

## **Bioenergy potential of various wastes (cassava residues, poultry droppings and household waste) in the gbêkê region (Bouaké, Central Ivory Coast).**

### **ABSTRACT**

Assessing the potential for biogas from cassava residues, poultry droppings and household waste in Bouaké will help to determine the viability of a sustainable energy project. Cassava is abundant in this region and its use produces residues rich in starch, a potential source of biogas via anaerobic digestion. Poultry droppings from livestock farming and household waste are respectively sources of biomass rich in nitrogen and various organic materials. Unfortunately, the poor management of this waste creates environmental problems, in particular foul smells that lead to 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, the available quantity of each type of material was first inventoried over a period of months, pre-treatments were then carried out on the waste and finally laboratory tests were carried out to measure the biogas potential of each biomass. The results of this quantification provide valuable insight for planning and developing biogas production facilities in Bouaké. They encourage the adoption of renewable energies, waste reduction and better management of organic residues, thereby contributing to the environmental and economic sustainability of the region.

Keywords : Biogas, Cassava residues, Poultry droppings, Household waste and Bouaké.

### **1. INTRODUCTION**

As a result of rapid urbanisation, economic development and population growth, the amount of waste produced worldwide is expected to rise to 3.4 billion tonnes over the next three decades (Li et al., 2018), compared with 2.01 billion in 2016, an increase of 54.62% on the 1.3 billion tonnes produced in 2012 (Hoorweg et al., 2013). In Africa, although waste production is lower by global comparison, the continent faces specific waste management challenges (Couth & Trois, 2011). Around 174 million tonnes of waste end up in uncontrolled landfill sites, at 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 more than 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 neighbourhood to another, depending on the socio-economic level and the season. Overall, average production is 0.3 kg/inhab/day in rural areas and 0.5 to 1.2 kg/inhab/day in urban and peri-urban areas (United Nations Framework Convention on Climate Change, 2011). These figures 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 is now an issue that directly affects every single person on the planet, as waste 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)). Agricultural waste, which is thrown away, burnt or

buried without precaution, releases substances that are 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. Much of this waste contains complex molecules that can be converted into energy by anaerobic digestion, producing biogas (Lacour et al., 2011). Identifying the waste best suited to this type of recovery is therefore crucial to making the most of these resources.

The aim of this study is to assess the bioenergy potential of waste in Bouaké, in particular cassava residues, poultry droppings and household waste. 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 economic solution for waste management. This approach encourages people to see waste not simply as a burden, but as an exploitable resource with the potential to generate energy and reduce environmental impact.

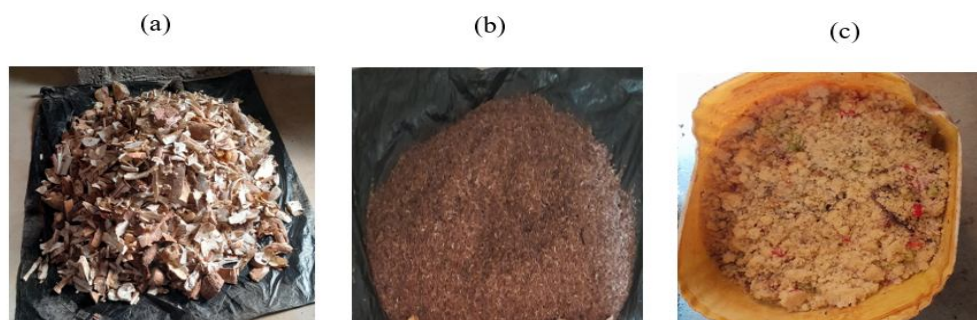
## 2. MATERIALS AND METHODS

### 2.1 Materials

The materials used for this study are organic matter 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 town of Bouaké, but in different districts where their respective production is greater.



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

#### 2.1.2 Technical equipment

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



**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 kg bag of cassava peelings from cooperatives that process

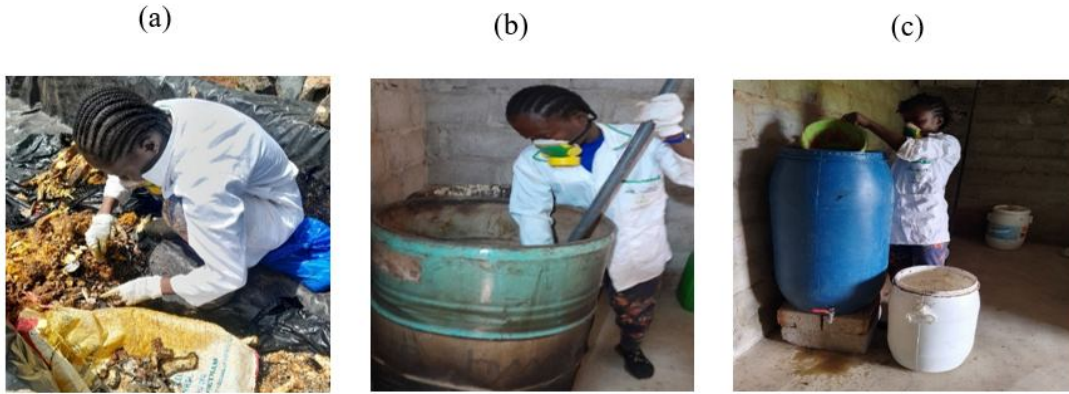
cassava into attiéké. Next, poultry droppings were collected in four (4) 150 kg bags from the various chicken farms, more specifically the henhouses. And finally, household waste, i.e. all biodegradable waste, was collected in two (2) 50 kg bags in restaurants and homes (fig. 4).



**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 pre-treatment increases the attack capacity of the microorganisms, resulting in faster hydrolysis (Djoms Brillant Wembe et al., 2023). Once the pre-treatment and mixing have been completed, we move on to filling the digesters (fig. 5).



**Fig. 5.** Mechanical waste pre-treatment: (a) wastesorting, (b) wastemixing and (c) digesterfilling

### 2.2.3 Waste formulations for biogas

For this study, we used four (4) digesters, including three (3) 160-liter and one (1) 200-liter. 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 H<sub>2</sub>O (water).

#### ➤ Formulation 1

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

We have:

$$F1 = 50 \text{ Kg de } A + 50 \text{ L de } B + 10 \text{ L de } H_2O \quad (1)$$



**Fig. 6. Formulation 1 (F1)**

➤ **Formulation 2**

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

We have :

$$F2 = 50 L \text{ de } B + 60 Kg \text{ de } C + 10 L \text{ de } H_2O \quad (2)$$



**Fig. 7. Formulation 2 (F2)**

➤ **Formulation 3**

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

Wehave :

$$F3 = 30 Kg \text{ de } A + 30 Kg \text{ de } C + 60 L \text{ de } H_2O \quad (3)$$



**Fig. 8. Formulation 3 (F3)**

#### ➤ Formulation 4

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

We have :

$$F4 = 30 \text{ Kg de } A + 30 \text{ L de } B + 30 \text{ Kg de } C + 30 \text{ L de } H_2O \quad (4)$$



Fig. 9. Formulation 4 (F4)

### 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 BOD5 and COD, inlet values range from 8522 mg/L to 5796 mg/L for BOD5 and from 24800 mg/L to 16600 mg/L for COD, while outlet values range from 52491 mg/L to 40127 mg/L for BOD5 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.

**Table 1.** Physico-chemical characteristics of substrates

| Settings                 | Valeurs | F1     | F2     | F3     | F4      | Min   | Max    | Moyenne | Ecart-type |
|--------------------------|---------|--------|--------|--------|---------|-------|--------|---------|------------|
| <b>pH</b>                | Entrée  | 6,2    | 6,1    | 7      | 6,4     | 6,1   | 7      | 6,4     | 0,4        |
|                          | Sortie  | 7,1    | 7,3    | 7,5    | 7,6     | 7,1   | 7,6    | 7,4     | 0,2        |
| <b>BOD5<br/>(mg/L)</b>   | Entrée  | 20 137 | 8 522  | 20 616 | 52 491  | 8522  | 52491  | 25442   | 18880      |
|                          | Sortie  | 15 435 | 5 796  | 16 540 | 40 127  | 5796  | 40127  | 19475   | 14589      |
| <b>COD<br/>(mg/L)</b>    | Entrée  | 58 800 | 24 800 | 60 200 | 153 800 | 24800 | 153800 | 74400   | 55406      |
|                          | Sortie  | 49 400 | 18 600 | 57 300 | 123 100 | 18600 | 123100 | 62100   | 43961      |
| <b>MES<br/>(mg/L)</b>    | Entrée  | 2 940  | 1 240  | 3 010  | 7 740   | 1240  | 7740   | 3733    | 2794       |
|                          | Sortie  | 1 350  | 850    | 2 100  | 6 400   | 850   | 6400   | 2675    | 2536       |
| <b>DM (%)</b>            | Entrée  | 11     | 10,5   | 13     | 11,9    | 10,5  | 13     | 11,6    | 1,1        |
|                          | Sortie  | 9      | 5,2    | 6,7    | 11,5    | 5,2   | 11,5   | 8,1     | 2,8        |
| <b>VDM de<br/>DM (%)</b> | Entrée  | 60,3   | 51,2   | 63,1   | 82,7    | 51,2  | 82,7   | 64,3    | 13,3       |
|                          | Sortie  | 55,2   | 44,5   | 57     | 76,2    | 44,5  | 76,2   | 58,2    | 13,2       |

With BOD5 (BiologicalOxygenDemand), COD (Chemical OxygenDemand), MES (SuspendedSolids), DM (Dry Matter) and DVM (Dry Volatile Matter).

### 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<sub>2</sub>) ranging from 0.004% to 0.008% with an average of 0.006%; oxygen (O<sub>2</sub>) with a value ranging from 1.30% to 2.16% with an average of 1.81%; dinitrogen (N<sub>2</sub>), which ranges from 0.66% to 2.30%, with an average of 1.59%; methane (CH<sub>4</sub>), which ranges from 49.84% to 62.97%, with an average of 56.46%; and carbon dioxide (CO<sub>2</sub>), which varies from 35.36% to 41.81%, with an average of 37.21% (Table 2).

**Table 2.** Biogas composition by formulation

| Settings                  | F1    | F2    | F3    | F4    | Min   | Max   | Moyenne | Ecart-type |
|---------------------------|-------|-------|-------|-------|-------|-------|---------|------------|
| <b>H<sub>2</sub> (%)</b>  | 0,007 | 0,004 | 0,005 | 0,008 | 0,004 | 0,008 | 0,006   | 0,002      |
| <b>O<sub>2</sub> (%)</b>  | 2,2   | 2,1   | 1,3   | 1,7   | 1,30  | 2,16  | 1,81    | 0,40       |
| <b>N<sub>2</sub> (%)</b>  | 2,1   | 0,7   | 1,3   | 2,3   | 0,7   | 2,3   | 1,6     | 0,8        |
| <b>CH<sub>4</sub> (%)</b> | 53    | 49,8  | 60,1  | 63    | 49,8  | 63    | 56,5    | 6,1        |

|                           |      |      |      |      |      |      |      |     |
|---------------------------|------|------|------|------|------|------|------|-----|
| <b>CO<sub>2</sub> (%)</b> | 35,9 | 41,8 | 35,7 | 35,4 | 35,4 | 41,8 | 37,2 | 3,1 |
|---------------------------|------|------|------|------|------|------|------|-----|

### 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 m<sup>3</sup> and 4.8 m<sup>3</sup>, with an average of 3.18 m<sup>3</sup> (Table 3).

**Table 3.** Estimated biogas production Estimation de la production de biogaz

| <b>Settings</b>                      | <b>F1</b> | <b>F2</b> | <b>F3</b> | <b>F4</b> | <b>Min</b> | <b>Max</b> | <b>Moyenne</b> | <b>Ecart-type</b> |
|--------------------------------------|-----------|-----------|-----------|-----------|------------|------------|----------------|-------------------|
| <b>VDM de DM (%)</b>                 | 57,7      | 47,9      | 60,1      | 79,5      | 47,9       | 79,5       | 61,3           | 13,2              |
| <b>Biogas volume (m<sup>3</sup>)</b> | 2,9       | 1,6       | 3,4       | 4,8       | 1,6        | 4,8        | 3,2            | 1,3               |

### 3.2 Discussion

The digesters are installed for households practicing livestock and attiéké production, and which can dispose of a sufficient quantity of waste for both 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 waste formulations at the inlet and outlet enabled us to note 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<sub>5</sub> and COD loads obtained, ranging from 8522 mg/L to 5796 mg/L for BOD<sub>5</sub> and from 24800 mg/L to 16600 mg/L for COD, are in line with values found in the literature; CAFIPOC (1996) records BOD<sub>5</sub> and COD at the digester inlet ranging from 22,000 mg O<sub>2</sub>/l to 169,000 mg O<sub>2</sub>/l, with a 50% reduction at the outlet. However, outlet values range from 52491 mg/L to 40127 mg/L for BOD<sub>5</sub> 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, which are 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<sub>4</sub>) it contains. The higher the methane content, the better the biogas (Phan, 2020). The CH<sub>4</sub> 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<sub>4</sub>) (Dupont, 2010). The values obtained are slightly lower than those of (Igoud et al., 2002), which is 61%. CH<sub>4</sub> concentrations can be significantly higher with other substrates, depending on the conditions. We can cite Biaudet et al. (2018) who obtain 80.5% under Sahelian conditions for the treatment of domestic wastewater and Bassila (2017) who find 83% CH<sub>4</sub> under Mediterranean conditions for the treatment of urban wastewater. This situation of low CH<sub>4</sub> rates observed during 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, these could suggest air ingress into the digesters or bags during sampling. A low level of air ingress 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<sub>2</sub> content (41.2%). Estimated daily biogas production averages 3.18 m<sup>3</sup> /day. This volume, slightly higher than the amount of sludge introduced daily into the digesters (2.4 m<sup>3</sup> /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 holding 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 auto-toxic substances by the microbes, as this process is a batch culture system. This may be due to the micro-organisms' use of waste products. This is in line with reports by Akintokun et al. (2017), who stated that total solids and volatile solids decrease as methane yield increases.

Les digesteurs sont installés pour des ménages pratiquant l'élevage et la production de l'attiké et qui peuvent disposer d'une quantité suffisante de déchets tant pour le chargement initial que pour le chargement quotidien (40 kg de substrat pour 40 litres d'eau). Le pH est compris en moyenne entre 6,4 et 7,4 à l'entrée et à la sortie des digesteurs, en accord avec

(Zerrouki, 2016) qui a indiqué qu'un pH compris entre 6,8, neutre et 7,4 était nécessaire pour une production optimale de biogaz. Selon (M'SADAK Youssef *et al.*, 2012), la caractérisation des formulations des déchets à l'entrée et à la sortie nous a permis de noter que les valeurs de pH se situent dans la plage des valeurs recommandées (6,00 à 7,5) pour la méthanisation ; l'optimum se situant autour du pH de neutralité. La charge en termes de DBO5 et DCO obtenue variable à l'entrée entre 8522 mg/L et 5796 mg/L de DBO5 et entre 24800 mg/L et 16600 mg/L de DCO est en accord avec les valeurs rencontrées dans la littérature ; CAFIPOC (1996) enregistre des DBO5 et DCO à l'entrée des digesteurs variant de 22000 mg O2/l à 169 000 mg O2/l avec une réduction de 50% à la sortie. Pourtant les valeurs à la sortie sont comprises entre 52491 mg/L et 40127 mg/L de DBO5 et entre 153800 mg/L et 123100 mg/L de DCO. Concernant les MS (matière sèche), nous avons des valeurs entre 10,5 % et 5,2 % à l'entrée, puis à la sortie, on a entre 13 % et 11,5 % qui sont proches des données de (Bekriet *et al.*, 2023) (MS=6,4% à l'entrée et 15% à la sortie) en Tunisie et de (Faiza & Soumia, 2013) et (Kalloumet *et al.*, 2007) en Algérie (MS=10% à l'entrée et 20 % à la sortie). La digestion anaérobie s'offre comme l'une des principales voies de traitement pour réduire la charge de ces effluents riche en matières organiques, en substances toxiques ((Gijzenet *et al.*, 2000) ; (Kpata-Konan *et al.*, 2011)) et de produire du biogaz (Bougrier, 2005 ; Saidi A. & Abada B., 2007 ; Kpata-Konan *et al.*, 2020).

#### 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 m<sup>3</sup> and 3.4 m<sup>3</sup> respectively) were significantly higher than those from formulations 1 and 2 (2.9 m<sup>3</sup> and 1.6 m<sup>3</sup> respectively). In terms of pollution control parameters, we found that BOD5 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.

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