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Physico-chemical Characterization of Comorian Household Waste for Energy Recovery

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Abstract Household waste has become a difficult problem for Comorian households to manage. The problem is intensifying as it is coupled with deforestation and the country's energy crisis. Indeed, Comorians make massive use of firewood for cooking and lamp oil for lighting. In order to contribute to the search for passive solutions to household waste management and the energy crisis, a physico-chemical characterization study was carried out. The aim is to determine the physico-chemical characteristics that can be used to assess the potential of Comorian household waste to produce biogas. The results obtained on the samples studied show that this waste can be converted into energy with a methane content of 42%. For a better valorization, these wastes can be mixed with other wastes having a much higher potential in order to have a better energy yield.

Keywords Waste-to-energy conversion, Comorian household waste, Biogas, Sustainable development

1. Introduction

The Comoros is a country where environmental degradation is a matter of great concern, the effects of which are becoming increasingly visible [1]. The phenomenon can be observed in several sectors of the country, with the waste sector being one of the most visible in recent decades. Mountains of garbage can be seen everywhere in the streets of the country's cities, and the phenomenon is even spreading to the villages. On average, a Comorian produces between 0.3 and 0.6 kg of waste per day [2], which, taking into account the average number of people in a Comorian household (5 people [3]), means that between 1.5kg and 3kg of waste is produced per household per day. Added to this are the energy problems of which the population is the first victim, particularly low-income citizens who cannot afford autonomous energy systems. In particular, the majority of Comorians use firewood and kerosene as their main cooking fuel. In rural areas, firewood is the main cooking fuel. Nowadays, with dry wood becoming increasingly scarce, people find themselves having to cut wood for cooking. Previous studies have shown that firewood is widely used in the Comoros as household fuel and in the distillation of ylang-ylang essential oil [4], [5], and that this is one of the main causes of deforestation in the Comoros Islands, particularly in Anjouan Island.

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Faced with this problem, solutions must be envisaged, exploiting all the possibilities that can meet the principles of ecological transition, including biomethanization, which appears to be one of the alternatives that can contribute to sustainable waste management, but also to a contribution to access to sustainable energy for households and even ylang-ylang essential oil distillers. Ali et al [2] show that 60% of household waste in the Comoros is fermentable, providing an opportunity to convert this waste into compost and biogas.

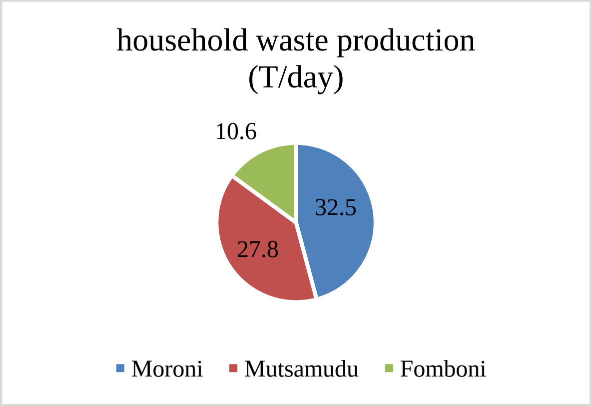

Figure 1. Household waste production in the principal city of each island [2]

Providing households with individual bio-digesters is a good alternative for managing biodegradable household waste, but it will also enable the household to save energy and limit the cutting of firewood.

Figure 1 shows waste production in the main towns on each island (Moroni for Ngazidja, Mutsamudu for Anjouan and Fomboni for Moheli). Comparison with figure 2 shows that, on average for the towns of Moroni, Mutsamudu and Fomboni, waste production per household, taking into account an average of 5 people per household [3] for each town, is 2.3 kg/day for Moroni, 4.3 kg/day for Mutsamudu and 2 kg/day for Fomboni.

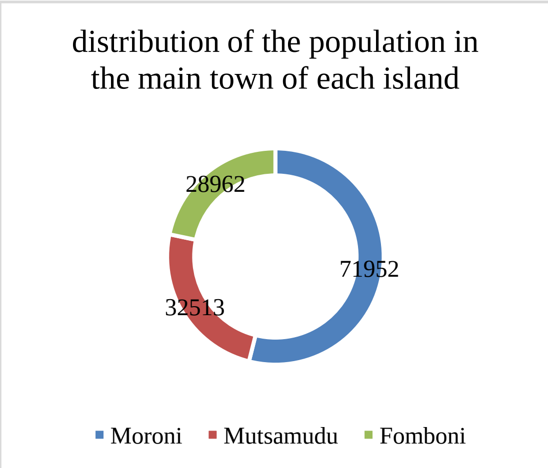

Figure 2. Distribution of population in Moroni, Mutsamudu and Fomboni in 2017 [3]

These figures are significant enough to warrant an assessment of the potential for converting household waste into bioenergy. The physico-chemical characterization of waste provides essential parameters for assessing its potential to produce biogas. Thus, the study of the physico-chemical characterization of waste with the aim of converting it into energy is an issue of growing interest to scientists around the world. AFILAL et al [6] have studied the physicochemical and microbiological characterization of organic substrates. In their studies, they were particularly interested in aromatic medicinal plants (AMPs). The main results of their work show that AMPs can still be used after hydrodistillation, and the dry residues are biodegradable. A study carried out on Reunion Island shows that, despite the variability of the properties of solid residual waste, it constitutes a potential raw material for thermochemical processes such as pyrogasification on the island [7]. David et al [8] propose a mathematical model to evaluate the lower heating value (LHV) of solid waste. The results show that this model can be used to determine the LHV of any solid waste. Once the lower calorific value has been obtained, it is possible to use this result to determine the upper calorific value from other equations. A study carried out by Blissbern et al [9] in Ghana in 2023 shows that Ghanaian household waste is suitable for biogas production, since it contains biodegradable organic matter. However, the main substrate proposed for biogas production is human extrema, and the results of the analysis show a very low C/N ratio, which could impact biogas production efficiency. Using small portions of kitchen waste and leftover food can balance the C/N ratio [9]. Anaerobic digestion is known to be one of the best ways of converting organic waste into energy [10]. The organic matter content and C/N ratio of waste is an essential parameter for assessing the potential for recovery, particularly energy recovery. Like other physico-chemical waste parameters, such as moisture content, dry matter content, pH, etc., organic matter content and C/N ratio are dependent on region, season and treatment characteristics [11]. This in turn affects methane yield.

Waste composition is another parameter that influences the physico-chemical characteristics of household waste. However, studies show that food waste has characteristics that can be extrapolated worldwide; in particular, it has a moisture content of between 74 and 90%, a high volatile solids content of around 85±5% and a pH of around 5.1±0.7 [11,12]. Biodegradable carbohydrates in food waste range from 41 to 62%, protein content from 15 to 25%, and lipid content from 13 to 30% [11,13]. Other studies reveal that the moisture content of food waste ranges from 0.5 to 11.61% [14,15,16], while volatile matter is between 31.46 and 80.04% [14]. The rate of biogas production is considerably linked to waste composition [17], notably for a substrate composed of 60% carbohydrates, 20% lipids and 20% proteins a rate of 65.05% gas can be obtained. Protein-rich substrates have a rapid biogas production rate, but can release ammonia and sulfides [18]. Food waste is becoming a promising substrate for biomass-to-energy conversion, particularly in biomethanization processes, due to its high moisture content and rapid degradation [19,20,21,22].

This work therefore focuses on the physico-chemical characterization of Comorian household waste, with the aim of subsequently studying the potential of this waste to produce biogas. The study is particularly interested in food waste associated with the traditional Comorian diet, which is the most widespread even today. This staple diet consists of starchy foods and green bananas, whose various menus require mixing, which produces waste consisting of a mixture of the peelings of the various ingredients present. For this purpose, an experimental study is carried out, after which the results are validated by comparison with the literature. Mathematical models are used to determine compositions that could not be determined experimentally.

2. Materials and Methods

2.1. Sample Collection and Preparation

The waste used in this study is kitchen waste. It consists of starch peelings, green bananas and breadfruit. Starchy foods, bananas and breadfruit are the mainstay of the Comorian diet, and most prepared menus are a mixture of these foods. As a result, Comorian kitchen garbage cans often contain a mixture of peelings from these foods. The waste was collected directly from households in their garbage state and brought back to the laboratory for analysis. Three samples were prepared according to waste origin, as shown in figure 3.

- Sample A is an average mixture of approximately 50% rotten breadfruit peelings and pieces, 35% green banana peelings and 15% cassava peelings.

- Sample B is a mixture of 75% banana peelings and 25% taro peelings.
- Sample C is an average mixture of 50% green banana peelings, 30% breadfruit peelings and 20% tarot peelings.

Figure 3. Different kitchen waste using for the sampler

The strong presence of banana peelings in all samples is noticeable. Green bananas are a Comorian speciality and are found on almost all menus and dinners.

To obtain representative samples for each batch of waste collected, a characterization was carried out for each batch of waste. After thoroughly mixing each batch of waste collected, a conical grouping was carried out, followed by a quartering of each batch (figure 4). In each batch, a quarter of the original waste is retained.

Figure 4. Cone shaping (A) and quatting (B) of waste

2.2. Physicochemical Analysis

In physico-chemical analysis, the aim is to determine the physico-chemical parameters that can be used to assess the waste's potential to produce biogas. The essential parameters to be determined during physico-chemical waste characterization are: density, moisture content, dry matter content, organic matter content, ash content and calorific value. However, other parameters can be determined depending on the purpose of the study. The aim of this study is to assess the potential of Comorian household waste to produce biogas.

2.2.1. Density

A fairly simple method is used to determine the density of each batch of household waste prior to sorting. The method consists of introducing the waste into a 10-liter bucket without settling it, and weighing it. The empty bucket is weighed so that the mass can be removed from the bucket later. The bulk density of the waste is calculated using the following equation:

$$\rho = \frac{m}{V} \tag{1}$$

ρ: Density (kg/m^3)
m: mass (kg)
V: volume (m^3)

2.2.2. Moisture Determination

Several authors recommend determining waste moisture by drying at 105℃ until a constant waste mass is obtained in the oven [23,24,25,26,27,28,29,30,31]. Drying times vary according to the author and sample size, and can range from 1 hour to 24 hours. In this study, given the lack of a drying oven, we carried out drying in a microwave oven at 540W. This type of drying has the advantage of being rapid [32].

Let M_0 and M_1 respectively be the mass in grams of the initial waste sample to be dried and the mass of the sample after oven drying to a constant mass, the moisture content is defined by:

$$MC(\%) = \frac{M_0 - M_1}{M_0} \times 100 \tag{2}$$

2.2.3. Total Solids

Knowing the moisture content of the sample, we can deduce the total solids of the sample [9,33]:

$$TS(\%) = 100 - MC(\%) \tag{3}$$

2.2.4. Volatile Solids (Organic Matter)

The most widely used method for determining organic matter is calcination or loss on ignition. Calcination is carried out at temperatures ranging from 550℃ to 650℃ between 1 hour and 4 hours, depending on the author [23,26,29,34,35,36]. After calcination of a dry sample of mass $\boldsymbol{M_1}$, the volatile solids content is obtained by the following equation:

$$\boldsymbol{VS}(\%) = \frac{\boldsymbol{M_1 - M_2}}{\boldsymbol{M_1}} \times \mathbf{100} \tag{4}$$

$\boldsymbol{M_2}$ is the mass of the calcined sample

2.2.5. Ash Content

The ash content is obtained after total combustion of the sample. After thermo conversion, the type of treatment to be applied depends on the quality of the ash, and its behavior at high temperature [7].

2.2.6. Heating Value

Qudais et al [37] and Katheravale et al [38] respectively proposed the model described by equation (5) to determine the net calorific value of waste given the moisture content and volatile solids content:

$$\boldsymbol{PCI = 45VS}(\%) - \boldsymbol{6MC}(\%) \tag{5}$$

2.2.7. Organic Carbon

Total organic carbon is an important parameter in the physico-chemical characterization of organic waste. It plays a major role in assessing waste degradation. Several methods exist for determining the total organic carbon of waste. In this study, we use an empirical method that relates total organic carbon to organic matter content according to the relationship:

$$\%\boldsymbol{C_{org} = a.VS}(\%) \tag{6}$$

The coefficient $\boldsymbol{a}$ is specific to each waste and depends on its composition and age. Depending on the author, this coefficient can vary between 0.42 and 0.58. The following table gives different values for this coefficient, depending on the author and the age of the waste [23].

Table 1. Different value of coefficent a

Auteurs	Braun et Jag, 1970 [24]	WHO, 1978 [34]	François, 2004 [29]			
	Déchets frais			Déchets de 3 ans	Déchets de 8 ans	Déchets de 30 ans
a	0.47-0.58	0.42	0.42	0.52	0.39	0.36

2.3. Theoretical Methane Potential

Knowing the physico-chemical characteristics of the waste, it is possible to assess its potential to produce biogas. Several models exist in the scientific literature, taking into account various parameters including, in particular, the mass composition of the elements making up the substrate [9,41,42]. Other models, which are more linear and only take physical characteristics into account, have also been proposed [47]. In this work, we have chosen the model proposed in [47]. This model takes into account the substrate's dry matter and organic matter content. Let PB be the biogas production of the substrate, it is evaluated by relation (7):

$$\boldsymbol{PB = \frac{m.VS}{100} P_1} \quad (7)$$

Where $\boldsymbol{m}$ is the substrate mass and $\boldsymbol{P_1}$ the biogas productivity at 60% methane. Methane production is therefore evaluated by relationship (8):

$$\boldsymbol{Methane\ production = PB * \frac{60}{100}} \quad (8)$$

3. Results and Discussion

3.1. Physico-Chemical Properties of the Wastes Studied

Table 2 shows the main results of this study. In this table, we can see that the samples studied have very high levels of moisture and volatile matter. For the three samples studied, the moisture content varies between 77% and 82%. This is in line with the results obtained by Katarzyna et al [11] and Fisgativa et al [12], who show that food waste has a moisture content of between 60% and 90%. Many other studies show that the moisture content of household waste is between 66% and 93% [9,43,44,45]. Particular attention is drawn to the results obtained by Blissbern et al [9], on the characterization of kitchen waste in Ghana. This waste consists of starch peelings and vegetable scraps, which are very similar to the types of waste studied in the present work.

The organic matter content of the respective samples was 62.68%, 83.33% and 66.66%. Compared with the results reported in the literature, we note that the results obtained in the present work align well with the results of other studies. In particular, studies carried out by Maillot et al [7] for Reunion Island, where certain dietary habits are similar to those of the Comoros Islands, show that the organic matter content of household waste varies between 21.5% and 87.3%. Other studies [9,46] show that the organic matter content of household waste, including kitchen waste (Food, vegetable, fruit waste, etc.), varies between 10.51% and 85.94%.

Table 2. Physico-chemical results of the characterization

Sample		1	2	3
Immediate analyses	MC (%)	77.66667	82.35294	77.5
	TS (%)	22.33333	17.64706	22.5
	VS (%)	62.68657	83.33333	66.66667
	AC (%)	12.7327	39.1837	12.8034
	Density (kg/m^3)	478.33	293	372
Thermal analyses	LHV (MJ/kg)	9.852883	13.62261	10.60644

The lower calorific value of the samples studied ranged from 9.85MJ/kg to 13.62MJ/kg. Results obtained for the characterization of household waste on Reunion Island range from 15.6MJ/kg to 18.4MJ/kg [7]. The calorific value of waste is highly dependent on its moisture content. in fact, the more moisture a material contains, the more incomplete its combustion is, which reduces its calorific value. Thus, the difference observed here is mainly justified by the fact that the waste studied in this study has a higher moisture content than the waste studied in [7].

3.2. Theoretical Methane Potential and Theoretical Biogas Potential

To evaluate the theoretical biogas potential and the theoretical methane potential for each sample, we use equations (7) and (8). The biogas productivity P_1 is obtained by Kouadio [48]. Indeed in their study on the characterization of household kitchen waste they obtained a value $P_1 = 0.42m^3.kg^{-1}.VS^{-1}$. The author proposed this value for fruits and vegetables, which is the case in this study. Indeed, the three samples studied in this study are mostly composed by fruit and vegetable peelings. The results for the three samples studied are summarized in the following table:

Table 3. Biogas potential and methane potential obtained

Samples	VS (%)	Masse (kg)	BGP_{TH}(m^3 /kg.SV)	BMP_{TH}(m^3 CH4/kg.SV)	CH4 (%)
1	62.68	0.3	0.19	0.08	42.10
2	83.33	0.102	0.085	0.036	42.35
3	66.66	0.040	0.033	0.014	42.42

The results obtained show that the wastes studied have a methane production potential of between $0.014m^3.CH_4/kg.SV$ and $0.08m^3.CH_4/kg.SV$. The methane percentage of the tested waste is around 42% for the 3 samples. This can be explained by the fact that the 3 samples are made up of the same types of waste but at different portions. These results differ slightly from those of some authors [9], a difference which may be explained by the composition of the waste and its geographical origin. However, these results clearly show that Comorian kitchen waste can be valorised into biogas. Analysis of the results shows that, for better production and energy yield, co-management with other wastes with greater potential is essential. It should also be noted that the samples studied in this work are fresh waste. It is quite possible that if they are already decomposed the yield will be even better. This will be the subject of the rest of this work.

4. Conclusions

The study carried out in this work assessed the potential of certain types of Comorian kitchen waste for biomethane production. The aim was, in the interests of sustainable development, to convert household waste into energy. The results show that it is indeed possible to convert the waste studied into energy. The results obtained are not far removed from those reported in the scientific literature. However, for greater efficiency, co-digestion with other types of waste with greater potential is necessary.

Other studies are underway to gain a better understanding of the characteristics of Comorian household waste. In particular, these studies, which aim to improve this work, involve the physico-chemical characterization of several samples of different Comorian household waste, in order to identify those that are more suitable for energy recovery, in particular biogas recovery. This will enable Comorian households to better manage their waste within a framework of sustainable development.

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