Biotechnology Journal International

Volume 28, Issue 6, Page 165-175, 2024; Article no.BJI.127736
ISSN: 2456-7051
(Past name: British Biotechnology Journal, Past ISSN: 2231–2927, NLM ID: 101616695)

Biogas Potential Assessment of Co-digestion of Various Wastes (Cassava Residues, Poultry Droppings and Household Waste) in the Gbêkê Region, Bouaké, Central Ivory Coast

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/bji/2024/v28i6759

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/127736

Original Research Article

Received: 10/10/2024
Accepted: 12/12/2024
Published: 16/12/2024

ABSTRACT

Assessing the potential for biogas from cassava residues, poultry droppings and household waste in Bouaké will help determine the viability of a sustainable energy project. Cassava is abundant in this region, and its exploitation produces starch-rich residues, a potential source of biogas through

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Cite as: *Abonouah, KOUASSI Barbara Sidoine, ADJIRI Oi Adjiri, and GROGA Noël. 2024. "Biogas Potential Assessment of Co-Digestion of Various Wastes (Cassava Residues, Poultry Droppings and Household Waste) in the Gbêkê Region, Bouaké, Central Ivory Coast". Biotechnology Journal International 28 (6):165-75. https://doi.org/10.9734/bji/2024/v28i6759.*

anaerobic digestion. Poultry droppings from livestock farming and household waste are respectively sources of biomass rich in nitrogen and various organic materials. Unfortunately, poor management of these wastes leads to environmental problems, including foul odors that encourage disease, and soil and groundwater pollution. It is therefore necessary to quantify this waste with a view to transforming it into renewable energy. To do this, we began by collecting cassava residues and household waste from attiéké production cooperatives and some restaurants, and poultry droppings from city farms. After collection, we sorted and mixed the different types of waste with water, then filled the digesters. And finally, we made different formulations from these wastes for biogas production. During the process, the results obtained from the physico-chemical characteristics of the waste give respectively for pH 6.4 and 7.4, for BOD_5 25 442 mg/L and 19 475 mg/L, for COD 74 400 mg/L and 62 100 mg/L, for MES 3 733 mg/L and 2 675 mg/L, for MS 11.6% and 8.1%, for VDM 64.3% and 58.2%. Concerning biogas composition and production, methane is estimated at 56.5% on average, with a standard deviation of 6.1, giving a biogas volume of 3.2 m3. These results provide valuable indications for the planning and development of biogas production facilities in Bouaké. They encourage the adoption of renewable energies, waste reduction and better management of organic residues, thus contributing to the environmental and economic sustainability of the region.

Keywords: Biogas; cassava residues; poultry droppings; household waste ; Bouaké.

1. INTRODUCTION

Driven by rapid urbanization, economic development and population growth, the amount of waste produced worldwide is expected to climb to 3.4 billion tonnes over the next three decades (Li et al., 2018), up from 2.01 billion in 2016, an increase of 54.62% on the 1.3 billion tonnes produced in 2012 (Hoornweg et al., 2013). In Africa, although waste production is lower by global comparison, the continent faces specific waste management challenges (Couth & Trois, 2011). Some 174 million tonnes of waste end up in uncontrolled landfills, with a rate of 0.46 kilograms per inhabitant per day. This represents 8.65% of global waste production in 2016 (Patou, 2019). In Côte d'Ivoire as a whole, the production of solid household and similar waste is estimated at over 2 million tonnes per year, including around 1.4 million tonnes in the Autonomous District of Abidjan alone. Waste production varies from one city to another and from one district to another, depending on the socio-economic level and the season. Globally, average production is 0.3 kg/capita/day in rural areas and 0.5 to 1.2 kg/capita/day in urban and peri-urban areas (United Nations Framework Convention on Climate Change, 2011). These data illustrate the crucial need for waste management and recovery systems to meet environmental and health challenges, while offering opportunities for sustainable development, such as bioenergy.

Unfortunately, waste management today is an issue that directly affects every inhabitant of the planet, as it is rarely recovered or properly managed. More than 90% of waste is burnt in the open air or dumped in illegal dumps, exposing the most vulnerable populations to health and environmental risks (Despotović et al., 2021; Begazo et al., 2023). Concerning agricultural waste, which is thrown away, burned or buried without precaution, releases substances harmful to public health and contributes to environmental degradation ((Faouzi Bensebaa & Fabienne Boudier, 2014); (Carlos-Alberola et al., 2021)).

Faced with this situation, waste recovery represents not only a solution for reducing risks, but also an opportunity for energy exploitation. Indeed, much of this waste contains complex molecules that can be converted into energy by anaerobic digestion, producing biogas (Lacour et al., 2011; Soha et al., 2021). Identifying the wastes best suited to this type of recovery is therefore crucial to making the most of these resources.

This study is part of this approach, seeking to assess the bioenergy potential of waste in Bouaké, in particular cassava residues, poultry droppings and household waste, using co-generation. The aim is to determine their capacity to be transformed into biogas, in order to contribute to the sustainable development of the region while providing an ecological and economical solution for waste management. This approach encourages us to see waste not simply as a burden, but as an exploitable resource with the potential to generate energy and reduce environmental impact.

2. MATERIALS AND METHODS

2.1 Materials

The materials used for this study are: organic materials and technical equipment.

2.1.1 Organic matter

The organic materials used in our experiments were cassava residues, poultry droppings and household waste (Fig. 1). These different types of waste were collected in the city of Bouaké, but in different neighborhoods where their respective production is greater.

2.1.2 Technical equipment

For the technical equipment, we used four (4) digesters made from 200 liter and 160 liter barrels. These digesters were used to produce the biogas we wanted to generate from the waste (Fig. 2). Once the gas had been produced, we stored it in four (4) gas bags made from tarpaulins (Fig. 3).

(a) (b) (c)

Fig. 1. Organic matter: (a) cassava residues, (b) poultry droppings and (c) household waste

(a) (b) (c)

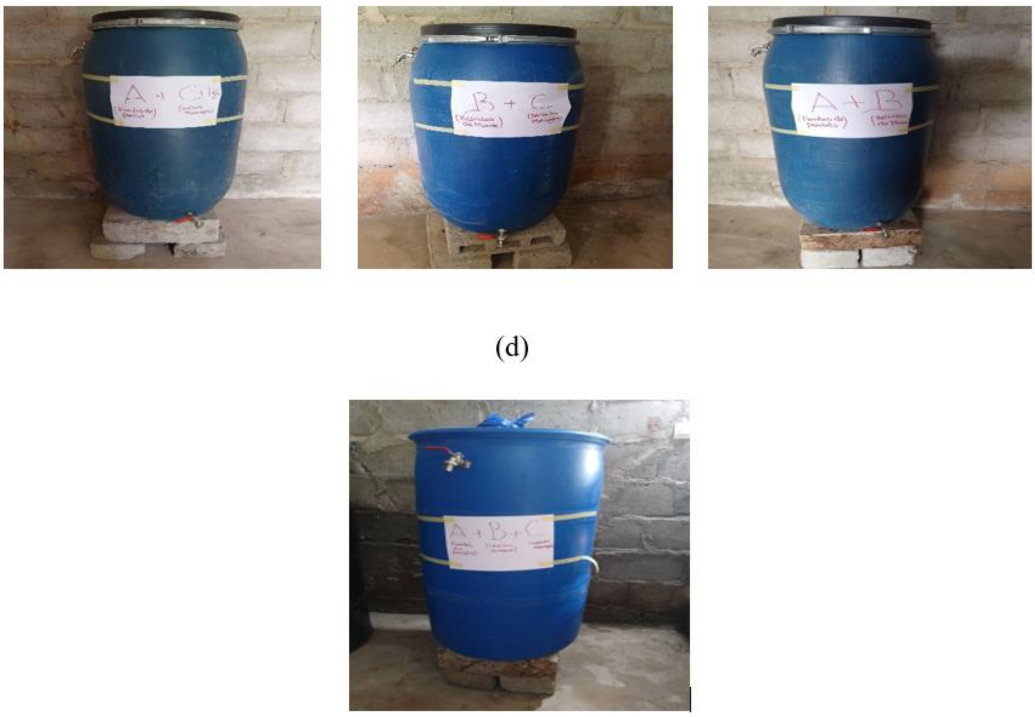

Fig. 2. The 160 liter and 200 liter digesters: (a) 160 liter digester 1, (b) 160 liter digester 2, (c) 160 liter digester 3 and (d) 200 liter digester 4

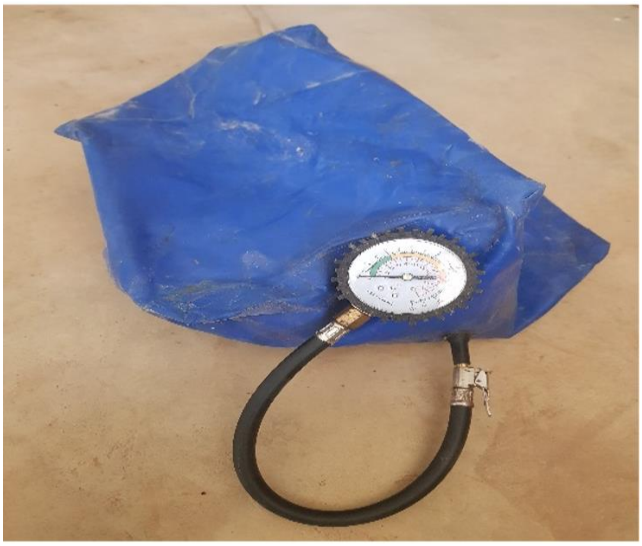

Fig. 3. Gas bag

2.2 Methods

2.2.1 Waste collection

As part of this study, regular waste collection missions were carried out in the Gbêkê region, and more specifically in the town of Bouaké. The aim was to collect cassava residues, poultry droppings and household waste. First, we collected four (4) 25 L cans of liquid cassava starch and one (1) 50 L bag of cassava peelings from cooperatives that process cassava into attiéké. Next, poultry droppings were collected in four (4) 150 L bags from the various chicken farms, more specifically the hen houses. And finally, household waste, that is to say everything related to biodegradable waste, was collected in two (2) 50 L bags in restaurants and homes (Fig. 4).

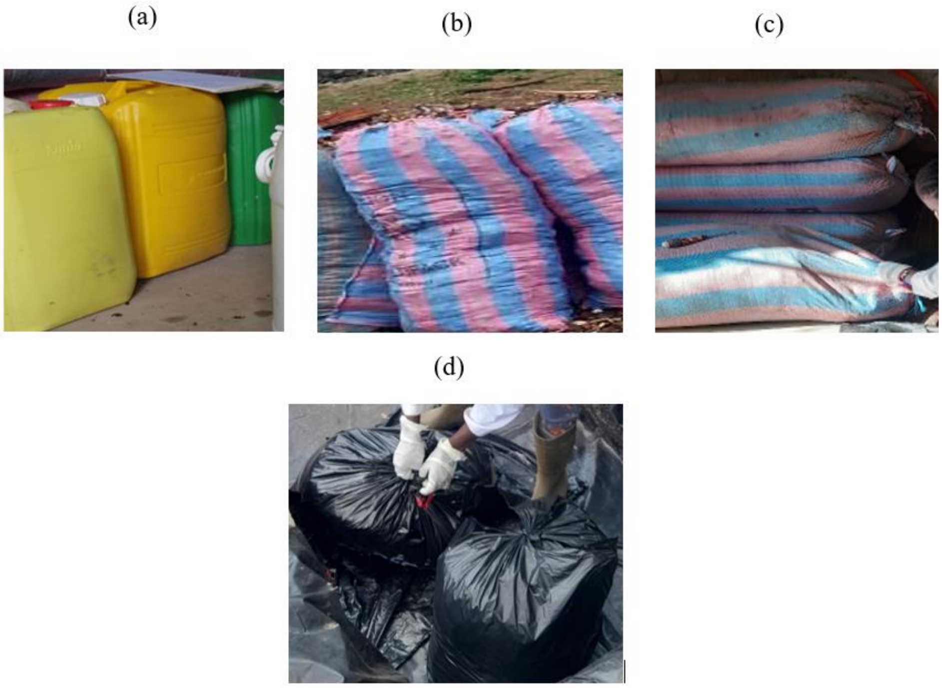

Fig. 4. Types of waste: (a) cassava starch, (b) cassava peelings, (c) poultry droppings and (d) household waste

2.2.2 Waste sorting, waste mixing and digester filling

After collecting the various types of waste on site, we carried out a mechanical pre-treatment, which generally consists of protecting and eliminating anything that could prevent the waste from fermenting inside the digesters. This was applied to cassava peelings, poultry droppings and household waste, with the aim of crumbling undesirable particles such as sand, feathers, wood fragments, bones, etc. These particles will prevent the waste from fermenting. These particles can prevent fermentation of the waste in the digesters. This pre-treatment was carried out in buckets, basins and an iron barrel, in order to apply a highly appropriate mixture of these wastes. However, mechanical pretreatment increases the attack capacity of the microorganisms, resulting in faster hydrolysis (Djomsi Brillant Wembe et al., 2023). Once the pre-treatment and mixing have been completed, we move on to filling the digesters (Fig. 5).

2.2.3 Waste formulations for biogas

For this study, we used four (4) digesters, including three (3) 160 liters and one (1) 200 liters. These digesters enabled us to ferment the waste. But before moving on to the methanization (fermentation) of these wastes, we drew inspiration from the study by (KPATA, 2014) to form formulations that will serve to produce biogas by being inside the digesters. These formulations allowed us to see among the associations of our waste, which produces more biogas in quantity and good quality. For the formulations, we have: A (poultry droppings), B (cassava residues), C (household waste) and H2O (water).

- **Formulation 1**

We mixed 50 liters of poultry droppings, 50 liters of cassava residue and 10 liters of water before putting it in digester 1 (Fig. 6).

We have:

$$\boldsymbol{F}1 = 50\ L\ de\ \boldsymbol{A} + 50\ L\ de\ \boldsymbol{B} + 10\ L\ de\ \boldsymbol{H_2O} \quad (1)$$

- **Formulation 2**

For this formulation we mixed 50 liters of cassava residues, 50 liters of household waste, and 10 liters of water before putting it in digester 2 (Fig. 7).

We have:

$$\boldsymbol{F}2 = 50\ L\ de\ \boldsymbol{B} + 60\ L\ de\ \boldsymbol{C} + 10\ L\ de\ \boldsymbol{H_2O} \quad (2)$$

- **Formulation 3**

In digester 3, 30 liters of poultry droppings, 30 liters of household waste and 60 liters of water were mixed (Fig. 8).

We have:

$$\boldsymbol{F}3 = 30\ L\ de\ \boldsymbol{A} + 30\ L\ de\ \boldsymbol{C} + 60\ L\ de\ \boldsymbol{H_2O} \quad (3)$$

- **Formulation 4**

In this formulation we have the mixture of all three different wastes. We have 30 liters of poultry droppings, 30 liters of cassava residue, 30 liters of household waste and 30 liters of water before putting it in digester 4 (Fig. 9).

We have:

$$\boldsymbol{F}4 = 30\ L\ de\ \boldsymbol{A} + 30\ L\ de\ \boldsymbol{B} + 30\ L\ de\ \boldsymbol{C} + 30\ L\ de\ \boldsymbol{H_2O} \quad (4)$$

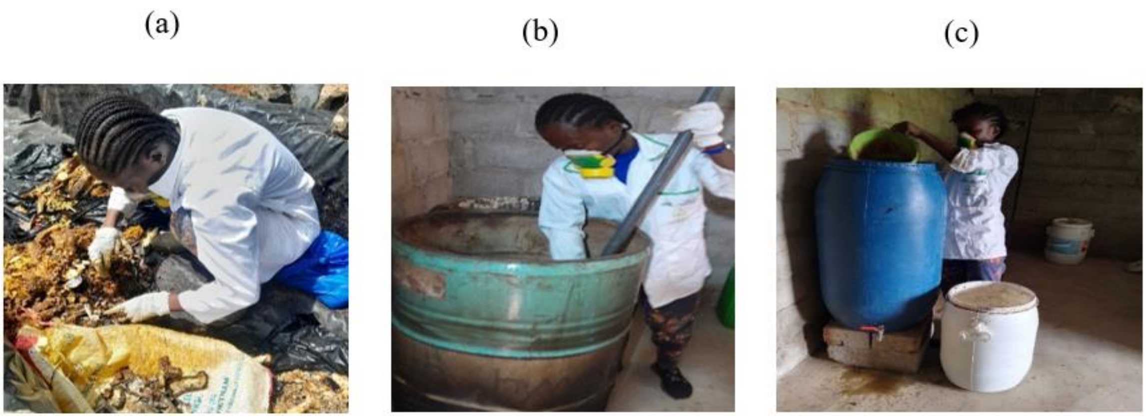

Fig. 5. Mechanical waste pre-treatment: (a) waste sorting, (b) waste mixing and (c) digester filling

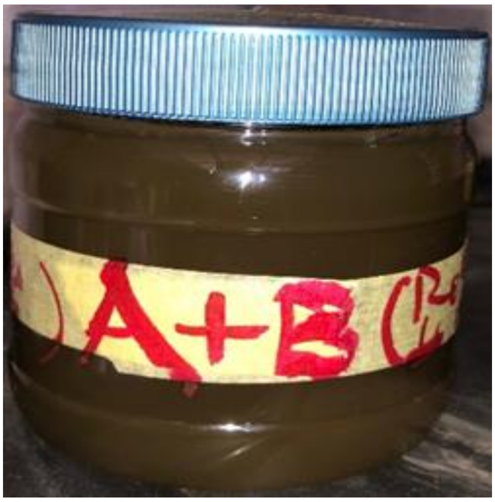

Fig. 6. Waste Formulation 1 (F1) for biogas

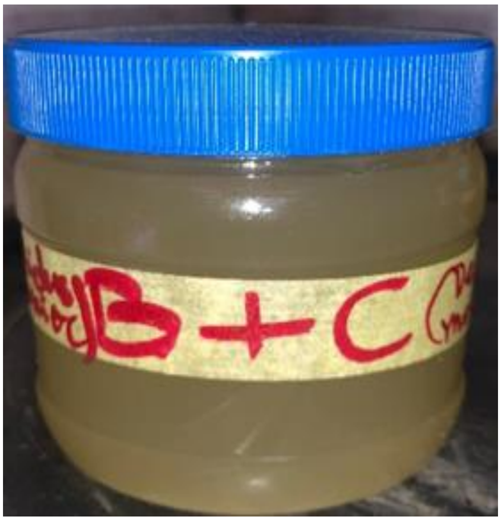

Fig. 7. Waste Formulation 2 (F2) for biogas

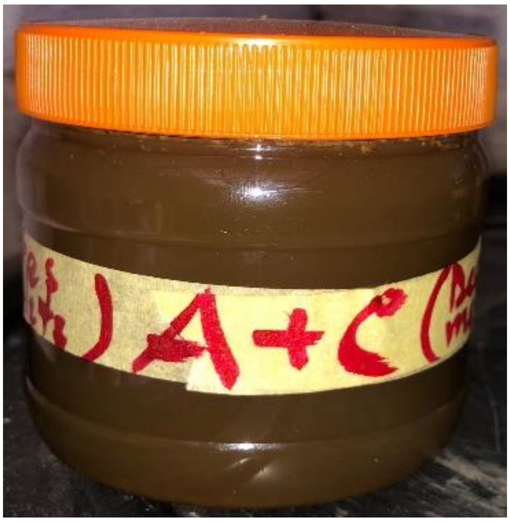

Fig. 8. Waste Formulation 3 (F3) for biogas

Fig. 9. Waste Formulation 4 (F4) for biogas

3. RESULTS AND DISCUSSION

3.1 Results

3.1.1 Physico-chemical characteristics

Table 1 shows parameter values at the digester inlet and outlet. These results show that pH is between 6.1 and 7 at the digester inlet and between 7.1 and 7.6 at the outlet, with an average of 6.4 and 7.4.

For BOD_5 and COD, inlet values range from 8522 mg/L to 5796 mg/L for BOD_5 and from 24800 mg/L to 16600 mg/L for COD, while outlet values range from 52491 mg/L to 40127 mg/L for BOD_5 and from 153800 mg/L to 123100 mg/L for COD. The MES (suspended solids) values range from 1240 mg/L to 850 mg/L at the digester inlet, and from 7740 mg/L to 6400 mg/L at the outlet.

With regard to DM (dry matter), we have values of between 10.5% and 5.2% at the inlet, then between 13% and 11.5% at the outlet. For VDM (volatile dry matter), we have values between 51.2% and 44.5% at the inlet and 82.5% and 76.2% at the outlet of the digesters.

3.1.2 Biogas composition by type of formulation

The results of biogas composition by type of formulation showed values for certain parameters such as dihydrogen (H_2) ranging from 0.004% to 0.008% with an average of 0.006%; oxygen (O_2) with a value ranging from 1.30% to 2.16% with an average of 1.81%; dinitrogen (N_2), which ranges from 0.66% to 2.30%, with an average of 1.59%; methane (CH_4), which ranges from 49.84% to 62.97%, with an average of 56.46%; and carbon dioxide (CO_2), which varies from 35.36% to 41.81%, with an average of 37.21% (Table 2).

3.1.3 Estimated biogas production by type of formulation

The results obtained for the estimation of biogas production by formulation type showed that biogas production is proportional to the quantity of volatile matter degraded. The minimum and maximum values for VDM were 47.9% and 79.5%, with an average of 61.3%, and for biogas volume 1.6 m3 and 4.8 m3, with an average of 3.18 m3 (Table 3).

3.2 Discussion

The digesters are installed for households practicing animal husbandry and attiéké, and which can dispose of a sufficient quantity of waste for the initial and daily loading (40 kg of substrate for 40 liters of water). The pH averages between 6.4 and 7.4 at the inlet and outlet of the digesters, in agreement with (Zerrouki, 2016) who indicated that a pH between 6.8, neutral and 7.4 was required for optimal biogas production. According to (M'SADAK Youssef et al, 2012), characterization of the input and output waste formulations enabled us to find that pH values fall within the range of recommended values (6.00 to 7.5) for methanization; the optimum being around pH neutrality. The BOD_5 and COD loads obtained, ranging from 8522 mg/L to 5796 mg/L for BOD5 and from 24800 mg/L to 16600 mg/L for COD, are in line with values found

Table 1. Physico-chemical characteristics of substrates

Settings	Values	F1	F2	F3	F4	Min	Max	Average	Standard deviation
pH	Input	6.2	6.1	7	6.4	6.1	7	6.4	0.4
	Output	7.1	7.3	7.5	7.6	7.1	7.6	7.4	0.2
BOD_5 (mg/L)	Input	20 137	8 522	20 616	52 491	8522	52491	25442	18880
	Output	15 435	5 796	16 540	40 127	5796	40127	19475	14589
COD (mg/L)	Input	58 800	24 800	60 200	153 800	24800	153800	74400	55406
	Output	49 400	18 600	57 300	123 100	18600	123100	62100	43961
MES (mg/L)	Input	2 940	1 240	3 010	7 740	1240	7740	3733	2794
	Output	1 350	850	2 100	6 400	850	6400	2675	2536
DM (%)	Input	11	10.5	13	11.9	10.5	13	11.6	1.1
	Output	9	5.2	6.7	11.5	5.2	11.5	8.1	2.8
VDM de DM (%)	Input	60.3	51.2	63.1	82.7	51.2	82.7	64.3	13.3
	Output	55.2	44.5	57	76.2	44.5	76.2	58.2	13.2

With BOD_5 (Biological Oxygen Demand), COD (Chemical Oxygen Demand), MES (Suspended Solids), DM (Dry Matter) and VDM (Dry Volatile Matter)

Table 2. Biogas composition by formulation

Settings	F1	F2	F3	F4	Min	Max	Average	Standard deviation
H_2 (%)	0.007	0.004	0.005	0.008	0.004	0.008	0.006	0.002
O_2 (%)	2.2	2.1	1.3	1.7	1.30	2.16	1.81	0.40
N_2 (%)	2.1	0.7	1.3	2.3	0.7	2.3	1.6	0.8
CH_4 (%)	53	49.8	60.1	63	49.8	63	56.5	6.1
CO_2 (%)	35.9	41.8	35.7	35.4	35.4	41.8	37.2	3.1

Table 3. Estimated biogas production by varions types of formulation

Settings	F1	F2	F3	F4	Min	Max	Average	Standard deviation
VDM de DM (%)	57.7	47.9	60.1	79.5	47.9	79.5	61.3	13.2
Biogas volume (m3)	2.9	1.6	3.4	4.8	1.6	4.8	3.2	1.3
Biogas volume (m3/Kg)	0.02	0.01	0.03	0.04	0.01	0.04	0.03	0.01

in the literature; CAFIPOC (1996) records BOD_5 and COD at the digester inlet ranging from 22,000 mg O2/l to 169,000 mg O2/l, with a 50% reduction at the outlet. However, outlet values vary from 52491 mg/L to 40127 mg/L for BOD_5 and from 153800 mg/L to 123100 mg/L for COD. Concerning DM (dry matter), we have values between 10.5% and 5.2% at inlet, then at outlet, we have between 13% and 11.5% which are close to the data of (Bekri et al., 2023) (DM=6.4% at inlet and 15% at outlet) in Tunisia and of (Faiza & Soumia, 2013) and (Kalloum et al., 2007) in Algeria (DM=10% at inlet and 20% at outlet). Anaerobic digestion is one of the main treatment methods for reducing the load of these effluents rich in organic matter and toxic substances ((Gijzen et al., 2000); (Kpata-Konan et al., 2011)) and for producing biogas (Bougrier, 2005; Saidi A. & Abada B., 2007; Kpata-Konan et al., 2020).

Biogas quality is assessed primarily by the percentage of methane (CH_4) it contains. The higher the methane content, the better the biogas (Phan, 2020). The CH_4 compositions of biogas 49.8% and 63% with an average of 56.5% obtained respectively by waste formulations are in line with the general composition of biogas (50% to 70% CH_4) (Dupont, 2010). The values obtained are slightly lower than those of (Igoud et al., 2002), which is 61%. CH_4 concentrations can be significantly higher with other substrates, depending on conditions. We can cite Biaudet et al. (2018) who obtain 80.5% under Sahelian conditions for domestic wastewater treatment and Bassila (2017) who finds 83% CH_4 under Mediterranean conditions for urban wastewater treatment. This situation of low CH_4 rates observed in the present study can be explained by the fact that several values in the literature are obtained experimentally and therefore under conditions optimized to have the best possible yields. It would be interesting to do the same in order to better reconcile the results. As for the average oxygen and nitrogen levels (1.8% and 1.6%) found in our biogas samples, they could suggest air ingress into the digesters or bags during sampling. Low air entry into the digesters would imply the coexistence of a large proportion of anaerobic digestion and a small proportion of aerobic degradation. This justifies the high average CO_2 content (41.2%). In fact, the two gases CH4 and CO2 are the main parameters contained in biogas, but methane has a higher percentage in the formulations, so it can be said that the gas is flammable, whereas carbon dioxide is lower, so the gas is not flammable. The low methane percentage found in our study could be explained by the lack of continuous digester agitation and the nature of the substrate. As for the oxygen percentages found in the biogas samples, air ingress due to leaks during sampling could be the cause. These leaks were noted when the device (air chamber) was transported to the site to measure the composition of the biogas. A low air intake into the digester would suggest the coexistence of biomethanization in large part, which would justify the percentage of CO_2. Nitrogen determination is important in the biomethanization process, but an excess of nitrogen partially or totally inhibits the process and thus breaks of biogas production.

Estimated daily biogas production averages 3.18 m3 /day. This volume, slightly higher than the amount of sludge introduced daily into the digesters (2.4 m3 /day), is in line with the predictions of Afilal et al. (2010). Gas production was observed with increasing temperature, in agreement with Anand et al. (2022) who reported that biogas production is favored by increasing temperature and that when temperature decreases, the biogas production rate decreases. The waiting and retention period for biogas production was eight days and ten days respectively. This may be due to acid build-up, nutrient depletion or the production of autotoxic substances by the microbes, given that this process is a batch culture system. This may be due to the use of waste products by the micro-organisms. This is in line with reports by Akintokun et al. (2017), who stated that total solids and volatile solids decrease as methane yield increases.

4. CONCLUSION

This study showed that biogas production by codigestion of waste formulations (cassava residues, poultry droppings and household waste) produced a good volume of biogas when the three wastes were mixed. We also found that methane plays a very important role in biogas production. On the other hand, we found that the quantities of biogas produced from formulations 4 and 3 (4.8 m3 and 3.4 m3 respectively) were significantly higher than those from formulations 1 and 2 (2.9 m3 and 1.6 m3 respectively). In terms of pollution control parameters, we found that BOD_5 and COD decreased at the end of the experiment (methanogenesis phase) for all four digesters (1, 2, 3 and 5), while a rapid increase in COD was noted for the 4th digester containing a high percentage of biodegradable waste.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/127736