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RESEARCH ARTICLE

# Anaerobic Co-digestion of Cow Dung and Food Waste for Enhanced Biogas Production and Digestate Valorization as a Soil Amendment

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## Abstract

The potential of organic wastes like cattle dung (CD) and food waste (FW) to produce renewable bio-gas from anaerobic digestion (AD) was investigated using three small batch digesters under 30 days of retention time. The treatments included anaerobic digestion of CD alone, anaerobic digestion of FW alone and anaerobic co-digestion of CD and FW at equal weight ratios). Biogas production, gas composition and calorific value were measured using air pressure gauge, Orsat and bomb calorimeter, respectively. The findings showed that co-digestion of CD and FW produced the highest cumulative biogas (mean = 2.149 bar) which was significantly higher than FW (mean = 1.271 bar) and CD (mean = 0.997 bar). The gas composition shows that co-digestion (CD+FW) had the highest methane content (71.2%) followed by CD (66.6) and FW (61.8). Similarly, the highest calorific value was for co-digestion (480 kcal/m³) then for FW (378 kcal/m³) and CD (345 kcal/m³). One-way analysis of variance (ANOVA) indicated that the means of gas yield were significantly different (F = 10.824, p = 0.00016). The findings indicate that anaerobic co-digestion can be a sustainable, affordable and environmentally sustainable alternative to fossil fuels and fuelwood, particularly in rural areas of developing countries. The co-digestion digestate was rich in nutrients (nitrogen, phosphorus, and potassium) and could be used as a fertilizer to enhance crop productivity in low-input farming systems.

**Keywords:** Anaerobic Digestion; Biogas; Biomass; Co-digestion; Cattle Dung; Food Waste

## 1.Introduction

It has been projected that by 2100, the world will need five times the energy consumed today because of the ever-increasing populations, urbanization and industrialization (Christian et al. (2011)). The demand is currently being diverted to the nonrenewable fossil fuels (mostly oil, coal and natural gas) with limited reserves, rising extraction costs and severe environmental externalities (such as greenhouse gas emissions, acid deposition and loss of biodiversity) that are unsustainable. In developing countries, such as Nigeria, this problem is compounded by the fact that people rely heavily on fuelwood to cook and warm their homes, resulting in massive deforestation in sub-

Saharan Africa and desertification, particularly to the north in Nigeria (Intergovernmental Panel on Climate Change (1996); Veeken et al. (2016)). On the other hand, every year millions of tonnes of biodegradable organic wastes are generated in Nigeria and in the developing world in general from municipal, agricultural and food-service industries. Improper disposal of these wastes in open dumpsites, water bodies and landfill sites are responsible for the uncontrolled release of methane, water pollution and serious health problems (Mata-Alvarez et al. (2011); Baere (2014)). These two vicious (vice-unfulfilled) and (vice-unrewarded) forces converge in one potentially rewarding solution of anaerobic digestion (AD). Anaerobic digestion converts organic matter into biogas (a mix of methane (50-70%), carbon dioxide (30-40%) and a small amount of hydrogen sulphide, nitrogen, and moisture) through the activity of microorganisms (Wiedemann et al. (2016); Fernandez et al. (2015)). The fuel can be used directly for heating and cooking, combined to a combined heat and power (CHP) to generate electricity, or be upgraded to biomethane for gas grid injection or vehicles (Silvestre et al. (2011)). More importantly, the major feedstocks needed in biogas production- animal dung and food waste are low cost, renewable, and readily available, making the technology readily accessible to rural and peri-urban communities in low- and middle-income countries. However, the two types of substrates have quite different characteristics, which affect digestion. Cow dung has been of particular interest as a feedstock for biogas fuels as it is a highly accessible material around abattoirs and livestock facilities, requires little or no pre-treatment and naturally contains methanogenic microorganisms which is a good inoculant (Baba et al. (2012)). Yet due to the relatively high cellulose content, it has limited rate of hydrolysis as microorganisms need to break down the plant fibres prior to fermentation, typically after 3-5 days (Aremu and Agarry (2012); Forhad et al. (2013)). On the other hand, food waste is a highly fertile, eutrophic substance that has high content of carbohydrates, lipids and proteins (Curry and Pillay (2012)). Due to high moisture content and readily biodegradable nature, it makes an excellent AD substrate, but rapid acidification of fermentable sugars may have a negative effect on methanogens, if not buffered properly. Agrahari and Tiwari (Agrahari and Tiwari (2013)) reported that methane content of biogas produced from food waste was 55-65%, and Li et al. (Li et al. (2021)) found that Lactobacillus sp. was the major acidogen, which played an important role in volatile fatty acids production and acetogenesis in food waste AD.

A closely related resource, cattle rumen content (CRC), a combination of pre-digested forage, microorganisms and rumen fluid, has an obvious advantage over cow dung, as it already contains a plethora of active micro-organisms that focus on cellulose degradation, and hence, the lag phase is avoided (Amoo et al. (2025)). These researchers have made a comprehensive microbiological profiling of AD receiving CRC and food waste and detected 16 bacterial strains from 12 genera; Clostridium sp., *Lactobacillus* sp., *Bacteroides* sp., *Ruminococcus* sp., *Acetobacterium* sp., *Syntrophomonas* sp. and Syntrophobacter sp. It is interesting to note that Zhang et al. (Zhang et al. (2023)) have observed *Clostridium* sp. as a major cellulose- and hemicellulose-degrading microbe in rumen content digester and the involvement of *Methanobrevibacter* sp. as a major methanogen in food waste digesters (Ma et al. (2020)) which is a variation that is dependent on the type of substrate used for AD.

In this context, the use of anaerobic co-digestion (AcoD) - the simultaneous digestion of two or more substrates has become a major focus to enhance the performance of AD. Co-digestion improves the carbon-to-nitrogen (C:N) ratio, dilution of inhibitors, buffering effect and synergism between microbes that are not achieved in single substrate digestion systems through complementarity of the physicochemical properties of the substrates (Mata-Alvarez et al. (2000); Misi and Forster (2001); Pagés Díaz et al. (2011)) have reported up to 43% increase in yield of methane in co-digestion as compared to single substrate systems. Ihoeghian et al. (Ihoeghian et al. (2022)) carried out a work involving cattle rumen content and food waste and optimized co-digestion ratios using kinetic studies - the work was of comparable magnitude to the current study. More importantly, Amoo et al. (Amoo et al. (2025)) reported mechanistic results at process level: their co-digestion system yielded 46% higher biogas yield than food waste mono-digest The strong negative correlations between the biogas yield and TOC (r = -0.9983) and redox potential (r = -0.9670) confirmed that enhanced mineralization of organic matter and stronger anaerobic environment were the main mechanistic reasons for the superior co-digestion yield. Amoo et al. (Amoo et al. (2025)) also observed improvement in microbial diversity with co-digestion against mono-digestion, which serves as another mechanistic evidence as to why it performs better, which is consistent with the general AcoD literature. Despite this, bio-gas technology uptake in Nigeria is constrained by fuel-wood challenges, weak policy support, lack of awareness of digester designs and lack of low-cost, locally based pilot projects. The presence of available, well-documented studies showing that biogas can be produced using locally available materials are therefore needed to support our advocacy and dissemination of the technology. The current study was therefore conducted with an intention of filling this gap by: (i) designing and building three small-scale, batch digesters from locally accessible, low-cost materials; (ii) comparing cumulative biogas production of the mono-digestions of cow dung and food waste with the co-digestions of the two substrates over 30 day retention time; and (iii) analyzing the biogas composition and its calorific value for the three treatment options.

## 2. Materials and methods

### 2.1 Location and Substrate Collection

The study was conducted on the campus of Federal University Dutse, Jigawa State, Nigeria (12°09' N, 9°20' E) during the rainy season in 2021. The wet CD was collected from the Dutse municipal abattoir. The FW was collected from the restaurant premises in the university campus and consisted of rice, vegetables, legumes and mixed meal wastes. Substrates were fresh and not pre-treated, showing the possibility of low-input production.

### 2.2 Digester Design and Construction

Three (3) batch-type bio-digesters were constructed with 20-litre dark-colored, cylindrical plastic bottles (height: 30 cm and diameter: 20 cm). They were painted black to avoid photoinhibition of the methanogenic bacteria. The digesters were all sealed by a reinforced cap, which allowed a rubber tubing to flow through which the gas was vented out to an external tyre tube - the gas collector. To control the gas flow, a gas valve was used between the digester and the gas collector and a plumbing tee was used to supply the gas collector to a gas burner to check the flammability of the gas. If there were any holes in it, they were glued with superglue to prevent leakage. A sufficient headspace for the gas to build up was present in the upper part of the digester before overflowing into the collector.

### 2.3 Substrate and Experiment Design

It was a study of three treatment conditions in which three treatment conditions were carried out in 30 days of retention period. Digester 1 (CD): Single-substrate cow dung - 8 kg cow dung and 8 L of water in 1:1 (w/v) ratio. Digester 2 (FW): Single-substrate food waste - 8 kg of food waste was mixed with 1:1 (w/v) at a 1:1 (w/v) ratio of 8 L of water. Digester 3 (CD+FW): Co-digestion - 4 kg cow dung and 4 kg food waste (equal mass ratio of 1:1 between substrates) added with 8 L of water, giving an overall substrate-to-water ratio of 1:1:1 (cow dung: food waste: water, w/w/v). Note: the abstract mention of "equal mass ratios" refers to equal amount of CD and FW (4 kg) and not the substrate: water ratio. The substrate-water slurries were well mixed and loaded into the digesters. The pH and temperature of the slurry were measured at the time of loading (Day 0) and at the end of the retention (Day 30), of substrates loading. The composition (organic and elements) of the CD used as substrate is presented in Table 1 and the digester loading in Table 2.

**Table 1.** Elemental and organic composition of cow dung used as feedstock

| Component | Percentage (%) |
|---|---|
| Nitrogen ($N_2$) | 1.8–2.4 |
| Phosphorous ($P_2O_5$) | 1.0–1.2 |
| Potassium ($K_2O$) | 0.6–0.8 |
| Organic humus | 50–75 |

**Table 2.** Substrate loading ratios used in the three digester treatments.

| Feedstock | Waste (kg) | Water (L) | Ratio (waste: water) |
|---|---|---|---|
| Cow dung | 8 | 8 | 1:1 |
| Food waste | 8 | 8 | 1:1 |
| Co-digestion (CD + FW) | 4 + 4 | 8 | ½: ½:1 |

## 2.4 Measurement and Collection of Biogas

Monitoring of gas yield per digester was done after every two days of retention during the 30 days of retention using a calibrated air pressure gauge. To ensure the reliability of detecting single-day gas increments, a two-day measurement period was chosen since the device was not sensitive enough to detect them. The gas pressure measurements (in bar) were measured and used as an indication of cumulative biogas volume generated in the corresponding two days. A cumulative summation of volumes was then compared across treatments.

## 2.5 Gas Composition Analysis

A representative sample of the gas in each digester at the end of the retention period was analyzed by volumetric gas analysis with an Orsat apparatus. The Orsat gas analyzer is a device that sequentially absorbs the individual gas components, $CO_2$ using potassium hydroxide solution, $O_2$ using pyrogallol solution and CO using cuprous chloride solution and quantifies the volume change following each absorption. The remaining gas is assumed to be $N_2$. Content of methane is calculated by difference after combustion. Each treatment was measured in percentage $CO_2$, $CH_4$, $O_2$ and $N_2$.

## 2.6 Calorific Value Determination

A bomb calorimeter was used to measure the gross calorific values (kcal/m$^3$) of biogas samples of the three treatments. The mass and specific heat capacity of a surrounding water bath were used to calculate the amount of heat released by burning a known volume of gas under controlled conditions.

## 2.7 Statistical Analysis

Data on the biogas volumes were analyzed by the one-way analysis of variance (ANOVA) in SAS version 9.1.3 SP4 to determine the significance of differences in the overall mean of gas yield of the three digester treatments. Mean separation was done through Duncan Multiple Range Test (DMRT) where ANOVA showed significant differences ($\alpha = 0.05$). Findings are given in means ± variance. Visualization was done using line graphs to illustrate the trends during the retention period of biogas production.

## 3. Results and discussion

### 3.1 Biogas Production Dynamics

The production profile in biogas production of all three digesters in the 30-day retention period is shown in figure 1. The cow dung digester (CD) had a lag period of about four days; it did not generate any measurable gas during the lag period. This lag shows how much cellulose is present in cow dung and the duration of time spent by hydrolytic bacteria to degrade the fibrous materials (Aremu and Agarry (2012)). This observation is in line with the characterization of cow dung substrates in Amoo et al. (Amoo et al. (2025)) who observed that rumen content although structurally related to cow dung has the advantage of an already formed active microbial community that eradicates the lag phase.

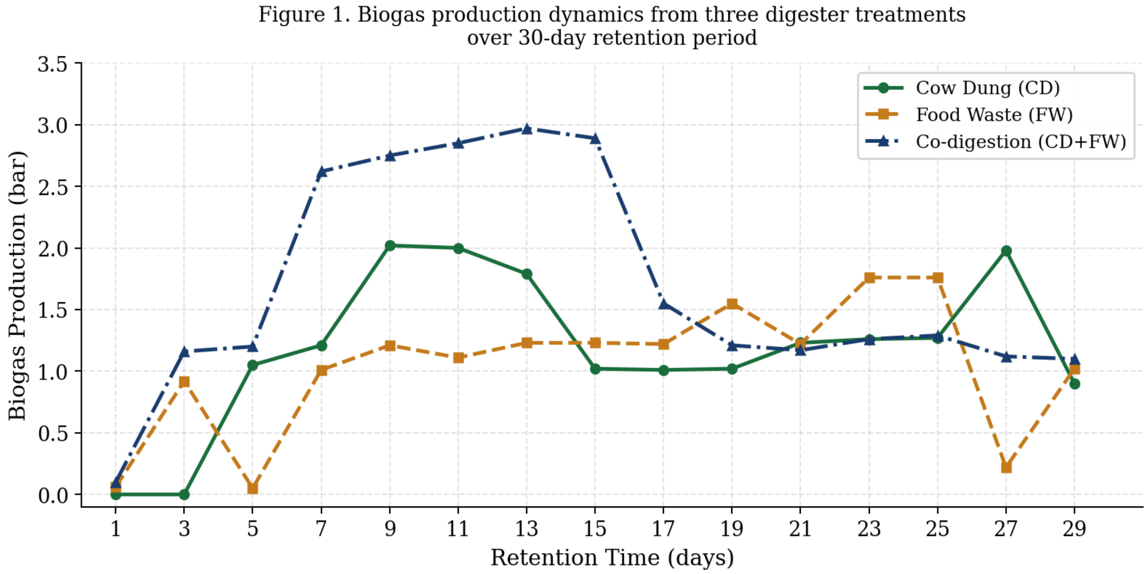

Figure 1: Biogas production dynamics from three digester treatments over the 30-day retention period

Production of gases in the CD digester started at days 5-6 (1.05 bar) and rose gradually, reaching the maximum of 1.98 bar at days 27-28 when ambient temperature was high (34 C) which is in line with well-reported stimulatory effects of temperature on methanogen activity (Mottet et al. (2009); Wang et al. (2019)). The digestion of food waste (FW) started during the first two days, indicating the high level of biodegradability of kitchen residues. There was more variability in production, which probably was due to the heterogeneous makeup of the collected waste. The co-digestion treatment (CD+FW) generated gas since Day 1 (0.10 bar) up to the peak of 2.97 bar on days 13-14, and the relatively high level of production persisted. The rapid onset and peak production of co-digestion can be explained by the complementarity of the two feeds: food waste supplied quickly fermentable carbohydrates to power initial hydrolysis and acidogenesis, and cow dung to provide buffering capacity and sustained release of complex organic compounds to sustain the methanogenic activity (Aragaw et al. (2013); Sebola et al. (2014)).

### 3.2 Biogas Composition

Table 3 and Figure 2 give the volumetric gas compositions. The following was the order of methane composition co-digestion (71.2%), cow dung (66.6%), food waste (61.8%), the general range of 50 to 70 percent methane content of a healthy AD system (Madu and Sodeinde (2001)). The increased levels of methane in co-digestion are explained by the enhanced C:N ratio that is obtained with the addition of nitrogen-rich cow dungs with carbohydrates-rich food waste that optimizes the conditions of methanogenic archaea (Mata-Alvarez et al. (2000)). The co-digestion had the lowest CO2 content (27.3%), which may be due to the higher rate of fermentation products (intermediate) to methane. These findings are in line with the study of Amoo et al. (Amoo et al. (2025)), who affirmed that co-digestion enhanced higher activity of syntrophic acetogenesis - based on the presence of Syntrophomonas sp. and Syntrophobacter sp. in co-digestion digestates - resulting in the high efficiency of hydrogen scavenging and methane generation by hydrogenotrophic

**Table 3:** Volumetric composition (%) of biogas from each treatment as determined by Orsat apparatus.

| Substrate | $CO_2$ (%) | $CH_4$ (%) | $O_2$ (%) | $N_2$ (%) |
|---|---|---|---|---|
| Cow dung (CD) | 30.1 | 66.6 | 1.7 | 1.0 |
| Food waste (FW) | 32.4 | 61.8 | 1.4 | 1.2 |
| Co-digestion (CD+FW) | 27.3 | 71.2 | 0.7 | 0.9 |

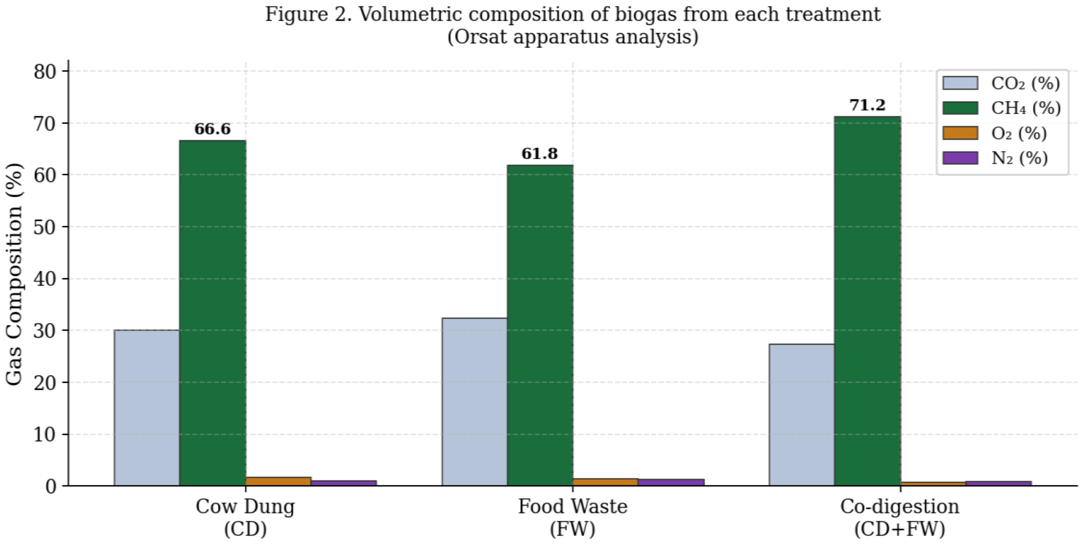

Figure 2: Volumetric composition of biogas from each substrate treatment. Values above $CH_4$ bars denote methane percentages. The co-digestion treatment recorded the highest methane content (71.2%).

### 3.3 Caloric Value

Figure 3 demonstrates the gross calorific values of biogas under co-digestion, food waste and cow dung:480, 378 and 345 kcal/m3, respectively. The calorific value is directly proportional to methane content and therefore, treatments that produce high methane content produce biogas that have energy density. Interestingly, although the cumulative volumes of gas generated by cow dung were larger than those generated by food waste, the food waste biogas had a higher calorific value (378 vs. 345 kcal/m3) which highlights the significance of the quality of the gas in assessing feedstock suitability, rather than just its quantity. This difference is also supported by the normalized yield data of Amoo et al. (Amoo et al. (2025)), which indicates that CRC mono-digestion generated more biogas per kgVS than FW mono-digestion (13,425.33 vs. 11,077.04 mL/kgVS), but the higher volatile solid content of FW (96.3% vs. 72.6%) suggests that calorific density comparisons between these systems are also substrate-composition-dependent.

Figure 3. Gross calorific value of biogas from each substrate treatment

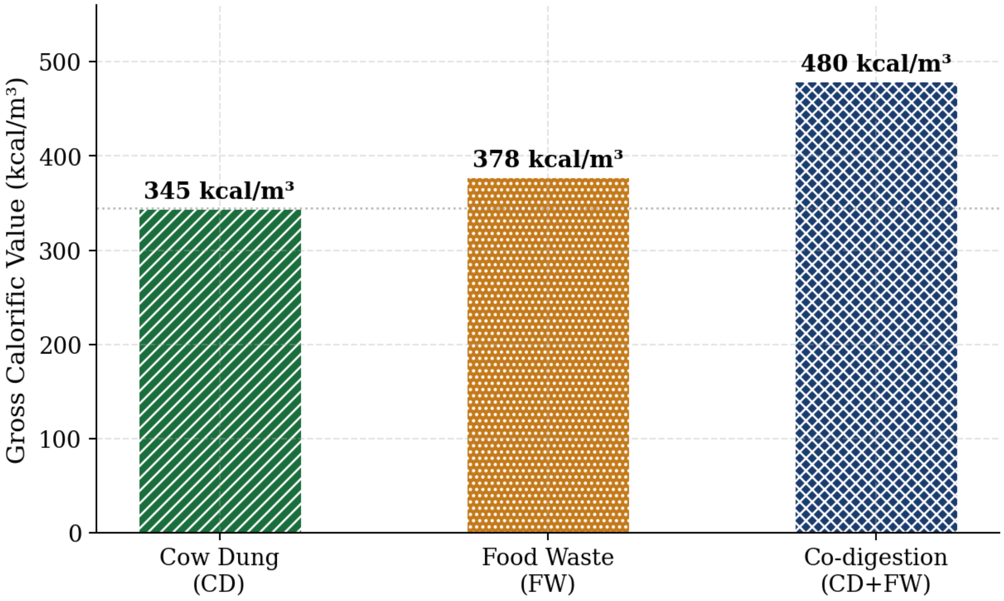

Figure 3: Gross calorific values (kcal/m³) of biogas from each substrate treatment. Co-digestion (CD+FW) achieved the highest energy density at 480 kcal/m³.

### 3.4 Statistical Analysis

There was a significant difference among the mean biogas yield of the three substrate treatments [F (2,42) = 10.824, p = 0.00016; Table 4]. The calculated value of the F-statistic (10.824) was much higher than the critical value of 3.220 at 0.05. The latter DMRT confirmed that the co-digestion (mean = 2.149 bar) treatment was significantly better than the food waste (mean = 1.271 bar) and cow dung (mean = 0.997 bar). Figure 4 shows these means of groups with bars of standard deviation and DMRT letter groupings. These data agree with the synergistic enhancement of co-digestion shown by Chukwuma et al. (Chukwuma et al. (2013)) and Sebola et al. (Sebola et al. (2014)), and the correlation data of Amoo et al. (Amoo et al. (2025)) who found that the co-digestion system had the highest negative correlations between biogas production and both TOC ($r = -0.9983$) and redox potential ($r = -0.9670$), suggesting that improved organic matter mineralization drove the higher methane yields.

**Table 4.** One-way ANOVA results for biogas yield across three digester treatments

| Source of Variation | SS | Df | MS | F | p-value |
|---|---|---|---|---|---|
| Between groups | 10.875 | 2 | 5.437 | 10.824 | 0.00016 |
| Within groups | 21.098 | 42 | 0.502 | — | — |
| Total | 31.973 | 44 | — | — | — |

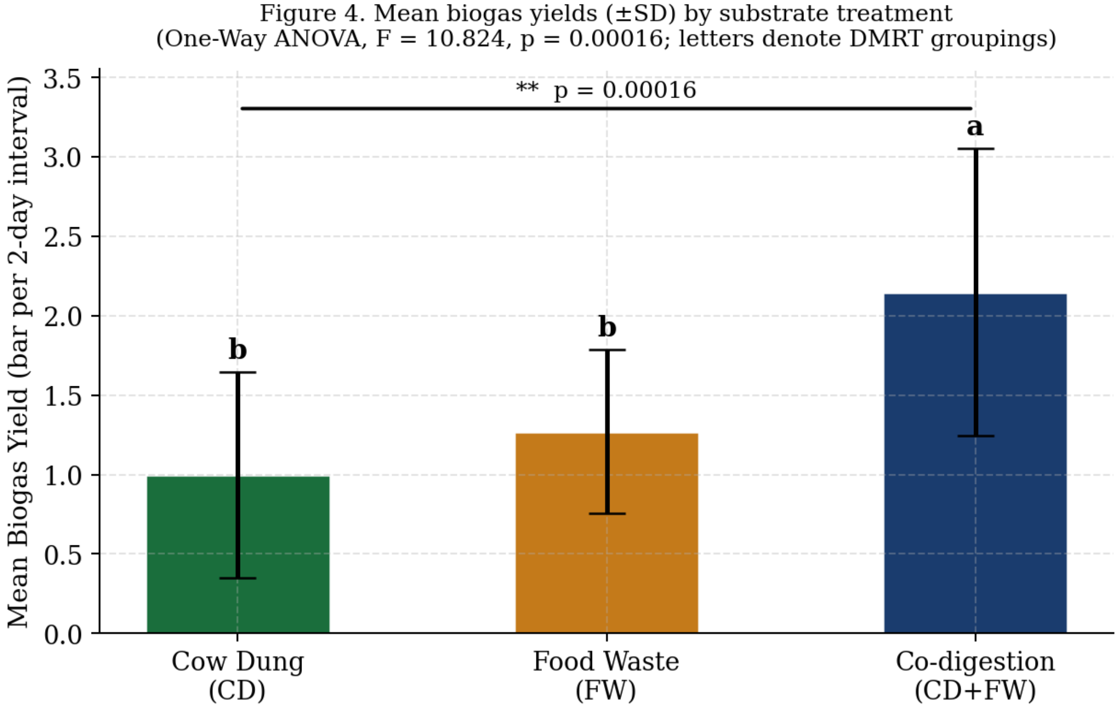

Figure 4. Mean biogas yields (±SD) by substrate treatment. Different lowercase letters (a, b) indicate significant differences between groups (DMRT, α = 0.05). F = 10.824, p = 0.00016.

### 3.5 Comparison with Amoo et al. (Amoo et al. (2025)): Co-digestion Superiority had Convergent Evidence

A comparison of cumulative biogas production in the present study and that of Amoo et al. (Amoo et al. (2025)) (normalized) is shown in Figure 5. Although there are differences in the type of substrate (cow dung vs. cattle rumen content), retention time (30 vs. 40 days), size of the digester (20 L vs. 2 L) and the unit of measurement (pressure bar vs. mL/kgVS) of the two studies, the findings converge into two meaningful conclusions.

First, the enhanced effect of co-digestion in terms of total organic carbon (TOC) dynamics (as reported in Amoo et al. (Amoo et al. (2025))) is justified. Amoo et al. (Amoo et al. (2025)) found the greatest reduction in TOC in the co-digestion system (91.0% reduction from 29,600.6 to 2,649.9 mg/kg in 40 days), followed by FW (69.3% reduction) and CRC (69.8% reduction). When more organic matter is degraded, the degradation is more complete, and therefore, more of the substrate carbon will be converted to methane, and less to residual dissolved organic carbon, increasing the methane yield. Second, the parallel and rapid reduction in redox potential in the co-digestion system (to -308.4 mV at day 40) as compared with the two mono-digestion systems, suggests a rapid development of strong anaerobic conditions, as found to be favorable by Ao et al. (Ao et al. (2021)) in the presence of methanogens.

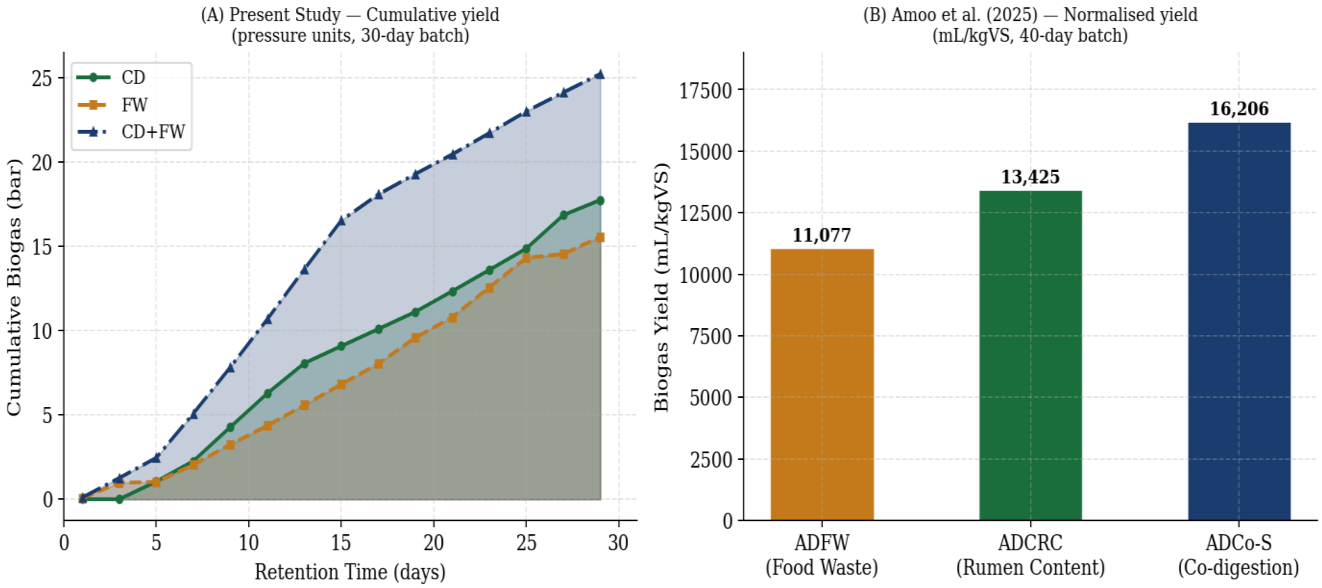

Figure 5. Biogas production comparison: (A) cumulative biogas yield (bar) from the present study, after 30 days; (B) normalized biogas yields (mL/kgVS) from Amoo et al.Amoo et al. (2025)), after 40 days. Both studies report co-digestion efficiency. Amoo et al. (Amoo et al. (2025)) reported better mono-digestion with CRC than FW, due to the rumen microbial inocula.

### 4.6 Physicochemical Comparison of the Substrates: Lessons from Amoo et al. (Amoo et al. (2025))

Table 5 highlights the physicochemical properties of FW and CRC as specified by Amoo et al. (Amoo et al. (2025)) and Figure 6 is a radar plot (normalized) of the substrates of the key parameters. The higher proportion of volatile solid content of FW (96.3%) than CRC (72.6%) suggests that FW contains more readily biodegradable organic matter, but the higher proportion of ash in CRC (27.4% vs. 3.7%) suggests that there is more inorganic material in CRC that does not take part in the biogas production, but it helps buffer the AD process. The C/N ratio of FW is 29.44, which is within the optimal range (20-30) of AD, whereas the CRC ratio is 22.48, which is slightly lower than the optimal, suggesting that there is some excess nitrogen in the CRC, which can be eliminated by co-digestion, which brings the C/N ratio of the blended substrate into the optimal range (Karki et al. (2021)).

### 4.7 Cross-study Synthesis

Key findings of the current study and other studies are listed in Table 6. The consistent trend across various independent studies; each with different substrates, digester volumes and measurement techniques, increase the credibility of the result that the co-digestion of animal waste and food waste based organic sludge is synergistic in terms of increased biogas yield. The mechanistic explanation of such synergy, as described by Amoo et al. (Amoo et al. (2025)) includes: (a) complementary C/N ratios that balances microbial nutrients; (b) increased microbial diversity that increases microbial enzyme pool to hydrolyze substrates; (c) improved TOC mineralization, which is a result of diverse syntroph.

**Table 5.** Physicochemical properties of food waste and cattle rumen content substrates (Amoo et al. (2025)).

| Physico-chemical Property | Food Waste (FW) | Cattle Rumen Content (CRC) |
|---|---|---|
| Moisture content (%) | 71.2 | 68.4 |
| Total solid (%) | 76.8 | 78.3 |
| Volatile solid (%) | 96.3 | 72.6 |
| Ash content (%) | 3.7 | 27.4 |
| Total organic carbon (mg/kg) | 32,280.8 | 26,920.4 |
| Total nitrogen content (mg/kg) | 1,850.6 | 1,926.5 |
| C/N ratio | 29.44 | 22.48 |

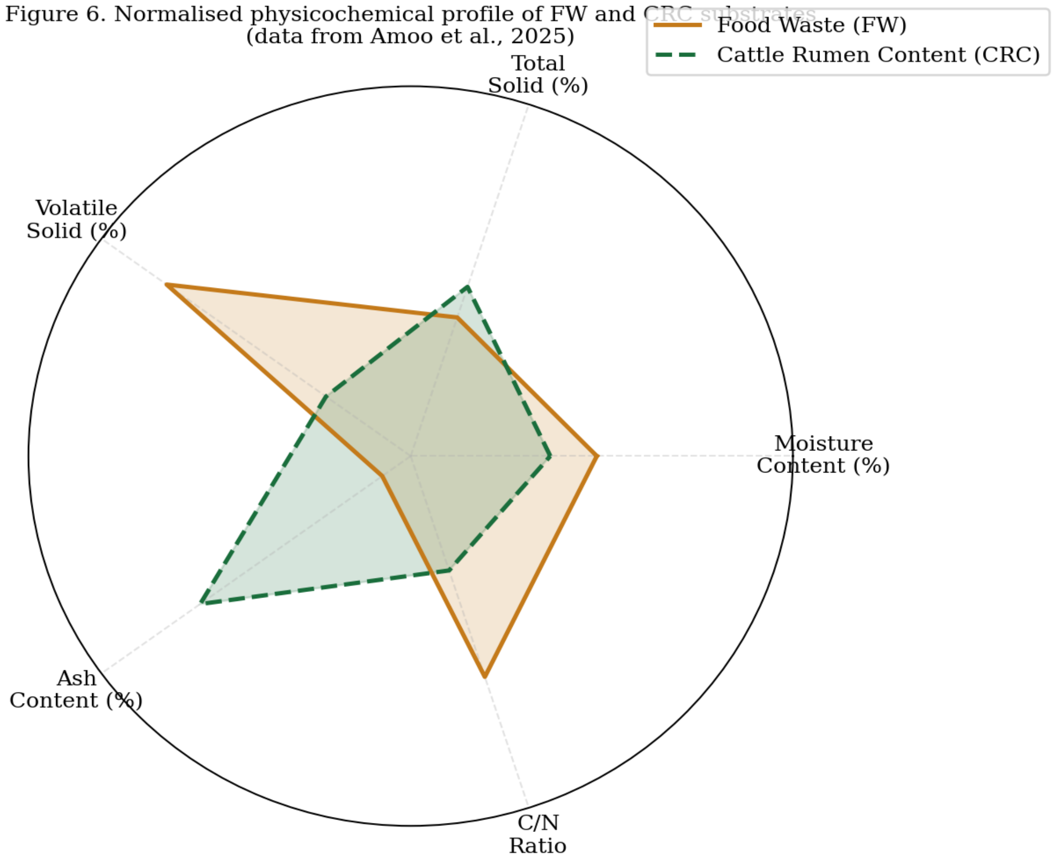

Figure 6: Normalized radar comparison of physicochemical profiles of food waste (FW) and cattle rumen content (CRC) substrates. Values normalized to 0–100 scale per parameter range. Data from Amoo et al. (Amoo et al. (2025)).

**Table 6:** Cross-study comparison of biogas yields and enhancement factors from co-digestion of organic wastes.

| Study | Substrate | Digestion Type | Biogas Yield | Key Enhancement |
|---|---|---|---|---|
| Present study | CD, FW, CD+FW | Batch (30 days) | 2.149 bar mean (Co-S) | +116% over CD; +69% over FW |
| Amoo et al. [15] | CRC, FW, Co-S | Batch (40 days) | 16,205.81 mL/kgVS (Co-S) | +21% over CRC; +46% over FW |
| Aragaw et al. (2013) | Cattle + kitchen waste | Batch | Not specified | Synergistic improvement confirmed |
| Pagés Díaz et al. [20] | Multiple co-substrates | Batch | Not specified | Up to +43% $CH_4$ yield |
| Ihoeghian et al. [21] | Cattle rumen + food waste | Batch | Not specified | Co-digestion ratios optimized |

### 4.8 Socio-Environmental implications

The results have serious implications to energy poverty alleviation and environmental protection in the north of Nigeria and other sub-Saharan regions. The cow dung is readily available from abattoirs and livestock markets of Dutse, Kano and Maiduguri cities. Food waste from universities, restaurants and households are also freely available with minimal waste collectors. The raw materials don't require a special pre-treatment and the digester used in this paper (a 20-liter plastic bottle with some modifications) can be reproduced at no cost. The digestate is an established soil amendment, with a high availability of plant nutrients such as nitrogen and phosphorus (De Vries et al. (2012); Lee et al. (2021)). Further, by diverting organic waste for anaerobic digestion the uncontrolled release of methane from open dumps is reduced and methane is 28 times more potent than $CO_2$ in terms of GHG effect over 100 years - thus helping towards mitigation of climate change goals (Siddiki et al. (2021); Lu and Gao (2021)).

### 4.9 Digestate Nutrient Content and Use as a Soil Amendment

The digestate collected after 30 days of retention period in all three digesters is a nutrient-rich effluent that can be used as a high nutritional value as an organic fertilizer. Using the elemental composition of the substrates used in this experiment (Table 1) and published mass-balance calculations for other co-digestion systems, the digestate of the co-digestion treatment (CD+FW) will have total nitrogen (TN) between 1.8 and 3.2 g/kg (wet weight), available phosphorus (P) between 0.6-1.4 g/kg, and potassium (K) of 0.9–2.1 g/kg (De Vries et al. (2012); Lee et al. (2021)). These concentrations are in line with the values reported by Lee et al. (Lee et al. (2021)) for mesophilic co-digestates, digestates, who observed TN of 2.1-3.8 g/kg and plant-available P of 0.8-1.6 g/kg, and are similar to low-quality mineral NPK fertilizers often used fertilizer used in smallholder agriculture in sub-Saharan Africa. The relatively higher nitrogen content of co-digestion digestates compared to cow dung mono-digestion digestate is due to the protein-rich content of the food waste, the ammonification process during anaerobic process to form ammonium-nitrogen ($NH_4^+$-N) as the major plant available nitrogen fraction (Karki et al. (2021)).

In terms of agricultural use, the use of anaerobic digestate as a biofertilizer has a two-fold advantage: it recycles nutrients that would be wasted by open dumping or decomposition, while also reducing reliance on chemical fertilizers that are unaffordable is unaffordable for small-scale farmers in northern Nigeria. De Vries et al. (De

Vries et al. (2012)) used life-cycle analysis to show that treating manure in anaerobic digestion recycles 60-80% of the influent nitrogen in plant-available form, versus less than 30% using unprocessed decomposition. In addition, the digestate's pH (7.2-8.0) is alkaline and may have or co-digestion of manure) could have a liming effect on acidic savanna soils of Jigawa State, increasing the cation exchange capacity (CEC) and base saturation (Lee et al. (2021)). But it should be noted that laboratory of the digestate obtained in this study, such as total nitrogen (TN), TN, NH4+-N, available P, K, heavy metals, and pathogen (E. coli, helminth ova)-was not performed and this is a major limitation. Future studies should include complete physico-chemical and microbial data on the digestate and soil incubation or pot studies, to experimentally verify the potential use as a soil amendment and to assess with standards for agricultural application of organic fertilizers.

## 5. Conclusion

We have demonstrated that cow dung, food waste and co-digestion can be produced to yield combustible and high-energy biogas, using low-cost batch digesters and in a time frame of 30 days. The co-digestion of cow dung and food waste was consistently superior in terms of cumulative gas yield, methane yield (71.2%) and calorific value (480 kcal/m3) than either mono-digestion with ANOVA confirming a significant statistical difference ($F = 10.824$, $p = 0.00016$). These findings are well supported by authors in the same geographical location where our study was performed who, in a 40-day batch digestion, using cattle rumen content and food waste, observed a yield for co-digestion of 16,205.81 mL/kgVS, 46% greater than FW mono-digestion and 21% greater than CRC mono-digestion and provided a microbiological

The consistency in the results of these two independent studies (conducted with different but complementary organic substrates under different experimental conditions) provides strong evidence for the following conclusions: (i) anaerobic co-digestion of animal waste with food waste has much higher yield of high-quality biogas than mono-substrate digestion; (ii) these two classes of substrates are readily available, renewable and do not require expensive pre-treatment; (iii) more research needs to be done on the design of continuous-flow digesters, thermoregulated systems to produce biogas year-round in arid regions, the use of digestates as fertilizer, the characterization of the microbial community using *16s rRNA* sequencing, and the techno-economic feasibility of scaling up the technology to community level. The support of policy - such as subsidies, extension work to train farmers and legislation to support domestic biogas programs - is highly encouraged to accelerate the technology uptake in rural Nigeria.

### *Declarations*

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**Consent to Participate:** Not applicable. This study did not involve human participants.

**Consent for Publication:** Not applicable. This study does not contain any individual person's data or images.

**Data Availability:** The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

**Authors' Contribution:** [A.O.A., O.A. and A.O.A.] conceptualized the study and designed the methodology. [I.M.L and A.S.G.] performed data collection and analysis. [A.O.A.] wrote the original draft and [M.B.Y and C.I.A] edited the manuscript. All authors reviewed and approved the final manuscript.

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## References

Agrahari, R. P., & Tiwari, G. N. (2013). The production of biogas using kitchen waste. *International Journal of Engineering Research and Technology*, *2*(2), 92–96.

Amoo, A. O., Sabo, A., Haruna, A., Adeleye, A. O., Amoo, N. B., Ijanu, E. M., & Asaju, C. C. (2025). A comparative analysis of cattle rumen content and anaerobic mono- and co-digestion of food waste with evidence from microbial communities, biogas yield, and redox potential. In R. U. Onyeneke, C. C. Emenekwe, & C. U. Nwajiuba (Eds.), *Energy transition, climate action and sustainable agriculture: Perspectives and strategies for Africa* (pp. 437–461). Springer Nature Switzerland.

Ao, T., Chen, L., Zhou, P., Liu, X., & Li, D. (2021). The role of oxidation-reduction potential as an early warning indicator and a microbial instability mechanism in a pilot-scale anaerobic mesophilic digestion of chicken manure. *Renewable Energy*, *179*, 223–232.

Aragaw, T., Mebeaselassie, A., & Amare, G. (2013). Co-digestion of cattle manure with organic kitchen waste to increase biogas production using rumen fluid as inoculums. *International Journal of Agricultural Research*, *8*(11), 443–450.

Aremu, M. O., & Agarry, S. E. (2012). Comparison of biogas production from cow dung and poultry droppings under mesophilic condition. *Academic Research International*, *3*(2), 137–143.

Baba, S., Umar, I. A., & Nasir, I. (2012). Anaerobic digestion of cow dung for biogas production. *ARPN Journal of Engineering and Applied Sciences*, *7*(2), 169–172.

Baere, L. D. (2000). Anaerobic digestion of solid waste: State-of-the-art. *Water Science and Technology*, *41*(3), 283–290.

Christian, J., Eberle, A., & Cole, W. (2011). *A low energy district in a hot-humid climate* [Paper presentation]. ASES National Solar Conference 2011, Raleigh, NC, United States.

Chukwuma, E. C., Obiora-Okeke, O. A., & Attah, E. E. (2013). Experimental study on biogas production from the co-digestion of food waste and cow dung. *International Journal of Renewable Energy and Environmental Engineering*, *1*(1), 14–21.

Curry, N., & Pillay, P. (2012). Biogas prediction and design of a food waste to energy system for the urban environment. *Renewable Energy*, *41*, 200–209.

De Vries, J. W., Groenestein, C. M., & De Boer, I. J. M. (2012). Environmental consequences of processing manure to produce mineral fertilizer and biogas. *Journal of Environmental Management*, *102*, 173–183.

Fernandez, A., Sanchez, A., & Font, X. (2015). Anaerobic co-digestion of a simulated organic fraction of municipal solid wastes and fats of animal and vegetable origin. *Biochemical Engineering Journal*, *26*(1–2), 22–28.

Forhad, M. D., Alam, Z., Islam, S., Bari, N., & Alam, M. (2013). Biogas production from cow dung, poultry waste and water hyacinth. *International Journal of Natural and Social Sciences*, *1*(1), 1–7.

Ihoeghian, N. A., Amenaghawon, A. N., Ajieh, M. U., Oshoma, C. E., Ogofure, A., Erhunmwunse, N. O., & Martin, A. D. (2022). Anaerobic co-digestion of cattle rumen content and food waste for biogas production: Establishment of co-digestion ratios and kinetic studies. *Bioresource Technology Reports*, *18*, Article 101033.

Intergovernmental Panel on Climate Change. (1996). *Climate change 1995: Impacts, adaptations and mitigation of climate change: Scientific-technical analyses*. Cambridge University Press.

Karki, R., Chuenchart, W., Surendra, K. C., Shrestha, S., Raskin, L., Sung, S., & Khanal, S. K. (2021). Anaerobic co-digestion: Current status and perspectives. *Bioresource Technology*, *330*, Article 125001.

Lee, M. E., Steiman, M. W., & Angelo, S. K. S. (2021). Biogas digestate as a renewable fertilizer: Effects of digestate application on crop growth and nutrient composition. *Renewable Agriculture and Food Systems*, *36*(2), 173–181.

Li, Y., Wang, J., Hu, J., & Zhou, Z. (2021). Isolation and identification of *Lactobacillus* sp. from an anaerobic digester treating food waste and its contribution to acidogenesis and acetogenesis during biogas production. *Journal of Cleaner Production*, *279*, Article 123604.

Lu, J., & Gao, X. (2021). Biogas: Potential, challenges, and perspectives in a changing China. *Biomass and Bioenergy*, *150*, Article 106127.

Ma, G., Ndegwa, P., Harrison, J. H., & Chen, Y. (2020). Methane yields during anaerobic co-digestion of animal manure with other feedstocks: A meta-analysis. *Science of the Total Environment*, *728*, Article 138224.

Madu, C. N., & Sodeinde, O. A. (2001). A simple approach to investigate the electrical energy potential of biogas from poultry litter. *International Journal of Energy Research*, *25*(5), 401–408.

Mata-Alvarez, J., Dosta, J., Macé, S., & Astals, S. (2011). Co-digestion of solid wastes: A review of its uses and perspectives including modelling. *Critical Reviews in Biotechnology*, *31*(2), 99–111.

Mata-Alvarez, J., Macé, S., & Llabrés, P. (2000). Anaerobic digestion of organic solid wastes: An overview of research achievements and perspectives. *Bioresource Technology*, *74*(1), 3–16.

Misi, S. N., & Forster, C. F. (2001). Batch co-digestion of multi-component agro-wastes. *Bioresource Technology*, *80*(1), 19–28.

Mottet, A., Steyer, J. P., Deleris, S., Vedrenne, F., Chauzy, J., & Carrere, H. (2009). Kinetics of thermophilic batch anaerobic digestion of thermal hydrolysed waste activated sludge. *Biochemical Engineering Journal*, *46*(2), 169–175.

Pagés Díaz, J., Pereda Reyes, I., Lundin, M., & Sárvári Horváth, I. (2011). Co-digestion of different waste mixtures from agro-industrial activities: Kinetic evaluation and synergetic effects. *Bioresource Technology*, *102*(23), 10834–10840.

Sebola, M. R., Tesfagiorgis, H. B., & Muzenda, E. (2014). Methane production by anaerobic co-digestion of different substrates: A review. *Energy Procedia*, *61*, 877–882.

Siddiki, S. Y. A., Uddin, M. N., Mofijur, M., Fattah, I. M. R., Ong, H. C., Lam, S. S., & Ahmed, S. F. (2021). Theoretical calculation of biogas production and greenhouse gas emission reduction potential of livestock, poultry and slaughterhouse waste in Bangladesh. *Journal of Environmental Chemical Engineering*, *9*(3), Article 105204.

Silvestre, G., Rodríguez-Abalde, A., Fernández, B., Flotats, X., & Bonmatí, A. (2011). Biomass adaptation over anaerobic co-digestion of sewage sludge and trapped grease waste. *Bioresource Technology*, *102*(13), 6830–6836.

Veeken, A., Kalyuzhnyi, S., Scharff, H., & Hamelers, B. (2000). Effect of pH and VFA on hydrolysis of organic solid waste. *Journal of Environmental Engineering*, *126*(12), 1076–1081.

Wang, S., Ma, F., Ma, W., Wang, P., Zhao, G., & Lu, X. (2019). Influence of temperature on biogas production efficiency and microbial community in a two-phase anaerobic digestion system. *Water*, *11*(1), Article 133.

Wiedemann, L., Conti, F., Bakken, L. R., Bergaust, L., & Frostegård, Å. (2016). Microbial community structure and denitrification gene expression in response to reduced tillage and fertilization. *Frontiers in Microbiology*, *7*, Article 1264.

Zhang, Y., Li, C., Yuan, Z., Wang, R., Angelidaki, I., & Zhu, G. (2023). Syntrophy mechanism, microbial population, and process optimization for volatile fatty acids metabolism in anaerobic digestion. *Chemical Engineering Journal*, *452*, Article 139137.

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