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Assessment of the Biogas Potential by the Methanization of the Corn Crops in the Prefecture of Kindia (Guinea)

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Abstract: The aim of this research is to assess the energy potential of cow dung and corn cob inputs, with a view to estimating their biogas potential. The inputs were characterized in the microbiology laboratory of the National Control Office Quality in Matoto, Conakry. The experiment to produce methane from cow dung and maize cob was carried out at the Applied Research in Natural Sciences Laboratory of the University of Kindia (UK) using the following equipment: Three digesters were each connected to an air chamber (gasometer) by means of flexible pipes 8 mm in diameter, connected by clamps, liquid adhesives, valves and Teflon. This research focused on determining the quantity of biogas contained in each type of substrate (cow dung, maize cob and their mixture). Three experiments on the methanization of these inputs were carried out, with anaerobic digestion lasting 27 days, in a temperature range of 27 ℃ to 31 ℃ (mesophilic range). The results were as follows: maize cob 28.4 L, cow dung 22.6 L and codigestion 38.7 L. These results compared with similar studies revealed a coincidence.

Key words: Cow dung, corn cob, physico -chemical parameters, biogas, potential assessment.

1. Introduction

The fight against global warming involves the development of renewable energies such as wind, solar, biomass, etc., according to the objectives set within the framework of “Renewable Energy for All” [1]. The development of renewable energies is necessary because fossil fuels, which are not renewable, are becoming scarce, but also and above all because of the growing demand for energy [2]. These fossil fuels have a negative impact on our environment.

It is also worth recalling the enormous positive impact that agriculture plays in reducing carbon dioxide in the ecosystem, through the phenomenon of photosynthesis [3]. This is why developing and promoting renewable energies in general, and biomass in particular, becomes a priority for their many environmental and energy benefits. Modern biomass remains little used in Africa, due to a lack of reliable data on their availability and methods of valorization.

About 85.7% of the population of the member states of the ECOWAS (Economic Community of West African States) use solid fuels (mainly wood and charcoal) for cooking (traditional use of biomass) according to the IEEF (Institute of Energy and Environment of the Francophonie) according to a progress report on renewable energies and energy efficiency of ECOWAS [4].

In 2014, ECOWAS member states had only 3.5 MW of installed and grid-connected biomass energy capacity [5]. However, Africa has a huge amount of

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unexploited agricultural biomass. Indeed, most African economies are based on agriculture. Agriculture generates a huge amount of unexploited agricultural biomass based on the state of play on agro-industrial by-products in West Africa [6].

This form of energy source can play a key role in improving the rural electrification rate from the moment the raw material is available, nearby and at low cost. Agricultural biomass is, for the most part, a dry biomass whose possible valorization would be thermochemical conversion (pyrolysis, combustion, carbonization and gasification) [7]. This type of conversion considerably increases the valorizable energy potential of biomass. This conversion aims at producing a gaseous mixture used as fuel in a gas turbine for the production of electrical energy and/or heat.

Guinea, a West African country, is characterized by relatively low energy consumption, with the traditional abusive use of biomass energy used in an unsustainable manner [8].

Biomass is being pushed back due to the lack of a reliable database to promote its development. The share of renewable energies in the total final energy consumption of the ECOWAS region is relatively marginal, even if it varies greatly from one country to another.

According to the Global Monitoring Framework of the Sustainable Energy for All initiative, Guinea-Bissau, Ghana and Sierra Leone occupied the top three regional positions in 2010 for the contribution of renewable energy to final consumption with 30.3%, 22.4% and 19% respectively. Their positioning was mainly due to the use of the resource called “modern biomass” [9] according to the progress report of the IEEF on renewable energy and energy efficiency of ECOWAS.

Better still, the ECREEE (Regional Centre for Renewable Energy and Energy Efficiency), in partnership with the governments of the Member States, has emphasized the role that renewable energy technologies play in improving electricity production and access to electricity across the region. In this context, mastering technologies relating to the energy recovery of biomass in Africa is essential. This will contribute effectively to the promotion of biomass energy in Africa, a form of energy that has so far remained poorly understood and poorly exploited to the detriment of solar energy, which is more widely used and developed.

Given the low electrification rate in general, at the national level and in rural areas in particular, and given the increasingly large quantity of unused agricultural residues recorded, biomass is the most suitable, not only because of its availability, but also because of its ease of conversion into usable energy in developing countries. It solves two major problems in developing countries: waste management, which is becoming increasingly cumbersome, and resolving the energy crisis through rural electrification [10, 11]. Concerning energy from biomass, there are different types of recovery, namely: thermal recovery, chemical recovery, biological recovery and thermochemical recovery [12-15]. However, we will be particularly interested in the thermochemical aspect of biomass recovery, given its optimal performance and its adaptation to agricultural waste in tropical countries, and their physicochemical characteristics. Guinea is one of the countries in the West African sub-region whose economy is heavily dominated by agricultural production. The many efforts made in this area, accompanied by the mechanization of agriculture, further improve agricultural yield. Also, new crops have emerged with an impressive quantity when harvested, thus generating residues that can be used for energy purposes [16, 17].

Guinea has considerable potential in agricultural and household waste that can be recovered into energy. Biomass feasibility studies show that comprehensive waste management would significantly reduce fossil fuel imports. However, there are no reliable statistics on the availability and nature of agricultural residues that can be recovered. In addition, few data on the physicochemical characterization and kinetics of any agricultural biomass are currently available. Our study deals with the biochemical conversion of agricultural biomass by methanization for the production of biogas, through a continuous biodigester.

Depending on their availability and certain physicochemical characteristics (in relation to biochemical valorization), a biomass is selected from the repertoire of agricultural biomass available in Guinea, namely: corn cobs. For several years, there has been a clear increase in corn cultivation in terms of agricultural production. However, corn cobs are not valorized, neither in the fields nor by the women selling cooked corn on the roadsides. The general objective of this research is to show the importance of agricultural biomass in the energy balance in Guinea on the one hand, and to contribute effectively to the energy valorization of biomass by biochemical means on the other hand.

Specifically, this study aims to:

- Determine the physicochemical characteristics of corn cobs;
- Evaluate the biogas production rate at different temperatures, humidities and pH;
- Analyze methanization reactions.

2. Materials and Methods

2.1 Description of the Study Area

The prefecture of Kindia is located between 10°3′29″ North latitudes, and 12°52′08″ West longitudes. It has an area of 9,115 km^2, a population of 469,446 inhabitants (2016), density 52 inhabitants/km^2. It is subdivided into 11 sub-prefectures: Kindia-centre, Bangouyah, Damakanyah, Friguiagbé, Kolenté, Madina-Oula, Mambia, Molota, Samayah, Sougueta and Linsan.

Located in Maritime Guinea in the Kindia region, the Kindia Prefecture is bordered to the East by the Mamou Prefecture, to the West by the Dubreka and Coyah Prefectures, to the North by Pita and Telimele, to the South by Sierra Leone, to the North-East by Dalaba and to the South-West by Forécariah.

The “monotonous” relief consists of plateaus with an average altitude of 400 m with Mount Gangan (1,117 m) as the highest point. The climate is of the humid tropical type marked by two seasons of equal duration. The average rainfall is 2,500 mm spread over approximately 150 rainy days.

The average annual temperature is 25 °C. The average relative humidity varies from 93% (wet season) to 51% (dry season). The prevailing winds are the monsoon and the harmattan. The soils are skeletal types of cuirass scree, ferralitic, gravelly and alluvial. The vegetation is composed of wooded savannahs, wooded savannahs and classified forests such as: Kourédi, Séguéya, Kombitidé, Koukou Park.

Kindia has many rivers that feed the Kolenté and Konkouré basins: Tokhou, Kolakhouré, Fissa, Wawa, Kilissi, Santa, Méyenkhouré, Condetta, Sorondo, Kolakhouré and Molékhouré, Samou, Soukou, etc.

2.2 Characterization of Inputs

The characterization of the inputs was carried out at the microbiology laboratory of the National Office of Quality Control in Matoto.

2.2.1 Materials

The following equipment was used for these experiments:

- Drying and calcining ovens, power 800 W;
- The DIAL-O-GRAM brand analytical balance (2,610 g);
- The glass stirrer (stirring and homogenization of the substrate);
- Tongs (allow handling of hot glassware);
- The test tube (for reactions of small quantities of reagents);
- The beaker, cylindrical container (for measuring volume).

2.2.2 Characterization Methods

This equipment allows the following characteristics to be measured: density, relative humidity, dry matter, OM (organic matter), mineral matter, carbon rate and the nitrogen rate [18] of the different samples of cow dung

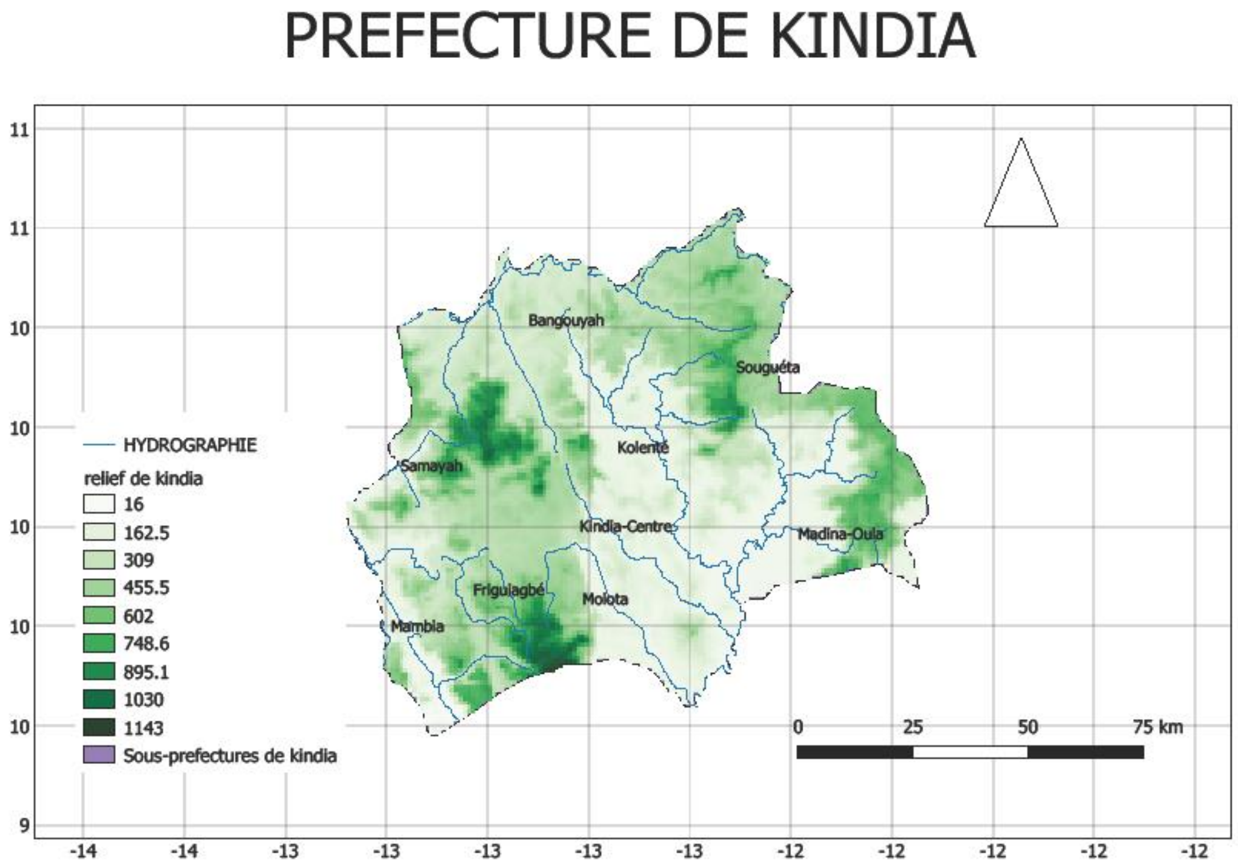

Fig. 1 Presentation of the Kindia prefecture.

and laying hen droppings were determined. In addition, cow dung and chicken droppings were characterized from the Mamou Prefecture using the following two methods:

- Gravimetric;
- Volumetric.

2.2.2.1 Density

A container, of 1 L volume is filled with organic waste (animal inputs) without compaction and weighed on a scale. The average density was calculated from the following formula:

$$\rho = \frac{m}{v} \qquad (1)$$

2.2.2.2 Relative humidity of the Substrate

Most protocols determine moisture by drying at 105 ℃ to a constant weight.

The moisture percentage of different organic wastes is determined by the difference in weight of the sample before and after drying until mass stabilization by the formula [19]:

$$H(\%) = \left[\frac{M_O - M_{Sec}}{M_O}\right] \times 100 \qquad (2)$$

The dry matter content was determined by Eq. (3).

$$MS\ (\%) = 100 - H(\%) \qquad (3)$$

2.2.2.3 OM Content

The determination of the rate of OM at the level of each substrate consists of weighing 20 g of each substrate which is placed in the oven for 24 h at 70 ℃, then calcining 3 g of the samples, previously dried for 2 h in the incinerator. The content of OM is determined, according to Eq. (4) [20]:

$$MO(\%) = \left[\frac{M_{\text{sec}} - M_{SI}}{M_{Sec}}\right] \times 100 \qquad (4)$$

where, M_{sec}, the weight before calcination (g), M_{SI} the weight after calcination (g).

2.2.2.4 Mineral Matter

After 6 h in the incinerator, an inorganic residue is obtained. This mass of the waste calcined at 600 ℃ (M_{SI}) is the mineral matter. Measuring the weight of the residual ash fraction by the loss on ignition allows us to determine the percentage of the mineral fraction contained in the waste [20].

The mineral matter is determined by Eq. (5):

$$MM(\%) = \left[\frac{M_{SI}}{M_{Sec}}\right] \times 100 \qquad (5)$$

2.2.2.5 Carbon (C)

From the OM, a deduction of the carbon content is possible by one of the relations (Eq. (6)) [21].

$$C(\%) = \frac{MO(\%) - 1{,}5}{1{,}4} \ (\mathrm{NT}) \qquad (6a)$$

$$C(\%) = \frac{MO(\%)}{1{,}725} \ (\mathrm{NF}) \qquad (6b)$$

$$C(\%) = \frac{MO(\%)}{2} \ (\mathrm{NB}) \qquad (6c)$$

2.2.2.6 Nitrogen (N) Rate

Total nitrogen is determined by the Kjeldahl method in two steps:

- mineralization of the sample of mass 1 g by concentrated sulfuric acid in the presence of a catalyst (copper sulfate plus sodium sulfate) for 2 h;
- a distillation and titration of the ammonia released in the last step using a sulfuric acid solution of concentration equal to 0.02 normal.

The total Kjeldahl nitrogen is given by Eq. (7) [22]:

$$\%N = V_{Titration} \times 0{,}195 \times Masse\ de\ prise\ d'essai \qquad (7)$$

2.3 Experimental Studies (Methanization)

After characterizing the samples, we conducted experiments on methane production from cow dung and laying hens' droppings. These experiments took place at the LEREA (Laboratory of Teaching and Research in Applied Energy) of UGANC (Gamal Abdel Nasser University of Conakry). They aim to compare the fermentation of different substrates (cow dung and chicken droppings and codigestion).

2.3.1 Description of the Digester

2.3.1.1 Materials

During this study we used the following materials: Cans (3), valves, flexible pipes, clamps, liquid glue, Teflon, inner tube (3).

2.3.1.2 Experimental Method

This research focuses on determining the quantity of biogas contained in 2 kg of each type of substrate (cow dung and corn cob) and the mixture of the two substrates (co-digestion) in the proportion of one (1) kg each.

We used simultaneously 3 plastic drums as digesters, they were filled to 3/4 of their volume respectively by the two types of substrate and their mixture. These samples were diluted in 2 L of water each. These three digesters were each connected to an air chamber (gasometer) by means of flexible pipes of 8 mm internal diameter. The tightness of the entire system was checked.

2.4 Substrate Degradation Rate

The degradation rate of a substrate is calculated from the volume of biogas (or methane) produced, relative to the theoretical production of biogas in L/kg.

$$D_{sub} = \frac{V_{Biogaz}}{V_{Théorique}} \times 100 \qquad (8)$$

The different characteristics of produced methane from the three samples (cow dung, chicken droppings and co-digestion) were determined by these methods.

3. Results

3.1 Results of the Physicochemical Characterization of Inputs

The corn cob samples were taken from Mr. Aboubacar Camara's field and the cow dung from Alpha Mamadou DIALLO park in the Friguiagbe Sub-Prefecture, Kindia Prefecture on May 22, 2022. The physicochemical characterization of the inputs was carried out at the ONCQ (Microbiology Laboratory of the National Control Office) in Matoto.

3.2 Physical Parameters

The physicochemical parameters of the substrates were determined on 3 g samples of each type of substrate. Tables 1 and 2 give the results obtained for humidity, dry matter and density for five samples of each substrate.

It can be seen from Tables 1 and 2 that cow dung and corn cobs have a significant dry matter content. The volumetric masses are 106.3 kg/m^3 for cow dung and 250.00 kg/m^3 for corn cobs.

The values of humidity, dry matter and density are given in Table 3 as well as OM.

The OM rate for each substrate was determined following the calcination of the previously dried samples (0.625 g for cow dung and 1.5 g for corn cob) in a muffle furnace for 6 h at 600 ℃. The weighed incinerated mass is 0.27 g for cow dung and 0.49 g for corn cob. Using Eq. (4), 57% OM for cow dung and 67% OM for corn cob were found.

3.3 Chemical Parameters of Cow Dung

The chemical parameters (carbon, nitrogen, C/N ratio) were determined by: carbon, deduced from OM, nitrogen from the Kjeldahl relation (Eq. (7)) and the C/N ratio was calculated. Table 4 gives these different parameters and the standards used: Tunisian Standard (NT), French Standard (NF) and Belgian Standard (NB).

Table 1 Physical parameters of cow dung.

Samples	Physical parameters				
	Mass (M_0) g	Mass (M_{sec}) g	Humidity (%) H	Dry matter (%) MS	Density (kg/m^3)
1	3	2.25	25.00	75.00	1,000.00
2	3	2.2	26.66	73.34	750.00
3	3	2	33.33	66.67	666.67
4	3	1.45	51.66	48.33	500.00
5	3	0.625	79.17	20.83	208.33

Table 2 Physical parameters of corn cob.

Samples	Physical parameters				
	Mass (M_0) g	Mass (M_{sec}) g	Humidity H (%)	Dry matter (%) MS	Density (kg/m^3)
1	3	2.63	33.00	87.00	333.00
2	3	2.44	34.00	82.00	291.67
3	3	2.25	36.00	75.00	270.83
4	3	1.55	40.33	51.67	208.33
5	3	1.88	38.00	62.00	250.00

Table 3 Physical characteristics of organic waste.

Types of inputs	Humidity H (%)	Dry matter MS (%)	OM (%)	Density (kg/m^3)
Cow dung	79.17	20.83	57	208.33
Corn cob	38.00	62.00	67	250.00

Table 4 Characterization of chemical parameters of cow dung.

Standards	Chemical parameters				
	Carbon (C %)	$V_{Titration}$ (mL/g)	Test mass (g/mL)	Nitrogen NT (%)	C/N ratio
1 (NT)	46.78	5	1.87	1.82	25.66
2 (NF)	38.88	5	1.87	1.82	21.32
3 (NB)	33.5	5	1.87	1.82	18.37

Table 5 Characterization of chemical parameters of corn cob ARABIC.

Standards	Chemical parameters				
	Carbon C(%)	$V_{Titration}$ (mL/g)	Test mass (g/mL)	Nitrogen NT (%)	C/N ratio
1 (NT)	46.78	5	2.62	2.55	18.35
2 (NF)	38.84	5	2.62	2.55	15.23
3 (NB)	33.5	5	2.62	2.55	13.14

Table 6 Physicochemical parameters of cow dung and corn cobs.

Types of inputs	Physicochemical parameters						
	Humidity H (%)	Dry matter MS (%)	MO (%)	Carbon % COT	Nitrogen % NT	C/N ratio	Report standards C/N
Dung	79.17	20.83	57	38.88	1.82	21.32	20-30
Roundup	38.00	62	67	38.84	2.55	15.23	15-25

The results of the chemical characterization of cow dung show that: The C/N ratio is equal to 21.32. This value being between 20 and 30 optimum (French Standard), means that the analyzed input can be used for the production of biogas.

3.4 Chemical Parameters of Corn Cob

Similarly, these parameters were determined for corn cob. The results obtained are recorded in Table 5.

After analysis, the results of chemical characterization of corn cob show that: the C/N ratio is equal to 15.23. In view of the established standards (15-25 optimum) it is deduced that the corn cob used can also be used for the production of biogas. The physicochemical parameters obtained for the two substrates are summarized in Table 6.

It can be seen from Table 6 that cow dung, like corn cob, is rich in carbon (38.88% and 38.84%). These two inputs have two organic nitrogen rates of 1.83% and 2.55% with a C/N ratio in accordance with the French standard, 21.32 for cow dung and 15.23 for corn cob. These two inputs analyzed can be used for the production of biogas.

3.5 Discussions of the Results of the Physicochemical Characterization

The physicochemical parameters of agricultural inputs in the Kindia Prefecture show that:

(a) The dry matter rates of the cow dung samples (20.83%) and corn cob (62%) are very appreciable according to the literature [21] i.e. (20%-50%) for cow dung and (60%-70%) for corn cob.

(b) The OM rate of cow dung (57%) is quite close to the result reported by Parra et al. [22], i.e. (20%-67%) of MO and for the corn cob (67%) are also close to the result given in Ref. [24], i.e. 60%-80% of MO.

(c) The ratios between carbon and nitrogen rates (C/N) obtained after the analysis with the French standard (NF) are respectively 21.83 for cow dung and 15.23 for corn cob. These are very close to the results reported by Ref. [24]. According to the literature we have (20-30) for cow dung and (15-25) for corn cob.

3.6 Experimentation of Inputs

Three experiments were carried out simultaneously: cow dung, corn cob and codigestion (cow dung and corn cob, 50% each). Biogas production began on the 3rd day after loading the digesters and lasted 27 days. The experimental devices are in paragraph III.3. The cumulative biogas production for each three (3) days is given in Table 7. The temperature during the experiments was between 27 and 28 ℃. Table 7 gives the different results obtained.

Fig. 4 shows the kinetics of cumulative biogas production of substrates (cow dung, corn cob and codigestion) during a retention time of 27 days. It should be noted that the scale used for the hydraulic retention time is 1/6.

Table 7 Biogas production.

No.	Date	Days	Temperature (℃)	Corn cobs (L)	Raffles+dung (L)
1	05/23/2022	0	30 ℃	0.795	0.73
2	05/24/2022	1	30 ℃	0.913	0.73
3	05/25/2022	2	26 ℃	0.924	0.73
4	05/26/2022	3	29 ℃	0.935	0.73
5	05/27/2022	4	27 ℃	0.946	0.73
6	05/28/2022	5	25 ℃	0.968	0.84
7	05/29/2022	6	29 ℃	0.978	0.84
8	05/30/2022	7	29 ℃	0.978	0.84
9	05/31/2022	8	30 ℃	0.978	0.84
10	06/01/2022	9	29 ℃	1	0.84
11	06/02/2022	10	32 ℃	1.011	0.90
12	06/03/2022	11	31 ℃	1.011	0.92
13	06/04/2022	12	27 ℃	1.021	0.96
14	06/05/2022	13	26 ℃	1.032	0.96
15	06/06/2022	14	26 ℃	1.032	0.97
16	06/07/2022	15	28 ℃	1.043	0.97
17	06/08/2022	16	26 ℃	1.043	0.93
18	06/09/2022	17	29 ℃	1.043	0.93
19	06/10/2022	18	28 ℃	1.054	0.95
20	06/11/2022	19	29 ℃	1.054	0.97
21	06/12/2022	20	31 ℃	1.054	0.97
22	06/13/2022	21	29 ℃	1.064	0.96
23	06/14/2022	22	29 ℃	1.043	0.96
24	06/15/2022	23	30 ℃	1.043	0.95
25	06/16/2022	24	25 ℃	1.011	0.94
26	06/17/2022	25	28 ℃	1.011	0.88
27	06/18/2022	26	25 ℃	1	0.84
	Average (L/d)			0.99	0.88

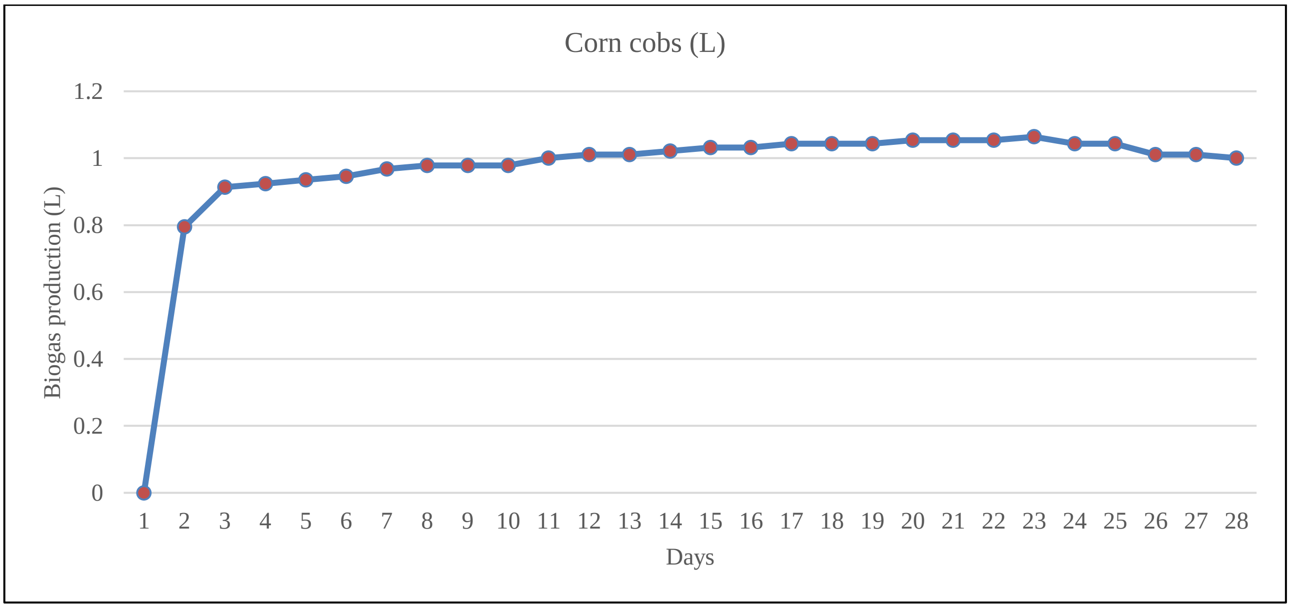

Fig. 2 Production of biogas from corn cob.

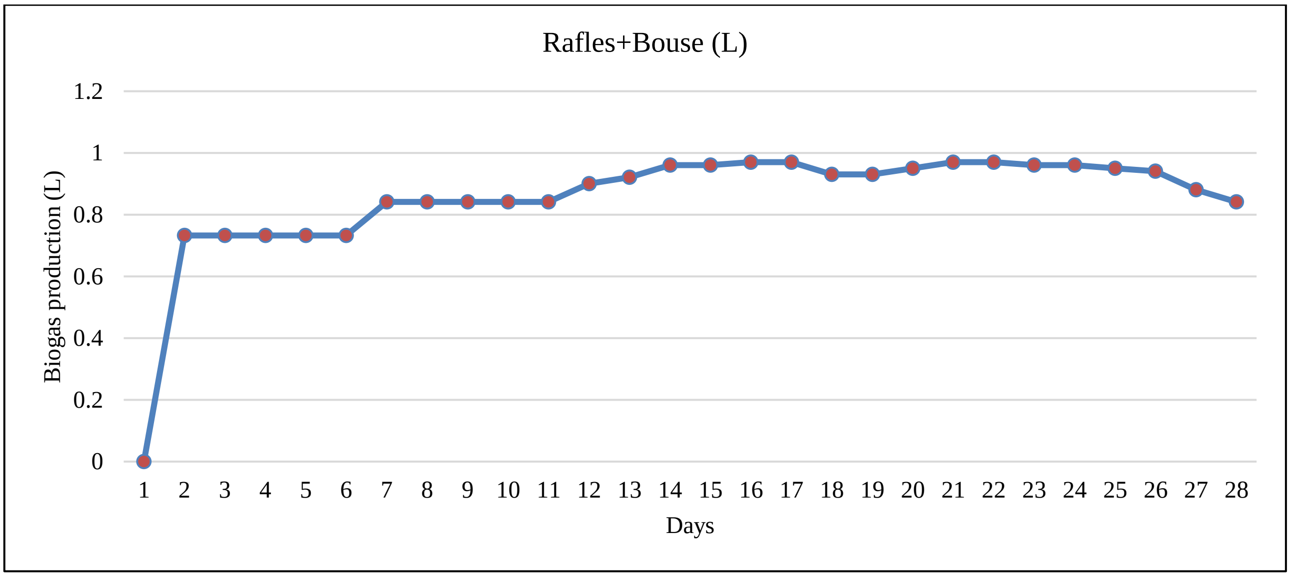

Fig. 3 Production of biogas from cow dung.

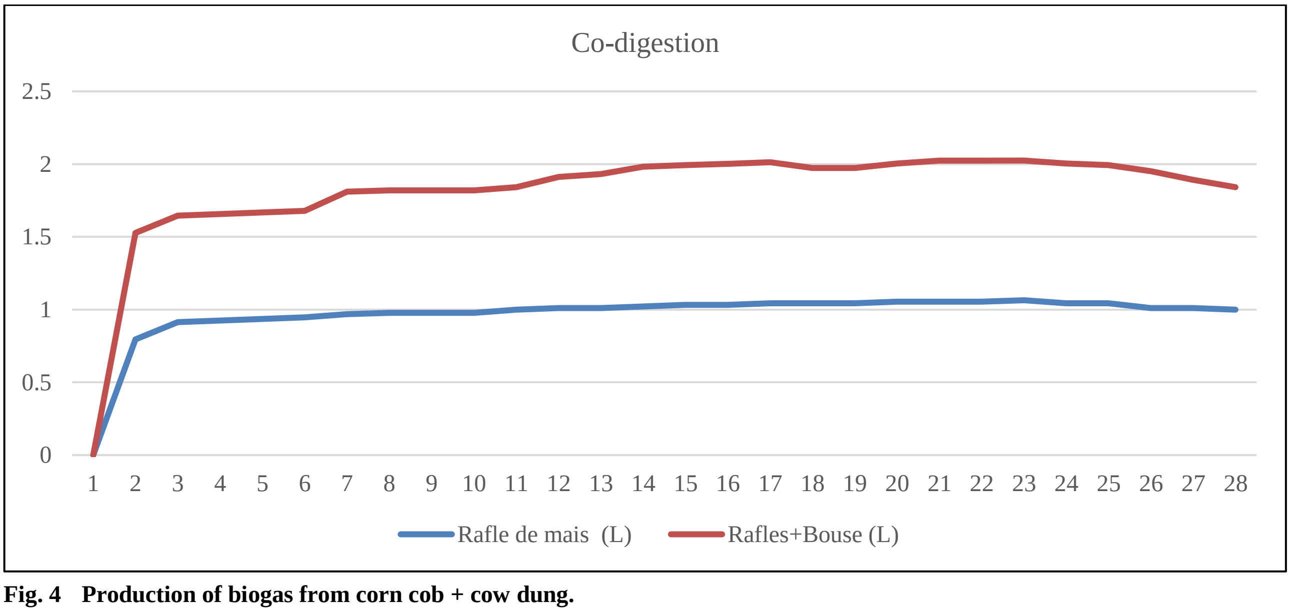

Fig. 4 Production of biogas from corn cob + cow dung.

3.7 Discussions of the Results of the Experimental Study

The transformation into gaseous compounds (CO_2 + CH_4) of a defined quantity of the organic substrate occurs as follows: (i) over a period of 27 days, 50% of the total volume of gas is produced in 9 days with a maximum on the 9th day of fermentation; (ii) the fermentation process continues all the remaining days.

The results of the experimental study of substrates at the University of Kindia show that biogas production began on the day for codigestion and on the 2nd day for corn cob. After 27 days of methanization in a temperature range of 27 ℃ to 31 ℃ (mesophilic range), the quantity of biogas for corn cob is 28.40 L, higher than that of cow dung (22.00 L). Codigestion gives a higher value (38.70 L); on average the daily specific production of biogas from the different inputs is: cow dung (0.50 L/day), corn cob (0.72 L/day) and finally codigestion (0.92 L/day) at an average temperature of 28 ℃.

The results of the experimental study and literature results are summarized in Table 8.

Table 8 Results of the experimental study.

No.	Substrates	Quantity of substrate (kg)	Quantity of biogas (L)				
			Experience results	Literature results [24]	Gap %	Literature Results [25]	Gap %
1	Corn cob	2	28.40	40	11.6	30	2.4
2	Cow dung	2	22.00	20	-2	22	0
3	Co-digestion	2	38.70	-		-	-

These results obtained are in perfect coincidence with those of Danevitch et al. [24]: only -2% difference for cow dung and 11.6% difference for corn cob. The same is true for Enyegue Mbia et al. [25]: similarly 0% difference for cow dung and 2.4% difference for corn cob. These slight differences could be due to environmental conditions (temperature, retention time, etc.) and techniques (equipment used).

4. Conclusion

This work allowed us to achieve the desired objectives, namely to evaluate the energy potential of cow dung and corn cob inputs, with a view to their energy recovery. The research allowed us to determine the physicochemical parameters:

(a) Cow dung: humidity (79.17%), dry matter (20.83%), OM (57%), density (208.33 kg/m^3), carbon rate (38.88%), nitrogen rate (1.82%) and C/N ratio (21.32).

(b) Corn cob: moisture (38%), dry matter (71%), OM (67%), density (250 kg/m^3), carbon rate (38.84%), nitrogen rate (2.55%) and C/N ratio (15.23). These results compared with those in the literature revealed a very good coincidence.

Three experiments on the methanization of these inputs were carried out, the anaerobic digestion lasted 27 days, in a temperature range of 27 ℃ to 28 ℃ (mesophilic range). It was obtained for: corn cob 28.4 L, cow dung 22.6 L and for codigestion 38.7 L.

Conflict of Interest

The authors declare they are no conflict of interest.

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