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Production of biogas with household peelings in households and estimation of energy potential in Côte d'Ivoire

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ABSTRACT: The aim of this study is to produce biogas with household peelings. The peels used are cassava (PM), yam (PI) and plantain (PB) peels. The bibliographic study allowed us to know that this waste has a high yield of biogas. However, the production of biogas with these peelings has acidification problems linked to their acid pH and a high C/N ratio. The use of a digestate from the anaerobic digestion of cow dung as inoculum (I) and a neutralizer such as human urine and cassava effluent allowed the pH to be adjusted around neutrality, which which made it possible to produce flammable biogas with its various peelings.

KEYWORDS: Biogas, household peelings, inoculum, human urine.

1 INTRODUCTION

More than half of the world's population uses solid biomass fuels (wood) for domestic energy needs, such as cooking and lighting. In sub-Saharan African countries, more than 70% of the entire population depends on wood as fuel (Dohoo et al., 2013). The city of Yamoussoukro alone consumes 98% of charcoal production and 58% of firewood. This rate is expected to grow due to unbridled urbanization and galloping demography. All these data demonstrate the preponderant place of biomass energy and particularly charcoal in meeting the energy needs of the populations of the city of Yamoussoukro (Dohoo et al., 2013). The inaccessibility to forms of modern cooking energy therefore makes the living conditions of populations more difficult, especially those of women who are generally responsible for collecting firewood in underdeveloped countries. The collection of firewood is also one of the main causes of deforestation and consequently the degradation of arable land (Tize et al., 2015). The current widespread and inefficient use of biomass energy also has repercussions on health human. Indeed, deaths from acute respiratory infections as a result of air pollution have been estimated at around 1.3 million each year (Gwavua et al., 2012).

Thus, to resolve the difficulties of access to firewood by rural households and reduce the harmful effects on the environment, the construction of household digesters therefore presents itself as a reliable opportunity to improve the living conditions of the populations while preserving environment (Smith, 2013). The biogas produced allows rural households to carry out cooking tasks (Jyothilakshmi et al., 2013). It contributes to the reduction of greenhouse gas (GHG) emissions released by animal manure placed on the ground (Diop et al., 2015). Methanization or anaerobic digestion (AD) takes place in confined enclosures called digesters inside which the fermentation reactions are optimized and controlled. The product of anaerobic digestion (biogas), is a mixture of 50-70% methane (CH4), 50-30% carbon dioxide (CO2) depending on the nature of the substrate (Rufai, 2010).

Methanization or anaerobic digestion is done in confined enclosures called digesters inside which the fermentation reactions are optimized and controlled; it produces biogas composed mainly of methane, while reducing by half the rate of organic matter in many waste or biodegradable by-products (Couturier et al., 2001). Anaerobic digestion or methanization is a biological process generally comprising four successive phases: hydrolysis and acidogenesis which result in the formation of volatile fatty acids, acetogenesis responsible for the formation of acetic acid, hydrogen and carbon dioxide and finally methanogenesis which requires very specific conditions for its triggering and the production of methane (Kalloum et al., 2007). Indeed, several parameters govern the smooth running of anaerobic digestion. The most important are: pH, temperature, C/N ratio (Kalloum et al., 2007; Merlin and Boileau, 2010). The optimal values of these parameters are presented in the table 1.

Table 1. Optimal parameters of anaerobic digestion (Merlin and Boileau, 2010)

Parameter	Hydrolysis/acidogenesis phase	Methanogenesis
PH	5.2- 6.3	6.7-7.5
Ratio C/N	10/1- 45/1	20/1 - 30/1
Temperature range (°C)	25°C - 35°C	32°C - 42°C (mesophilic) 50°C -58°C (thermophilic)
Redox potential (mV)	-300 to+400 mV	Under -250 mV

The favorable pH range for anaerobic microbes is 6.8-7.5. Biogas production is generally inhibited or even fails at pH values below 6 or above 8 (Kpata-Konan et al., 2011). Methane production is generally increased in the temperature range of 35°C to 40°C under mesophilic conditions (Kpata-Konan et al., 2011).

The C/N (carbon to nitrogen) ratio in the feedstock is very important because a high level of nitrogen (>80 mg/l) in the form of undissociated ammonia (at a low C/N ratio) can cause toxicity, while a low level of nitrogen (at a high C/N ratio) can inhibit the rate of digestion. It is necessary to maintain the correct C/N ratio of the substrate in between. Co-digestion of different compatible substrate can be used to maintain C/N ratios (Gupta et al., 2012).

The difficulties of households to respect these parameters is at the origin of the abandonment of the use of digesters in households (Rajendran et al., 2012). These difficulties encountered by households can be explained by the fact that in discontinuous anaerobic treatment systems (batch), the digester is initially fed with the substrate and sealed throughout the processing period. The fermentation reactions take place sequentially and when the production of biogas drops or becomes zero, the reactor is emptied and a new substrate is introduced (Arras, 2017). However, the disadvantage of this type of reactor is the coexistence of all the bacteria in the same volume. This then requires the maintenance of an environment acceptable to all (Arras, 2017).

The technique commonly used in the literature is pH adjustment using chemicals such as lime, soda and sodium bicarbonate (Matheri et al., 2015). The use of these chemicals contributes to increasing the cost of biogas production, which could be an obstacle to the use of biogas in households (Gonzalez et al., 2022).

This present work aims to produce biogas with cassava, yam and plantain peelings. To maintain the C/N ratio, the digestate from the anaerobic digestion of cow dung is used as inoculum. Cassava slurry and human urine are used to adjust the pH of the substrate in the digester. The objective is to determine the optimal conditions for the biodigestion of household peelings (banana, yam and cassava peelings) by avoiding any inhibition and to compare the volume of biogas obtained with the peelings.

2 Materials And Methods

2.1 Collecting Of Peeling

Fresh banana, cassava and yam peels are the raw materials used for the production of biogas in this research work. These peelings were chosen because of their high methane yield. The different yields and the C/N ratio are presented as follows:

Table 2. Methane yield of household peelings and C/N

Substrates	MS %	PH	MO%	Specific prod of CH_4% ((Nm^3_{ch4})	C/N	Ref
Cassava peels	20	5.68	75	267	49.9	(Lacour, 2012 ; Adekan and Bamgboye, 2009)
Yam peels	20		75	267	43.5	(Lacour, 2012 ; OjikutuAbimbola and Olumide, 2014)
Plantain peels	20		89	322	37,1	(Lacour, 2012 ; OjikutuAbimbola and Olumide, 2014)

These peelings were collected from households in Djahakro. The various peels have been pretreated by soaking in water for 7 days as to reduce the cyanide content which is detrimental to microbial activities. The materials were ground into small pieces using a blender (Oparaku et al., 2013).

2.2 Sample Characterization

Fresh cow dung samples used in this study were collected from the INP-HB cattle farm. Human urine is collected in latrines and cassava effluent is collected from women in Djahakro (Yamoussoukro).

2.2.1 Measurement Of PH And Redox Potential

The pH was measured on 2 g of sample homogenized with 20 ml of distilled water using a pH meter (HAINA). The pH meter is switched on and the probes are plunged directly into the various beakers containing the substrate. The value of these parameters is read directly on the digital display screen of the device presented as follows (Traoré et al., 2016).

2.2.2 Determination Of Dry Matter

The dry matter was determined from 5 g of samples, by differential weighing, after passage in the Heraeus T 5042 oven at 105°C for 24 hours. The following formulas were used to calculate the dry matter (DM) and moisture (H) of cow dung (Afilal et al., 2014).

$$\% H = \frac{M_0 - M_1}{M_0} \quad (1)$$

$$\%DM = 100 - \%H \quad (2)$$

With:

%H: humidity percentage
M0: initial mass of the sample before drying (fresh cow dung)
M1: final mass of the sample after drying in an oven at 105°C
%DM: dry matter

2.2.3 Organic Matter (OM)

The organic matter (OM) content is obtained by weighing the difference between the mass of the dry waste (M_1) and the mass of the waste calcined at 600°C (M_2) up to a constant weight for 2 hours (Afilal et al., 2014).

$$\% MO = \frac{M1 - M_2}{M_1}\ 100 \quad (3)$$

With:

M_2: the final mass of waste calcined at 600°C
M_1: final mass of the sample after drying at 105°C

2.2.4 ORGANIC CARBON (%C)

The organic carbon content was deduced from the organic matter content after calcining the sample in a muffle furnace at 600°C for two (02) hours. The following formula is used to calculate organic carbon (Subramani and Ponkumar, 2012).

$$\%C = \frac{\%\,MO}{1.8} \quad (4)$$

2.2.5 NITROGEN

Total Kjeldahl nitrogen takes into account two forms of nitrogen: total organic nitrogen and ammoniacal nitrogen. This assay includes three steps: mineralization of organic nitrogen into ammoniacal nitrogen, distillation and titration (Afilal et al., 2014).

- Mineralization

The 50 ml sample and 50 ml of distilled water (control) were introduced into matras digestion tubes with the addition of 1 g of mineralization catalyst (selenium + potassium sulphate) and 10 ml of sulfuric acid at 95 - 97%. The whole is brought to 350° C. for two hours under the hood. Since the reaction is exothermic, the tubes are cooled to ambient temperature (25° C.).

- Distillation

After cooling, the acid is neutralized by adding 50 ml of 40% sodium hydroxide (NaOH). The mixture is placed in the tank of the distiller. The distiller's condenser lanyard is then immersed in a beaker containing 20 ml of boric acid with the addition of mixed indicator (methyl red + methyl blue). The solution turns from blue to purple. The distillation is done for 10 minutes. At the end of the distillation, the solution turns green.

- Titration

The titration of the distillate is carried out with 0.1 N sulfuric acid. The return to the violet color marks the end of the assay presented in the figure below. Then the volume of 0.1 N sulfuric acid used is recorded.

- Expression of results

The total Kjeldahl nitrogen (%N) is determined according to the following relationship.

$$\%N = ((V\_1 - V\_0\ ) * N * 14 * 1000))/V\_2 \quad (5)$$

With:

Vo: volume of H_2SO_4 used to titrate the control (distilled water);
V_1: volume of H_2SO_4 used to titrate the sample;
V_2: test portion volume;
N: normality of H_2SO_4 (0.1 N);
14: Atomic mass of Nitrogen

2.3 DESCRIPTION OF THE PROTOTYPE DIGESTER

The digester used in this research work was fabricated using polyethylene (plastic) canisters (Agu and Igwe, 2016). The experimental device is composed of two parts. The first part consists of a polyethylene container with a capacity of 25 L, a diameter of 25 cm and a height of 50 cm. This tank contains the reaction medium, i.e. the substrate obtained after mixing the dung and the water. The second part consists of the car inner tube which will trap the biogas produced during the methanisation. The inner tube acts as a gas holder. The gasometer is designed for two reasons:

- Cover biogas demand during hourly consumption peaks
- And contain the production of biogas during the longest period of zero consumption (Aboubacar et al., 2016)

Gas lines are used to connect the digester, air chamber and gas valve. The gas pipe is connected to the digester tank and the T-valve; and that this T-valve is connected to a rubber tube that connects a gas valve and the air chamber. The gas valve is used to burn biogas. This prototype digester used in this work was manufactured in a workshop in the mechanical and energy engineering department of INP-HB.

A TM-6 type digital thermometer is connected to the digesters to observe the temperature variation in the digester. The synoptic diagram of these digesters is presented in Figure 1.

Fig. 1. Diagram of the digester

The objective of this work is to produce biogas at an affordable cost by households. Also make a digester that is easy to move. Thus, our choice of materials for the realization of the digester fell on the plastic container, the car inner tube and the gas pipes. These materials are available locally.

The digester is placed in a sheet metal box painted black and exposed to the sun in order to maintain the temperature in the digester around 35°C to 40°C (Fitia Tsimbina, 2016). Indeed, the production of methane is generally carried out in the temperature range of 35° C to 40° C under mesophilic conditions. The variation in temperature is a very important element to take into account because it can irreversibly affect the quantity of methanization microorganisms. Thus an empty space of 15 cm is left between the digester and all the walls of the box. In fact, to guarantee the fermentation process, the temperature inside the digester must be uniform; temperature fluctuations should be avoided as much as possible. Slight temperature fluctuations can nevertheless be tolerated by microorganisms if they are less than 2°C to 3°C/h per day for mesophilic (Paterson and Kuhn, 2010).

Then it must be added that when the digester is installed in the metal box painted black (Figure 2), the digester is protected from sunlight, since sunlight prevents the production of algae inside the digester which reduces the production of biogas. The inside of the metal crate remained dark because light could not enter.

Fig. 2. Digester installed in the box exposed to sunlight

2.4 SUBSTRATE PREPARATION

2.4.1 PREPARATION OF THE INOCULUM

The digestate obtained from the anaerobic digestion of cow dung in this study is taken as a co-substrate. To obtain this digestate, a 25 liter digester is installed in the black box and exposed to sunlight with pH adjustment with 1 liter of cassava effluent and 200 mL of human urine. 9kg of fresh cow dung is mixed with 8.5 liters of water for introduction into the digester.

This digestate is used for seeding the medium (inoculum) because it is rich in methanogenic bacteria responsible for the production of biogas. These different substrates are introduced into the fermenter previously containing digestate from the anaerobic digestion of cow dung. The addition of a seeding inoculum when starting the biomethanation tests provides an active microbial biomass which makes it possible to avoid cases of inhibition linked in particular to an accumulation of volatile fatty acids (VFAs) and a drop in pH, and promotes a balanced state of the entire anaerobic digestion process.

2.4.2 CO-DIGESTION OF HOUSEHOLD PEELINGS WITH INOCULUM

The calculation of the masses of the peelings as well as the volume of the inoculum to put in each digester is calculated according to the ratio inoculum/substrate (I/S). Indeed, the I/S ratio is one of the most important factors likely to influence the kinetics of PBM tests, while the effects related to this parameter are still poorly understood. Indeed, Sri Bala et al propose a standard I/S ratio equal to 1 to maximize biogas production (Kameswari et al., 2012). Each test was performed under anaerobic conditions. For this, a nitrogen sweep was carried out in the atmosphere of the headspace. (Angeli, 2019).

Thus, in the context of this work, cassava effluent and human urine are used to neutralize the pH of the substrate. The urine ofa healthy person. The characteristics of the urine used and the cassava effluent are presented in Table 3.

Table 3. Characteristics of human urine and cassava effluent

	pH	Nitrogen (N)	Reference
Human urine	8.9	3600 mg/L	(Kpata-Konan et al., 2011 ; Youssef, 2013)
Cassava effluent	3.4		(Kpata-Konan et al., 2011)

Cassava effluents are acidic due to their composition (richness in starch, presence of cyanogenic compounds). About 90% of the nitrogen is concentrated in the urine (Youssef, 2013). The main constituents of human urine (urea, sodium chloride, sodium sulphate) reveal that human urine has a basic character therefore replace the chemicals such as lime, soda and sodium carbonate generally used to adjust the pH. According to these authors the pH of cassava effluent is 3.4 and human urine is 8.9 (Kpata-Konan et al., 2011).

Solar energy can be used for temperature control between 35°C to 37°C. Human urine is collected in latrines and cassava effluent is collected from women in Djahakro (Yamoussoukro).

2.4.3 FEEDING THE DIGESTERS

The peelings are crushed (pound the waste or even better mix them) to ensure homogenization of the substrate (physical treatment) which facilitates assimilation by bacteria during anaerobic digestion. Indeed, the study conducted by Djaafri et al. (2014) showed that the physical pretreatment of easily biodegradable organic waste (rich in sugar and starch), accelerates anaerobic digestion and represents a promising solution for the start-up of new digesters various types in pilot and semi-pilot scale (Djaafri et al., 2014). Before filling the reactors, each fraction of biodegradable organic waste was weighed and reduced to small particles (2 cm) using a mixer.

Fresh household waste mixed with sludge from the methanization of cow dung (inoculum) in an Inoculum/substrate ratio = 1 (Rameswari et al., 2012). This ratio makes it possible to maximize the production of biogas. Thus, to know the quantity of waste and inoculum necessary to fill the reactor. Mathematical reasoning allows us to determine the share that goes to each type of substrate. The quantity of substrate (peeling) and inoculum to add is calculated according to the ratio r = inoculum/substrate according to the organic matter. This ratio is set at 1 for these trials.

$$\text{Mass inoculum (g)} * \%MS\ \text{inoculum} * \%MO\ \text{inoculum} = X \quad (7)$$

X/r = y (8)

y/MO substrate=z (9)

z/MS substrate= M (10)

With:

X represents the quantity of organic matter present in the inoculum (g)
Y is the quantity of organic matter to add with the substrate in (g)
z is the amount of MS to add substrate (g)
M represents the quantity of substrate in MF to put in the digester (g)

The organic load rate (Br) also depends on the mass of substrate to put in the digester. In the mesophilic zone, this rate is evaluated at 3 kg DM/m^3/d. For a period of 40 days; we will have Br=120kg DM/m^3/40d. This rate is expressed as (Paterson and Kuhn, 2010):

B_r= M*MOsub/Vr*100 (11)

With:

M: amount of substrate added per unit time (kg/d);

MO sub: concentration of organic matter in the substrate (volatile solids (% SV)

Vr: reactor volume (m3)

The mass of substrate is therefore calculated as follows:

M=B_r*Vr*100/MOsub (12)

Once the mass M of substrate has been obtained, the previous relations make it possible to obtain the mass of the inoculum.

.The samples thus formed are introduced into the reactors. To ensure permanent contact, the amount of water to be added to each substrate in the reactor should be calculated as follows (Al Imam et al. 2013):

$$V_{water} = M\left(\frac{MS_{sub}}{8} - 1\right) \quad (13)$$

With:

MS sub: The dry matter of the substrate
M: the mass of waste

2.5 EVALUATION OF THE VOLUME OF BIOGAS PRODUCED

The volume of biogas obtained from each peeling is calculated from one torr. The volume of biogas at the end of digestion can be calculated as (Ishaya et al., 2016):

$$V(m^3) = 2\pi^2 * R * r^2 \quad (14)$$

The quality of the gas obtained is the best key to assessing each recorded production. The gas flammability test would therefore provide a more precise idea of the nature of the gas, i.e. to recognize whether the gas obtained is indeed biogas (Tize et al., 2015). The analysis of biogas makes it possible to know its composition (methane, carbon dioxide, etc.).

The gas analyzer is a gas detector which could detect combustible gas, O_2 and other two kinds of toxic gas continuously and simultaneously. It is widely used in the area where explosion proof is required or toxic gas leakage, such as underground canals or mining industry, so as to protect workers' lives and avoid damage to equipments. The start-up of the digester is described as follows:

Mix the raw material to be fermented and the inoculum and fill the digester. Several difficulties can arise after feeding the digester, some of which are:

- After 3 to 10 days, the digester will produce biogas. At first, the gas cannot ignite because the % methane is too low. In this case, the entire gasometer must be emptied and fresh gas must be waited until the gas can be used
- In the event of acidification (more gas production quickly, rapid drop, the water coming out becomes yellow...) you can:
    - If the PH is not below 6, the digester will adjust its PH naturally but this may take time. Adding inoculum can speed up this time
    - If the pH is below 6, add inoculum and a little human urine to raise the pH
    - If the PH is 7 and the digester still does not produce, it means that the liquid contains chemicals that kill bacteria. In this case, you have to empty everything and start over
    - If the PH is 7 but the gas production is very low, this may be due to a leak, then the pipes and gasometer must be checked

The digesters will be fed with cassava, yam and banana peelings and mixtures of peelings. Each digester is installed in the east slush box and exposed to sunlight. The PH adjustment will be made with cassava effluent and human urine.

2.6 Estimation Of The Amount Of Energy Produced From Peelings (Availability Of Peelings)

Agriculture is a key sector in Côte d'Ivoire that provides the maximum biomass. The work of Zinla et al. (2021) showed that yam; cassava and banana are among the top 5 crops in Côte d'Ivoire. These crop residues (CR) discussed in this study have the annual production presented in the Table 4 (Fitia Tsimbina, 2016).

Table 4. Production of some crops in Côte d'Ivoire

Number	Crop residues	Production per year (ton)
1	yam	6 361 046
2	cassava	3 535 531
3	Sugar cane	1 912 954
4	Oil palm tree	1 877 745
5	plantain	1 708 567

The consumption of yams, plantains and cassava generates peelings. A small part of these peelings is used to feed ruminants and pigs, while a large part is thrown into the environment, which rots and releases a foul smell. The quantity of peelings generated in Côte d'Ivoire for each year from these crops is presented in the table 5.

The theoretical RC potential is calculated by multiplying the production of agricultural crops by the residue-to-product ratio (RPR). The RPR of cassava, yam and banana peels is shown in the table 5 (Jekayinfa et al., 2015).

Table 5. The product residue ratio (RPR) of selected peelings

Residues	Type of residue	RPR
Cassava	Peeling	0.250
yam	Peeling	**0.200**
Plantain	Peeling	0.40

2.6.1 Energy Determination

To determine the energy potential of the biogas (Ebiogas) produced from the selected peeling, the experimentally determined data for the biogas produced per kg of each peeling were used. An illustrative example of determining the energy potential of biogas for cassava peel is presented as (Jekayinfa et al., 2015):

- Annual amount available: 0.88 × 106 t
- Biogas per kg of crop residues: 0.65 m^3
- Biogas per year of crop residues: 0.88 × 0.65 × 106× 103 m3= 0.572 × 109m^3
- 109 m^3 of biogas is equivalent to 26,199 PJ of energy

Therefore, the annual energy of biogas, Ebiogas = 26.199 × 0.572PJ = 14.98PJ

1 PJ =277777777.778 kWh

So, 14.98 PJ = 277777777.778 × 14.98 = 416272999 kWh

Values assessed for other selected crop residues followed the same calculation procedure

3 RESULTS

3.1 CHARACTERIZATION OF CASSAVA EFFLUENT AND URINE

The physico-chemical characterizations of the urine and cassava effluent used are given in the following table:

Table 6. Effluent and urine parameters

	Cassava effluent	Human urine
Nitrogen (N)	**0.41g/L**	**2.4g/L**
PH	**3.8**	**8.9**

The physico-chemical characteristics of the cassava effluent show an acid effluent with a pH below 7 and a low quantity of nitrogen which is 0.41 g/L. The PH value of human urine used in this work is greater than 7 and rich in nitrogen (2.64 g/L).

3.2 PHYSICO-CHEMICAL CHARACTERISTICS OF SUBSTRATE RESIDUES

The characterization of the peelings gives the table below.

Table 7. Characterization of peelings

	pH	%MS	%MO	%C	%N	C/N
Peel yam (PI)	5.2	16.5	96.2	55.9	1.06	59.74
Peel plantain (PB)	5.67	11.6	89.6	52.09	0.63	33.33
Peel cassava (PM)	5.2	14.95	95.8	55.6	0.70	49.42
Inoculum	7.3	10.25	59	28.3	1.73	16.35

The data of the physicochemical parameters of the peelings and the inoculum are recorded in the Table above. The table shows that cassava peelings; yams and bananas have an acidic pH. The dry matter of the peelings of cassava, yam, plantain banana and the inoculum are respectively 14.95%; 16.5%, 11.6% and 10.25 The organic matter content of the different peelings is high; 95.8% for cassava peelings, 96.2% for yam peelings and 89.6% for banana peelings.

The carbon/nitrogen (C/N) ratios of cassava, yam and plantain peelings, which are very decisive in determining the biomethanization parameters of a substrate, were respectively 49.42; 59.74 and 33.33. The table above shows that cassava peels, banana peels and yam peels have a high organic carbon value and a low total nitrogen value, which results in a particularly high C/N ratio.

3.3 EFFECT OF INOCULATION ON THE C/N RATIO OF PEELINGS

The different C/N ratios of peelings and inoculum are given in the table below:

Table 8. C/N values measured for each substrate

	C/N
Digester 1 (PB+I)	29.13
Digester 2 (PM+I)	28.9
Digester 3 (PI+I)	26.32

The addition of cow dung digestate to each peeling contributed to the reduction of the C/N ratio. 49.6 for cassava peelings changed to 28.9 after adding the inoculum. 59.74 for yam peels went to 29.13 and finally 33.33 for banana peels went to 29.13.

3.4 Parameters Of Anaerobic Digestion

The mass of peeling to be used is calculated according to the dry matter (DM), the organic matter (OM), the inoculum/substrate ratio and the organic load rate. Equations (7), (8), (9) and (10) are used to calculate the amounts of substrate and inoculum to be used. We obtain table 9 and table 10 below:

Table 9. Quantity of peelings

	Mass of waste (kg)	Volume of water (L)	inoculum quantity (kg)	Human urine (L)	Cassava effluent (L)
Digester 1 (PB+I)	3.3	1.5	5.7	1.8 liter	350 mL
Digester 2 (PM+I)	3.1	2.7	6.9	1.8 liter	350 mL
Digester 3 (PI+I)	3.1	3.3	8.1	1.8 liter	350mL

Table 10. PH measurement before and after experimentation

	Initial PH	Final pH	MO consumed
Digester 1 (PB+I)	**7.02**	**7.3**	60
Digester 2 (PM+I)	**7.1**	**7.2**	57
Digester 3 (PI+I)	7.02	7.2	45

The addition of human urine and cassava effluent on the one hand and the inoculation on the other hand made it possible to have a neutral pH for the different peelings at the beginning and at the end of the anaerobic digestion. The organic matter consumed for the banana peel; of yam and cassava are respectively 60%, 57% and 45%.

3.5 Analysis Of The Biogas Obtained With Each Peeling

Table 11. Composition of biogas with each peel

	Methane (CH_4)	CO_2	O_2	H_2S	CO
Cassava	55%	19.1%	14.9%	2ppm	13ppm
Plantain	53%	15%	13%	2ppm	12ppm
Yam	49%	17%	12%	2ppm	12ppm

After 15 days; Cassava peel produced 165 liters of biogas; yam peel is 164 L and 225 L for banana peels.

3.6 ESTIMATED AMOUNT OF ENERGY FROM PEELINGS

Table 12. Estimation of the biogas potential of peelings in Cote d'Ivoire

	Annual quantity available (ton)	Biogas per kg of residue (m3)	Annual energy (Ebiogas) PJ
Peeling of cassava	0.88×10^6 t	0.65	14.98PJ
Peeling of plantain	0.71×10^6 t	0.42	7.8 PJ
Peeling of yam	1.27×10^6 t	0.56	19.05 PJ

4 DISCUSSION

4.1 CHARACTERIZATION OF EFFLUENT AND URINE

Cassava effluents are biorecalcitrant because they are acidic (pH < 4) and present a nitrogen deficiency (0.6 - 0.8 g/L) according to Kpata-Konan et al. (2011). The PH value of human urine used in this work is greater than 7 and rich in nitrogen (2.64 g/L). These values are not fixed, they can vary from one individual to another. Acidic human urine is sometimes found. However, the composition varies according to several factors such as the time of urination, type of food consumed and the physical conditions of the person concerned. The high content of nitrogen is explained by the high content of urea in human urine as mentioned in the thesis work of Youssef (2011). Because human urine is rich in nitrogen, it therefore has a basic character.

4.2 PHYSICO-CHEMICAL PARAMETERS OF VEGETABLE RESIDUES

The pH of the different peelings are acidic. This constitutes a serious problem because the production of biogas is impossible when the pH is acidic. This was also confirmed by (Rajameena and Velayutham (2018), citing that one of the major problems associated with the production of biogas from cassava roots (cassava waste water, cassava solid waste and cassava tuber), yam peel and cassava peel of plantain is acidification (low pH). Indeed, the methanogens that produce flammable gases from the waste are very sensitive to pH (Ofoefule and Uzodinma, 2009). Therefore, it is necessary to ensure pH control when carrying out biomethanation tests in the laboratory. In most of the work done on biogas production using cassava materials, inoculums and neutralizers were applied to the suspension to bring the pH to neutrality (Kpata-Konan et al., 2011; Djaafri et al., 2014).

The determination of the dry matter (DM) is one of the criteria which makes it possible to classify the substrate according to its ability to be more or less degradable by biochemical means (Al Imam et al., 2013). It determines the thermochemical choice (pyrolysis, gasification) for dry matter contents higher than 30%, or biochemical by fermentation, for lower contents as in the specific case in this study. The dry matter content of the peelings reinforces an anaerobic digestion by "wet process" which is suitable for the treatment of waste with between 5 and 20% dry matter (DM) content. To grow properly, the microorganisms present in the reactor need a high quantity of water. Thus, a moisture content of 50% in the reaction medium seems to be a minimum to allow the development of bacterial populations. It is the transport vector for soluble matter. It dissolves nutrients and substrates and ensures their diffusion from porous media to bacterial cells (Kalloum et al. 2007).

The high levels of equivalent organic matter (OM) indicate preferred substrates for microorganisms in anaerobic digestion. The concentration and nature of organic matter is decisive for the biomethanogenic potential of substrates (Faouzia, 2008). A compound having the high MO is rich in carbon. A substrate rich in carbon (C) produces a high proportion of methane, up to 90% according to Faouzia (2008).

The C/N ratios make it possible to generally predict the general state of equilibrium influencing the digestibility of a substrate. Latinwo and Agarry (2015) shown that the desirable ratio is between 20 and 30, with 25 being the ideal ratio for C/N. For the different peelings, these values are well above the optimal value which is 30 for C/N (Latinwo and Agarry, 2015). The C/N ratio of a sample makes it possible to generally predict the state of equilibrium influencing the digestibility of a substrate (Haider et al., 2015).

4.3 EFFECT OF INOCULATION ON THE C/N RATIO OF PEELINGS

A high C/N ratio indicates that the material is not good for biogas production and will not produce biogas appreciably (Paterson and Kuhn, 2010). Since the C/N ratios are high, these values will have to be corrected during anaerobic digestion. However, work indicates that such a material could be mixed with another with a much lower C/N ratio to stabilize the ratio at an optimum value between 22 and 30 (Adelekan and Bamgboye, 2009). Thus the digestate from the anaerobic digestion of the cow dung is taken as an inoculum to reduce the C/N ratio of the peelings in order to promote the production of biogas. This inoculum has a C/N ratio of 16.35 and can reduce the C/N ratio of high peels. Also, this digestate is rich in methanogenic bacteria responsible for the production of biogas. By mixing the inoculum with the peelings, the C/N ratios will be close to 35 which is the optimum zone (Latinwo and Agarry, 2015)

The objective being to improve the stability and/or the production of methane, For this, digestate from anaerobic digestion of cow dung has been added to the peelings used. The latter in fact have a high C fraction for a very low nitrogen composition. They thus facilitate the adjustment of the C/N ratio. The optimum being, according to the literature, between 20 and 30.

4.4 Parameters Of Anaerobic Digestion

The use of digestate from the methanization of cow dung as inoculum and human urine, which has a basic character, will provide a favorable pH for production during the methanogenesis phase. The overall results indicate that the flammability of digested peelings can be significantly improved when combined with animal waste (Oparaku et al., 2013). This same study reinforces the fact that the quantity of inoculum makes it possible to avoid inhibition by accumulation of intermediate metabolites. The pH of different peelings at the end of the methanization remained around neutrality. This shows the stability of the digester and the process of anaerobic digestion.

4.5 Analysis Of The Biogas Obtained With Each Peeling

After 15 days; Cassava peel produced 200 liters of biogas; the result for yam peel is 164 L and 185 L for banana peels. It is noted that, as during the first tests, the biogas produced during the first two days gives higher proportions of CO_2. Following the first 3 days, there is a rapid drop in the CO_2 fractions and an increase in the CH_4 fraction of methane. Indeed, a 50% methane content is acceptable for anaerobic digestion of organic waste (Tize et al., 2015).

4.6 Energy Potential

The results obtained on the biomethanization of cassava, yam and banana peelings suggest their potential and their relevance for waste treatment. Energy produced in the form of methane when used efficiently, it not only improves the overall economy but also provides on-site solutions to waste management issues. One kg of PM, PB and PI used as raw materials for biogas production could produce 14.98 PJ, 7.8 PJ and 19.05 PJ of energy respectively.

5 Conclusion

We were able to design a digester using locally available material which was used to demonstrate that the peelings have the potential and ability to generate biogas. Mixing the peels with the inoculum significantly improved biogas production and reduced retention time. Adjusting the pH with human urine resulted in a pH range of 7.01 to 7.3 and a mesophilic temperature range of 27 to 33°C resulted in higher biogas production. This work allowed us to understand that the anaerobic digestion process is more or less optimizable at the laboratory scale. Nevertheless, before an application of the process on a household scale, there remain several questions relating to the determination of these deposits and these parameters. “What size of waste is to be considered for the scale of a household? Can we recycle this waste together? What parameters should be applied for stable and optimal methanization? Finally, is knowledge of these parameters sufficient to guarantee the production of biogas on a household scale? Answering these questions will allow us to size a digester for a four-member household. Modeling and simulation of anaerobic digestion will allow us to observe the quality of biogas with this sized digester.

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