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Optimizing Biogas Production by Anaerobic Co-Digestion of Poultry Dropping and Litter at Mesophilic Temperature and pH

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Abstract

The purpose of this study is to determine the ideal mesophilic temperature and pH range for producing biogas from chicken waste. Three substrate samples poultry droppings, poultry litter, and a combination of poultry droppings and litter were used in the investigation, which was carried out in a laboratory-sized biogas reactor. Ten kilograms of substrates and ten liters of water were combined to create the slurry for each sample, which was then put into a different reactor with the same mesophilic temperature setting. According to the results, temperature has an impact on the amount of biogas produced from the substrates. The ideal mesophilic temperature range for biogas output is 37.01–38 °C. Additionally, the ideal biogas yield is influenced by a pH range of 6.66-7.02m. In comparison to the yield of 1917 cm^3 for poultry dropping, and 1884 cm^3 for poultry litter, the optimal cumulative biogas yield of 2258 cm^3 was obtained for the co-digestion of poultry dropping and litter.

Keywords: Biogas, Temperature, pH, Poultry dropping, Poultry litter.

1 | Introduction

Fuel and energy issues are the biggest problem facing humanity in the twenty-first century since there are more and more energy-consuming industries and fossil fuels, which provide the majority of the energy used by these companies, are running out [1]–[4]. Finding clean, affordable, and sustainable energy alternatives has become crucial for maintaining both environmental sustainability and global economic stability, as the pollution caused by these fossil fuels is a significant global issue [5], [6]. In order to reduce their dependency on fossil fuels and guarantee the sustainable use of these resources, industrialized and semi-industrialized countries are looking for alternative energy sources [7]–[9]. Furthermore, reliance on oil and gas has decreased as a result of rising oil and gas prices brought on by global economic expansion and rising energy use.

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Furthermore, the large amount of organic waste produced by chicken raising raises serious environmental challenges, such as pollution and waste management problems; therefore, it is crucial to find a way to use chicken waste to produce biogas. This study investigates the possibility of using anaerobic digestion to turn chicken manure into biogas, as a sustainable energy source and waste management technique for cities. A better environment, sustainable energy, high-quality fertilizer, and localized energy creation are just a few advantages of producing biogas. Developing creative, locally appropriate renewable energy solutions is essential to addressing the issues of the energy crisis and climate change, especially in developing nations [10], [12]. Fossil fuels must give way to renewable energy sources as a result of climate change, a major worldwide problem. Because of the worldwide energy crisis and environmental air pollution, building biogas plants is necessary for optimal usage in the search for sustainable energy solutions and efficient waste management techniques [13]–[16]. Biogas can be generated from a variety of organic wastes using such technology and knowledge.

The effectiveness of anaerobic bio-digestion, a well-known and proven process for turning waste into useful products, needs to be improved, particularly in light of climate unpredictability. Anaerobic digestion has historically operated best in a sterile, oxygen-free environment [17], [18]. As a renewable energy source, biogas provides a sustainable alternative to liquefied petroleum gas and natural gas. Anaerobic digestion of a variety of organic wastes, including animal manures such as chicken waste, sewage sludge, food waste, and agricultural waste, can yield biogas [19–23]. In particular, waste from the production, processing, and consumption of chicken is referred to as poultry waste. This comprises mortality (dead birds and offal), litter (bedding materials), manure (droppings from chickens, ducks, and turkeys, among other poultry droppings), and processing waste (blood, feathers, and other byproducts from poultry processing) [24]. Because of its large volume, nutrient richness, and potential for pollution if improperly managed, poultry manure presents serious environmental concerns. Poultry waste can, however, be turned into a useful resource with the right handling and use. For chicken waste to be managed and used effectively, it must be handled, stored, and treated appropriately to maximize its benefits and reduce its negative effects on the environment. Because of its high organic matter content (rich in proteins, fats, and carbohydrates), nutrient-rich composition (rich in potassium, nitrogen, and phosphorus), moisture content (suitable moisture content for anaerobic digestion), and carbon to nitrogen ratio (which can be balanced to maximize microbial growth and biogas production), poultry waste is an excellent substrate for the production of biogas [24].

Additionally, for the best biogas yield, some of the operating factors like pH and temperature are crucial. investigated the anaerobic digestion of primary sludge and found that the pH value had an impact on the synthesis of Volatile Fatty Acids (VFAs) during the biogas generation process [25]. The generation of VFAs, especially propionic acid, was enhanced by anaerobic digestion of waste-activated sludge under alkaline conditions [26]. This process can also boost the production of VFAs from primary sludge [27], [28]. In order to produce biogas from all biowastes, it is crucial to investigate the pH parameter in the anaerobic digestion process. Temperature is another factor that needs to be taken into account while developing the biogas manufacturing process. A number of researchers are looking into the 25–55°C temperature range in biogas production processes [29], [30]. Vanegas and Bartlett [31] discovered that mesophilic reactors (35 °C) generated more biogas than the other two reactors for seaweed biomass when psychrophilic, mesophilic, and thermophilic reactors were examined for biogas generation. The production of biogas from sheep dung has also been investigated utilizing a range of methods at mesophilic controlled temperatures [32], [33]. Determining the impact of temperature and pH on the optimum production of biogas from poultry waste is therefore essential.

2 | Materials and Methods

2.1 | Materials

For this study, the following materials and equipment were used: a laboratory scale biogas reactor, a thermometer, a weighing balance, a funnel, a pH meter, a polytene bag, chicken litter and droppings, a connecting tube, and water.

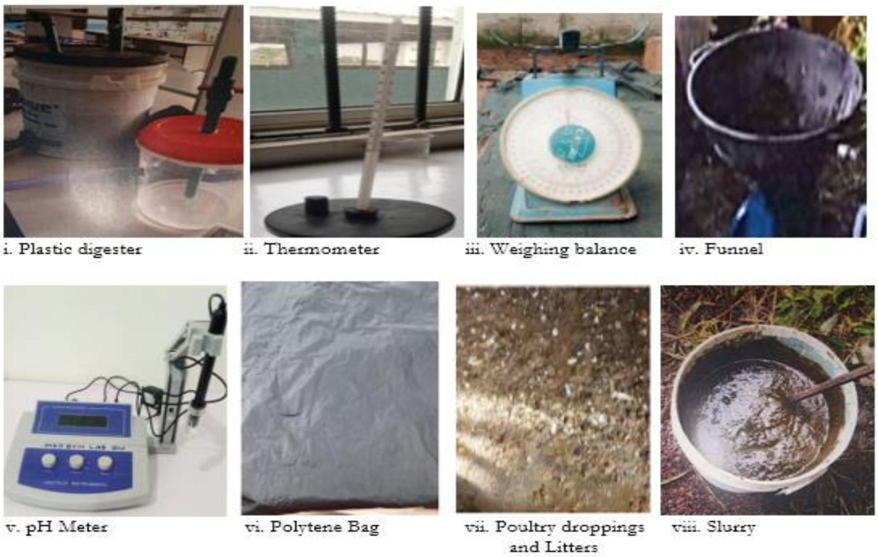

Fig. 1. List of equipment and materials.

2.2 | Preliminary Trial Study

Two substrates from distinct sources were used to consider three samples: sample A (poultry dropping), sample B (poultry litter), and sample C (a mixture of poultry droppings and litter).

2.3 | Sample Collection

The Iyahamo Osagie (IO) and Benson Idahosa University poultry farms provided the poultry dropping (pure feces of the poultry) and poultry litter (a mixture of bedding material, manure, and feathers that result from intensive poultry production).

2.3 | Experimental Setup

Separately, the litter and poultry dropping utilized in this project were pulverized into a tiny size. The anaerobic digestion process was conducted in a 20-liter plastic container with a self-designed plastic containment system; a second container was filled with water to collect gas and had rubber tubes for gas evacuation. The water displacement method was used to collect the biogas generated by anaerobic digestion, and all of the containers were sealed with airtight rubber stoppers [2], [34]. The amount of water that moved from the first bottle into the second as a result of the gas pressure that accumulated inside the containers was used to calculate the amount of biogas that was produced. The slurry was made by co-digesting the litter and dropping (sample C), digesting the poultry dropping separately (sample A), and digesting the poultry litter separately (sample B). Ten (10 kg) kilograms of ground substrates were weighed and thoroughly combined with ten liters of water to create a 1:1 ratio in each individual and co-digested sample. Under identical conditions, the mixtures of samples A-C were digested and co-digested in a separate biogas reactors. As advised by [18], anaerobic digestion and co-digestion were permitted for complete hydraulic retention time at the ideal mesophilic temperature range of 35°C to 38°C. The biogas reactors were shaken twice a day (morning and evening) to allow digestion to occur throughout the medium, and the bio-digester was covered with black polythene sheets *Fig. 1* primarily to maintain the optimal mesophilic temperature. Also, the black polythene sheets will prevent light penetration that could encourage the growth of algae, and trap the heat that had been absorbed during the day. Throughout the digestion and co-digestion period, measurements and records of temperature, pH, and gas production volume were made every three days. A waterproof pH meter was used to monitor the slurry's pH, and a thermometer was used to assess its temperature. By placing the thermometer and pH meter probe into the slurry exit pipe, the temperature and pH of the slurry were measured and recorded.

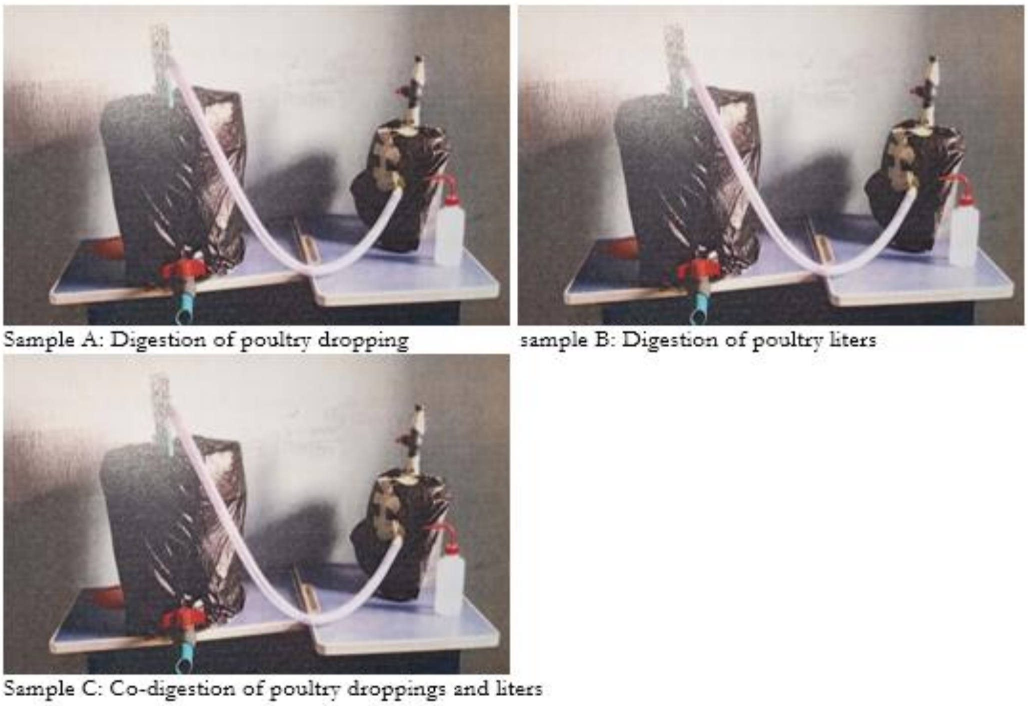

Fig. 2. Experimental setup.

3 | Results and Discussion

Tables 1-3 display the findings for samples A, B, and C.

Table 1. Results of digestion of poultry droppings sample (A).

Days	Temperature (^{0}C)	pH (m)	Biogas Yields (cm^3)	
			3 Days Interval	Cumulative
3	36.33	6.01	0	0
6	36.78	6.25	250	250
9	36.00	6.50	252	502
12	36.68	7.23	234	736
15	37.01	6.66	280	1016
18	37.12	6.86	287	1303
21	38.00	6.88	324	1627
24	37.45	6.82	290	1917
∑	295.37	53.21	1917	1917
Ave.	36.92	6.65	239.63	239.63

Table 2. Results of digestion of poultry liters sample (B).

Days	Temperature (⁰C)	pH (m)	Biogas Yields (cm³)	
			3 Days Interval	Cumulative
3	36.33	5.35	0	0
6	36.78	5.45	0	0
9	36.00	6.38	201	201
12	36.68	7.45	154	355
15	37.01	6.65	220	575
18	37.12	6.66	260	835
21	38.00	6.67	262	1097
24	37.45	6.68	270	1367
27	37.86	6.67	260	1627
30	37.85	6.67	257	1884
∑	371.08	64.43	1884	1884
Ave.	37.11	6.44	188.40	188.40

Table 3. Results of co-digestion of poultry droppings and liters sample (C).

Days	Temperature (⁰C)	pH (m)	Biogas Yields (cm³)	
			3 Days Interval	Cumulative
3	36.33	6.01	0	0
6	36.78	6.05	256	256
9	36.00	6.55	248	504
12	36.68	7.18	257	761
15	37.01	6.69	263	1024
18	37.12	6.78	293	1317
21	38.00	7.02	345	1662
24	37.45	6.99	299	1961
27	37.86	6.98	297	2258
∑	332.23	60.65	225.8	2258
Ave.	37.03	6.74	250.89	250.89

Figs. 3 and *4* display the biogas yield results. It was noted that the three samples' biogas output began as early as possible. For samples A and C, biogas production began on the sixth day, whereas sample C's production began on the ninth. Additionally, the 21st day of digested and co-digested substrates produced the largest biogas yields in samples A and C, but the 24th day was the case for sample B. Previous studies have demonstrated that, in contrast to other substrates [2], [7], [34] animal waste undergoes early digestion because of the bacteria present, leading to the formation of biogas. As a result, they make excellent seeding agents for biogas reactors [35]. While biogas generation without microorganisms takes longer days, biogas production with microbes in any slurry begins virtually instantly [35], [36]. The particle sizes of the substrates were another element that might have improved the three samples' early biogas generation. The collected poultry feces was ground up and appropriately combined with water in a 1:1 ratio for this study. Particle reduction through crushing, grinding, and shredding is necessary because feedstock sizes directly impact its decomposition, as previously observed [37], [38]. Microbes have a larger surface area when feedstock sizes are reduced, which eventually increases the digester's efficiency [37]. Additionally, mixing speeds up the biological conversion process and increases the rate of AD process kinetics [39]. However, sample B took six more days to complete than sample A and three more days to complete than sample C since it began biogas yielding on the ninth day and terminated production on the thirty-first day, in contrast to samples A and C. Spilled feed, feathers, and certain bedding materials, like wood shavings or sawdust, that combined with the poultry droppings are what caused the longer days in sample B. All biodegradable organic materials can be broken down by anaerobic bacteria. However, the amount of biodegradable organic matter utilized determines the rate of digestion [40]. While certain organic materials require a longer hydraulic retention period, others can be readily broken down in a shorter amount of time. For example, compared to vegetables, organic matter containing a high lignin content will take longer to digest [41], [42]. Therefore, substrates that contain enough microorganisms decrease hydraulic retention time therefore improves biogas output.

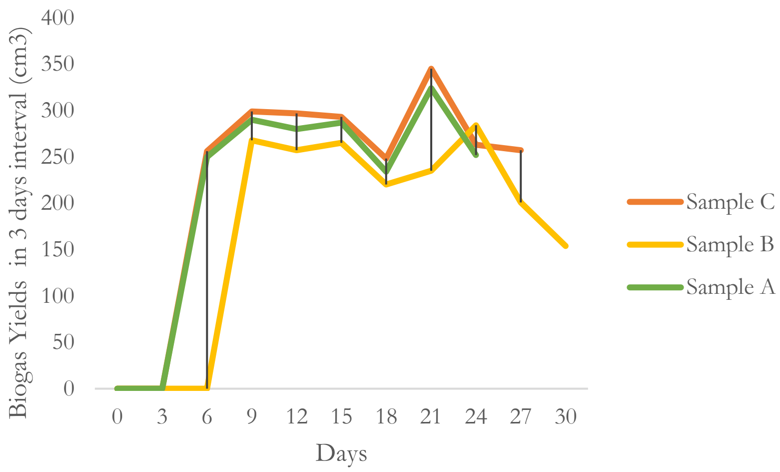

Fig. 3. Biogas yields in 3 days interval (cm³).

Co-digestion of substrates can result in optimal biogas yields under the same environmental circumstances of mesophilic temperature, according to the results of biogas yield as shown in *Fig. 3*, cumulative biogas yields as shown in *Fig. 4*, and average biogas yield *Fig. 5*. In comparison to the yield of 1917 cm³ and 1884 cm³ for the digestion of poultry dropping and poultry litter, the optimal cumulative biogas yield of 2258 cm³ was obtained when both substrates (poultry dropping and litter) were co-digested. Due to the generation of ammonia and VFAs, which suppress methanogenic-forming bacteria and, consequently, biogas yield, sole digestion of substrates in ADs might cause unsteadiness [2]. Co-digestion of various substrates is regarded as a beneficial way to get around the drawbacks of substrate digestion alone. Because of the beneficial interactions in the acclimation media, anaerobic co-digestion increases the synthesis of methane [2], [7].

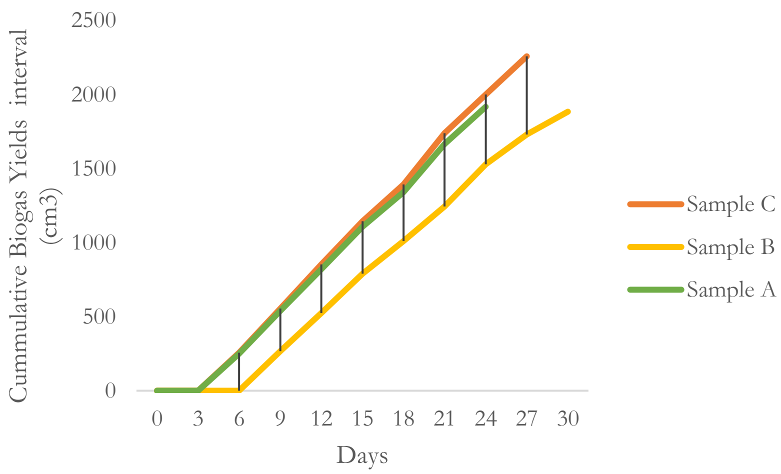

Fig. 4. Cumulative biogas yields (cm³).

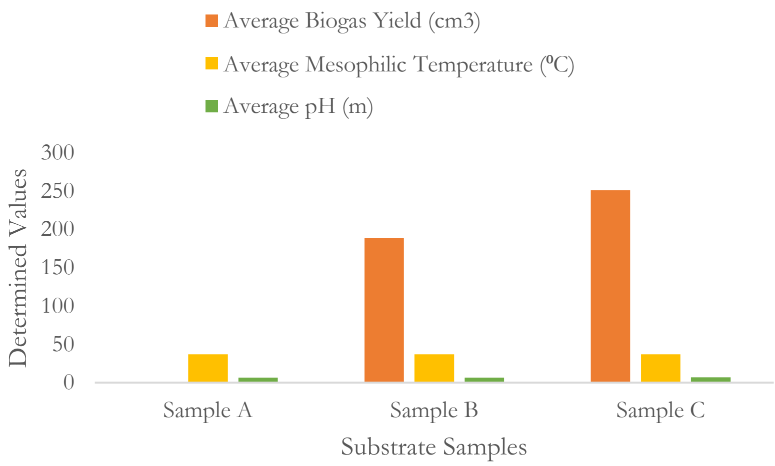

Fig. 5. Evaluation of average biogas yield.

The examination of pH values during substrate digestion and co-digestion is displayed in *Fig. 6* The solution was initially acidic in each of the substrate samples, which was clearly a sign that hydrolysis was occurring in the system [25]. The initial generation of VFAs, especially propionic acid, was boosted by anaerobic digestion of substrates. This process can also increase the production of VFAs from primary sludge [27], [28]. In order to produce biogas from all biowastes, it is crucial to investigate the pH parameter in the anaerobic digestion process. Ammonia, on the other hand, is free during the protein degradation process and reaches its maximum concentration in the reactor on the first day of sample A-C. However, as demonstrated on day 12 through the conclusion of the hydraulic retention period for all samples, the buffering structure created by the presence of these substances creates an environment where pH is maintained at levels higher than 6.5 m, guaranteeing appropriate acid–base environments for methanogenic bacteria to function [27], [43]. Additionally, all samples had pH ranges between 5.35 and 7.45 m *Figs. 7* and *9*, with sample B achieving the highest pH values at 7.45 m.

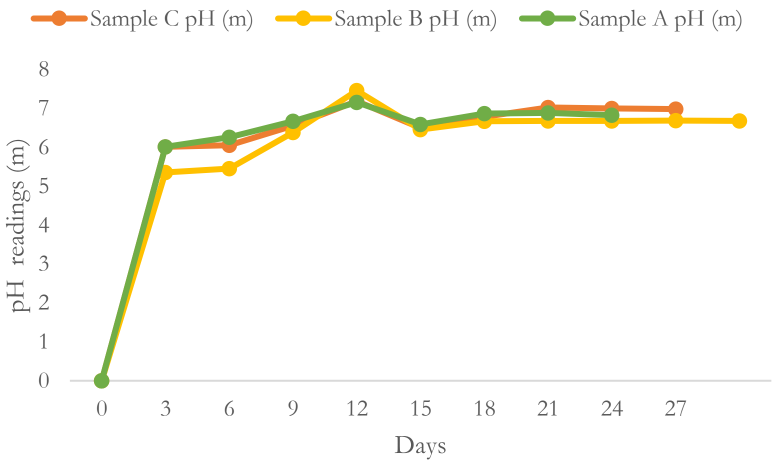

Fig. 6. Evaluation of pH readings (m).

Any energy grid may gain from implementing the ideal circumstances found in this study, which include neutral pH, mesophilic temperature, and a broad range of carbon-to-nitrogen ratios, in a scale-up procedure. As seen in *Tables 1* and *3* and *Figs. 7* and *9*, the results suggest that mesophilic temperature ranges between 37.01 and 38 °C, as well as maintaining a pH level between 6.66 and 7.02 m, are ideal for generating the highest biogas outputs from the digestion and co-digestion of poultry dropping and litter.

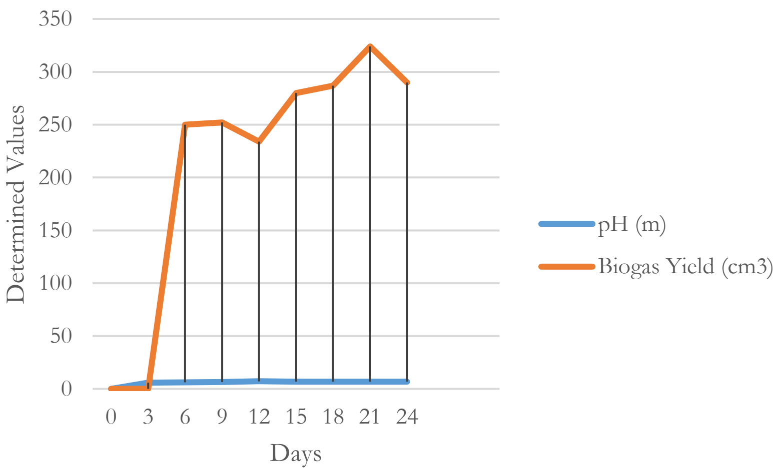

Fig. 7. Effect of pH on biogas yield for anaerobic digestion of poultry dropping.

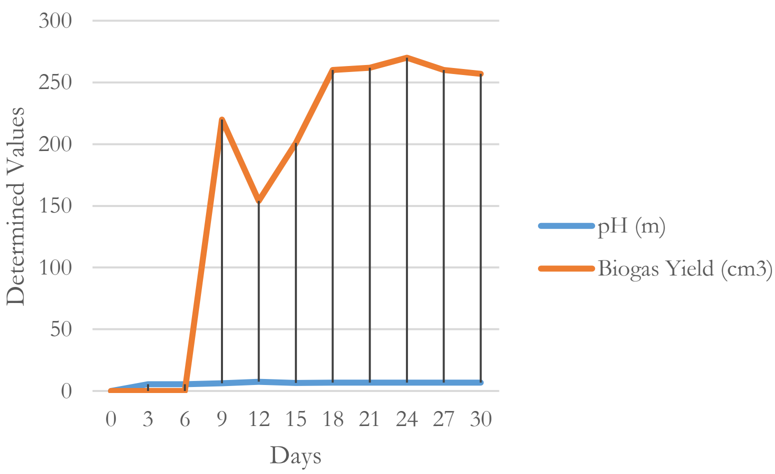

Fig. 8. Effect of pH on biogas yield for anaerobic digestion of poultry litters.

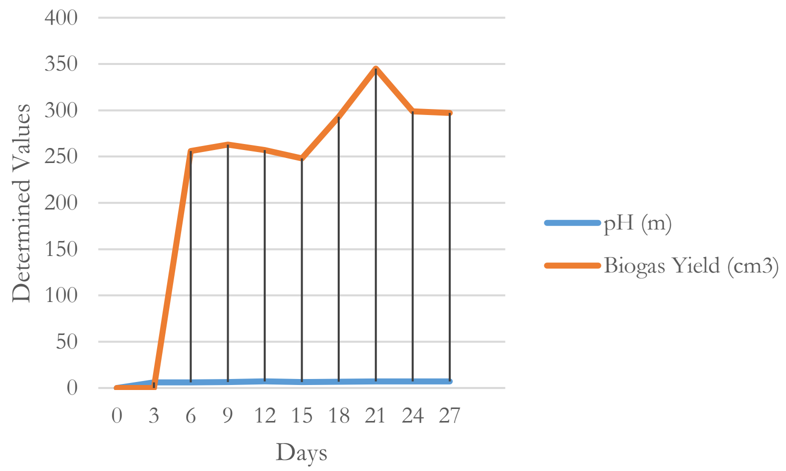

Fig. 9. Effect of pH on biogas yield for anaerobic co-digestion of poultry dropping and litters.

The experiment was carried out at the same mesophilic temperature conditions, as shown in *Fig. 10*. It required 24 days for the digestion of the dropping, 30 days for the digestion of the poultry litter, and 27 days for the co-digestion of the dropping and poultry litter. Additionally, 36–38°C was the mesophilic temperature range. The temperature variation did not abruptly shift. Bacterial populations are inhibited by abrupt changes and swings in the process temperature. Therefore, for efficient results and stable anaerobic digestion plant operation to be attained, controlling the process temperature always is required [44]. In general, optimum mesophilic temperature brings about shorter hydraulic retention time (more production of biogas) since more methanogenic bacteria are working upon substrate [18]. The optimum mesophilic temperature for biogas yield was obtained for a mesophilic temperature range of 37.01 °C to 38 °C, as shown in *Figs. 10* and *11* and *Tables 1* and *3*.

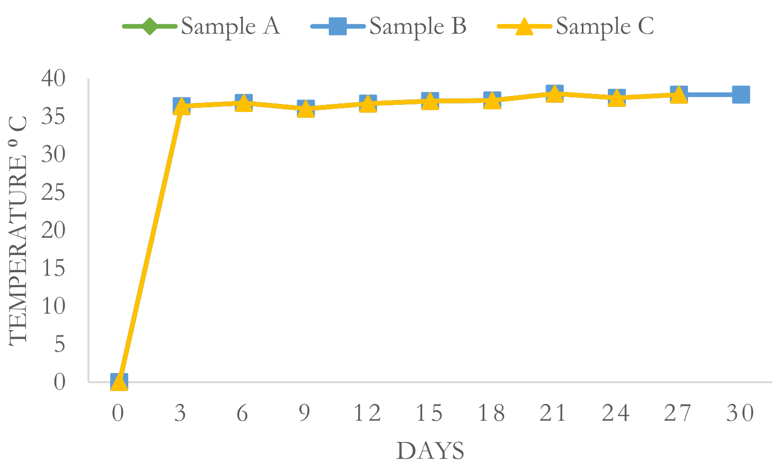

Fig. 10. Evaluation of mesophilic temperature against days of digestion and co-digestion.

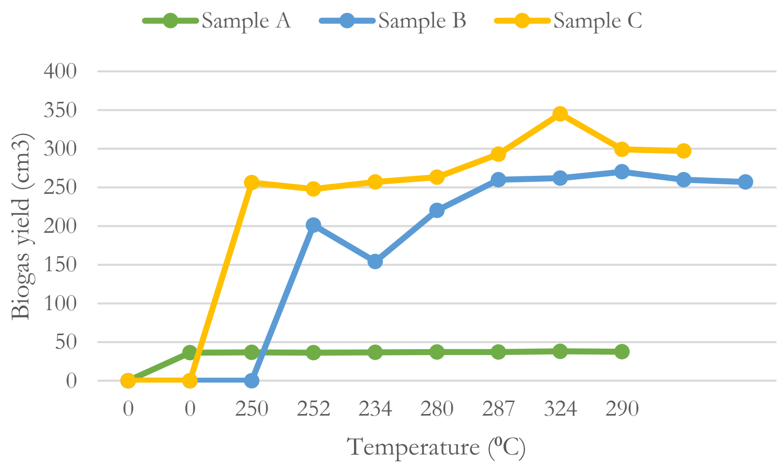

Fig. 11. Evaluation of mesophilic temperature against biogas yield for digestion and co-digestion of poultry dropping and litters.

4 | Conclusion

According to the study's findings, poultry dropping and litter could be a good substrate for the production of biogas, but a better inoculum is required. By using this substrate to produce biogas, disposal issues may be resolved and a new, plentiful supply of sustainable energy could be created. Significant variations in pH and temperature between the experimental runs were revealed by the data. The best biogas yield from the digestion and co-digestion of poultry waste is determined by the ideal mesophilic temperature. For the best biogas yield, mesophilic temperatures between 37.01 and 38 °C and pH ranges between.66 and 7.02 m have the biggest effects. Therefore, it appears that the two most important factors influencing the formation of biogas from poultry dropping and litter are temperature and pH. Furthermore, it took 24 days for the digestion of the droppings, 30 days for the digestion of the poultry litter, and 27 days for the co-digestion of the droppings and poultry litter.

Author Contributions

The conceptual framework was created by Eniola Dorcas Olaoluwa, who also gathered the study's materials. Additionally, she produced the data through substrate digestion and co-digestion. The generated data utilized in this study was verified and authorized by Maryann Ogoamaka Ezugwu. She oversaw the research project and assessed the consistency of the findings. The experimental test, analysis, and discussion of the produced results were all overseen and directed by Ejiroghene Kelly Orhorhoro.

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Data Availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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