(11), 2645. https://doi.org/10.3390/diagnostics12112645.
- American Public Health Association (APHA). (2017). Standard Methods for the Examination of Water and Wastewater (23rd ed.). American Public Health Association.
- Atelge, M. R., Krisa, D., Kumar, G., Eskicioglu, C., Nguyen, D. D., Chang, S. W., ... & Unalan, S. (2020). Biogas production from organic waste: recent progress and perspectives. *Waste and Biomass Valorization*, *11*, 1019-1040. https://doi.org/10.1007/s12649-018-00546-0
- Awasthi, S. K., Joshi, R., Dhar, H., Verma, S., Awasthi, M. K., Varjani, S., Sarsaiya, S., Zhang, Z., & Kumar, S. (2018). Improving methane yield and quality via co-digestion of cow dung mixed with food waste. *Bioresource technology*, 251, 259–263. https://doi.org/10.1016/j.biortech.2017.12.063.
- Barrera, E. L., & Hertel, T. (2021). Global food waste across the income spectrum: Implications for food prices, production and resource use. *Food Policy*, 98, 101874. https://doi.org/10.1016/j.foodpol.2020.101874
- Chen, Y., Pinegar, L., Immonen, J., & Powell, K. M. (2023). Conversion of food waste to renewable energy: A techno-economic and environmental assessment. *Journal of Cleaner Production*, 385, 135741. https://doi.org/10.1016/j.jclepro.2022.135741
- DeMartini, A. (2017). Reducing the environmental impact of cows' waste. News article. College of Food, Agricultural, and Environmental Sciences. Ohio State University. https://cfaes.osu.edu/news/articles/reducing-the-environmental-impact-cows-waste.
- Food Wastage Footprint (Project). (2013). Food wastage footprint: impacts on natural resources: summary report. Food & Agriculture Org. https://www.fao.org/3/i3347e/i3347e.pdf

- Gautam, M., & Agrawal, M. (2021). Greenhouse gas emissions from municipal solid waste management: a review of global scenario. Carbon footprint case studies: municipal solid waste management, sustainable road transport and carbon sequestration, 123-160. DOI: 10.1007/978-981-15-9577-6_5
- Grote, U., Fasse, A., Nguyen, T. T., & Erenstein, O. (2020). Food Security and the Dynamics of Wheat and Maize Value Chains in Africa and Asia. *Frontiers in Sustainable Food Systems*, 4, 617009. https://doi.org/10.3389/fsufs.2020.617009
- Hoang, A. T., Goldfarb, J. L., Foley, A. M., Lichtfouse, E., Kumar, M., Xiao, L., Ahmed, S. F., Said, Z., Luque, R., Bui, V. G., & Nguyen, X. P. (2022). Production of biochar from crop residues and its application for anaerobic digestion. *Bioresource Technology*, 363, 127970. https://doi.org/10.1016/j.biortech.2022.127970
- Jama-Rodzeńska, A., Białowiec, A., Koziel, J. A., & Sowiński, J. (2021). Waste to phosphorus: A transdisciplinary solution to P recovery from wastewater based on the TRIZ approach. *Journal of Environmental Management*, 287, 112235. https://doi.org/10.1016/j.jenvman.2021.112235
- Koniuszewska, I., Korzeniewska, E., Harnisz, M., & Czatzkowska, M. (2020). Intensification of biogas production using various technologies: A review. *International Journal of Energy Research, 44*(8), 6240-6258. https://doi.org/10.1002/er.5338.
- Li, Y., Zhao, J., Krooneman, J., & Euverink, G. J. W. (2021). Strategies to boost anaerobic digestion performance of cow dung: Laboratory achievements and their full-scale application potential. *Science of The Total Environment*, *755*(Part 1), 142940. https://doi.org/10.1016/j.scitotenv.2020.142940
- Ma, Y., & Liu, Y. (2019). Turning food waste to energy and resources towards a great environmental and economic sustainability: An innovative integrated biological approach. *Biotechnology advances, 37*(7), 107414. https://doi.org/10.1016/j.biotechadv.2019.06.013.
- Mohan, S., & Jagadeesan, K. (2013). Production of Biogas by Using Food Waste. *International Journal of Engineering Research and Applications (IJERA), 3*(4), 390-394.
- Mokrane, S., Buonocore, E., Capone, R., & Franzese, P. P. (2023). Exploring the global scientific literature on food waste and loss. *Sustainability*, *15*(6), 4757. https://doi.org/10.3390/su15064757
- Obileke, K., Makaka, G., & Nwokolo, N. (2022). Efficient Methane Production from Anaerobic Digestion of Cow Dung: An Optimization Approach. *Challenges*, *13*(2), 53. https://doi.org/10.3390/challe13020053
- Olowolafe, E. A. (2008). Effects of using municipal waste as fertilizer on soil properties in Jos area, Nigeria. *Resources, Conservation and Recycling, 52*(11), 1266-1270. https://doi.org/10.1016/j.resconrec.2008.07.005.
- Perin, J. K. H., Borth, P. L. B., Torrecilhas, A. R., da Cunha, L. S., Kuroda, E. K., & Fernandes, F. (2020). Optimization of methane production parameters during anaerobic co-digestion of food waste and garden waste. *Journal of cleaner production*, *272*, 123130. https://doi.org/10.1016/j.jclepro.2020.123130
- Prakash, E. V., & Singh, L. P. (2013). Methanogenesis of vegetable and fruit waste in co digestion process. *International Journal of Advanced Engineering and Emerging Technology, 3*(6), 2250-2459.
- Pucker, J., Jungmeier, G., Siegl, S., & Pötsch, E. M. (2013). Anaerobic digestion of agricultural and other substrates–implications for greenhouse gas emissions. *Animal, 7*(s2), 283-291. DOI: https://doi.org/10.1017/S1751731113000840.
- Schmidt, L., & Mohr, A. (2018). Biofuels from cow dung? A review and a feasibility study by using the example of Germany. *Renewable and Sustainable Energy Reviews*, 82, 3927-3936. https://doi.org/10.1016/j.rser.2017.10.039
- Seberini, A. (2020). Economic, social and environmental world impacts of food waste on society and Zero waste as a global approach to their elimination. In SHS Web of Conferences (Vol. 74, p. 03010). EDP Sciences.
- Shamurad, B., Sallis, P., Petropoulos, E., Tabraiz, S., Ospina, C., Leary, P., ... & Gray, N. (2020). Stable biogas production from single-stage anaerobic digestion of food waste. *Applied energy*, *263*, 114609. https://doi.org/10.1016/j.apenergy.2020.114609
- Sheahan, M., & Barrett, C. B. (2017). Review: Food loss and waste in Sub-Saharan Africa. *Food Policy*, 70, 1-12. https://doi.org/10.1016/j.foodpol.2017.03.012
- Sutton, M. A., Howard, C. M., Mason, K. E., Brownlie, W. J., & Cordovil, C. (2022). Nitrogen opportunities for agriculture, food & environment. UNECE guidance document on integrated sustainable nitrogen management. https://unece.org/sites/default/files/2022-11/UNECE_NitroOpps%20red.pdf
- United States Environmental Protection Agency. (2021). Food recovery hierarchy. https://www.epa.gov/sustainable-management-food/food-recovery-hierarchy
- Wang, P., Sakhno, Y., Adhikari, S., Peng, H., Jaisi, D., Soneye, T., & Wang, Q. (2021). Effect of ammonia removal and biochar detoxification on anaerobic digestion of aqueous phase from municipal sludge hydrothermal liquefaction. *Bioresource Technology*, 326, 124730. https://doi.org/10.1016/j.biortech.2021.124730.
- Wang, Z., Hu, Y., Wang, S., Wu, G., & Zhan, X. (2023). A critical review on dry anaerobic digestion

of organic waste: Characteristics, operational conditions, and improvement strategies. *Renewable and Sustainable Energy Reviews*, 176, 113208. https://doi.org/10.1016/j.rser.2023.113208

- Xu, M., Yang, M., Sun, H., Meng, J., Li, Y., Gao, M., & Wu, C. (2022). Role of multistage inoculation on the co-composting of food waste and biogas residue. *Bioresource Technology*, 361, 127681. https://doi.org/10.1016/j.biortech.2022.127681.