

Physicochemical Characterization And Confirmatory Testing Of Dehydrated Bioethanol Obtained From The Recycling Of Tropical Fruit Waste (Banana, Papaya, And Pineapple)

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Abstract:

This study aims to evaluate the quality of second-generation bioethanol obtained from agro-food waste consisting of tropical fruit peels (banana, papaya, and pineapple). Fresh fruit peels were collected, sorted, and stored at 4°C. Fermentation was carried out in four fermenters, followed by simple distillation (78–80°C), rectification, and dehydration using magnesium sulfate to obtain high-purity bioalcohol. The results obtained are comparable to those reported in scientific literature, confirming the feasibility of producing bioethanol from biodegradable waste such as fruit peels: the boiling points of the four distillates—derived from banana, papaya, and pineapple peels, as well as a mixture of the three—were around 78°C. The pH values of the four distillates were all around 7. The densities of the four distillates ranged from 0.759 to 0.79. Alcohol yields ranged from 53% to 66%, and alcohol concentrations ranged from 33% (v/v) to 69% (v/v). Three tests were conducted to confirm the presence of bioethanol: potassium dichromate and combustion flammability tests confirmed the success of the alcoholic fermentation process, demonstrating the conversion of fermentable sugars into ethanol by yeast. The Lucas test confirmed that the alcohols obtained from banana, pineapple, and papaya peels were indeed primary alcohols. Ultimately, tropical fruit peels appear to be viable sources for bioethanol production.

Keywords: waste, fermentation, bioethanol, banana, pineapple, papaya.

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I. Introduction

Global interest in the development of biofuels—reflecting a collective desire to promote renewable and environmentally friendly energy sources in order to reduce dependence on fossil fuels—has grown significantly since the mid-2000s [1]. Energy needs, which are constantly rising due to population growth and rapid urbanization, stand in contrast to the slow pace of development in the use of available renewable resources. Faced with this imbalance, it is imperative that Africa transition to modern and sustainable energy sources, optimize energy efficiency, and harness the still largely untapped potential of renewable energy, particularly biomass. In this context, the use of agricultural waste to produce second-generation biofuels represents a sustainable alternative. Biofuels, derived from the processing of organic biomass, offer a strategic alternative for reducing dependence on fossil fuels [2]. Among these approaches, the use of biodegradable waste to produce bioethanol is both an environmentally friendly and economically viable solution. The banana industry, for example, plays a strategic role in global trade. Bananas, a staple food for more than 400 million people in developing countries in South America, Southeast Asia, and Africa, are in fact the world's leading fruit in terms of export volume and the second-largest in terms of trade value after citrus fruits [3]. In Congo, bananas are the second most important food crop after cassava, with annual production ranging from 75,000 to 82,000 metric tons [4]. Furthermore, Africa is the world's third-largest producer of papaya [5], with the bulk of its production concentrated in West Africa (64.07%), East Africa (19.91%), and Central Africa (15.10%). Pineapple is the third most widely produced tropical fruit after bananas and mangoes [6; 7]. The extensive use of these tropical fruits generates significant quantities of byproducts currently considered waste. These byproducts—consisting of leaves, stems, bark, roots, peels, and seeds—are a major source of highly diverse natural substances [5] that can be utilized in the production of second-generation (2G) biofuels. Several studies have shown that the waste from these fruits has high potential

for fermentable sugars, which can be converted into bioethanol through fermentation and distillation, with a profitability index of 1.33 and an internal rate of return of 28.45% [8]. Production optimization relies in particular on enzymatic hydrolysis and controlled fermentation processes [8]. Finally, the utilization of lignocellulosic biomass through anaerobic digestion and saccharification-fermentation offers a dual benefit: reduction of solid waste and production of clean, renewable energy without additional CO₂ emissions [9]. In Congo-Brazzaville, where approximately 70% of the waste produced is biodegradable [10], banana, pineapple, and papaya waste is abundant in urban areas, particularly in Brazzaville. This abundance represents an opportunity to develop innovative solutions for energy and environmental recovery. This potential is further enhanced by fruit overproduction linked to logistical challenges in high-production areas. The present study aims to compare the physicochemical characteristics of various bioethanols obtained through alcoholic fermentation of banana, papaya, and pineapple peels.

II. Materials And Methods

Description of the study site

This study was conducted at Brazzaville, capital of Republic of Congo. The Republic of Congo covers an area of 342,000 km². It is located in Central Africa, straddling the equator between latitudes 3°30' North and 5° South and longitudes 11° and 18° East. South and longitudes 11° and 18° East [11]. Brazzaville metropolitan area covers an area of nearly 265 km² and is located in the southern part of Congo, between latitudes 4°6'15" and 4°22'30" South and between longitudes 15°6'0" and 15°19'15" East [12]. The districts of Brazzaville targeted for this operation are: Makélékélé, Baongo, Poto-Poto, Talangai, Mfilou, and Madibou (Fig. 1). These sites were chosen for several reasons, namely the high density of commercial activities related to fruit sales and processing; the presence of unloading points for fruit from rural areas, particularly banana ripening facilities; and the diversity of consumption methods (frying, doughnuts, artisanal processing), which generates significant quantities of usable organic waste. This study was conducted within the Faculty of Science and Technics of Marien NGOUABI University at Brazzaville.

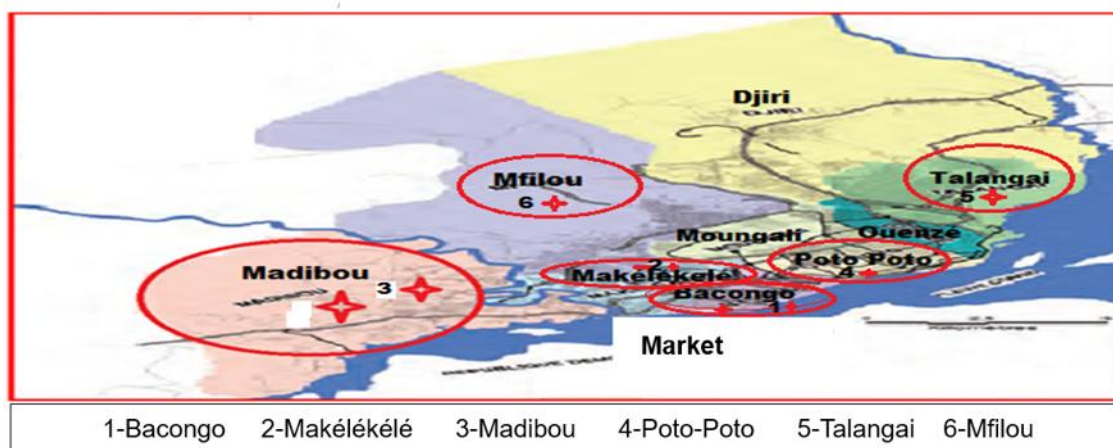


Fig. 1 : Waste collection area [13]

Material and reagents

The biological material used in this study consists of organic waste from tropical fruits, specifically banana peels (*Musa spp.*), pineapple peels (*Ananas comosus*), and papaya peels (*Carica papaya*). These residues were selected for their high content of fermentable sugars (glucose, fructose, sucrose) as well as their local availability and production in large quantities, particularly in urban areas with high commercial activity. The reagents used consist of distilled water, sodium sodium hydroxide (NaOH) for pH adjustment, sulfuric acid (H₂SO₄) for possible hydrolysis, Fehling's solution for detecting reducing sugars, DNS reagent (3,5-dinitrosalicylic acid) for estimating total sugars, *Saccharomyces cerevisiae* yeast used for inoculation, and magnesium sulfate (MgSO₄) used as a dehydrating agent.

Sampling and sample pretreatment

Three (03) types of samples were selected for this study. Each type of substrate was subdivided into four fermentation tanks of 10 liters each, in order to test the effect of different quantities of yeast and substrate on bioethanol yield. The codes are defined as follows:

- **Sample 1 (Fig. 2):** pineapple skins, distributed equally among four separate tanks (P1, P2, P3, and P4).

- **Sample 2 (Fig. 3):** banana peels, distributed among four fermenters (B1, B2, B3, and B4), with varying amounts of yeast and substrate.
- **Sample 3 (Fig. 4):** Carica papaya peels, also divided into four fermenters (C1, C2, C3, and C4) in different proportions.

The peels of tropical fruits (bananas, pineapples, and papayas) were collected in plastic bags and transported to the laboratory for physical pretreatment.



Fig. 2 : Pineapple peels



Fig. 3 : Banana peels



Fig. 4 : Carica papaya peels

After collection, the tropical fruit peels were sorted, cut into small pieces, cleaned with distilled water to remove impurities (dust, sand, etc.), and then mechanically ground using a blender to obtain a homogeneous pulp. Fig. 5 illustrates the fermentable substrate of banana peels.



Fig. 5: Weighing, cleaning, and grinding of banana peels followed by must extraction

Fermentation Process, distillation, and dehydration of the resulting alcohols

After weighing, the peels of the collected tropical fruits were cut up, rinsed, and crushed to obtain a virtually homogeneous mixture (must), whose initial parameters (before fermentation) were measured, namely: organoleptic parameters (color, smell, and taste) to properly monitor the fermentation process. The mixture (must) thus formed was placed in a fermentation tank after adding water (2 liters) and yeast (*Saccharomyces cerevisiae*, 40g). For each peel, the fermentation tank (fermenter) will be hermetically sealed, as fermentation must take place in an anaerobic environment between 15- 35°C to allow the yeast to convert glucose into alcohol. Fermentation lasted one week. The fermented must obtained is then filtered. At the end of fermentation, the mixture (must) was filtered and then subjected to simple distillation in a 2000 ml flask and placed in the distillation apparatus prepared beforehand to recover a hydroalcoholic solution. This is an important phase of this work for obtaining second-generation alcohol. This operation separates alcohol from water based on their different boiling points: water boils at 100°C, while ethanol boils at 78.5-80°C. At 20°C, the first drops of distillate (hydroalcoholic solution) began to fall into the hydroalcoholic solution recovery vessel. The hydroalcoholic solution obtained then undergoes fractional distillation or rectification, which is a process for purifying a low-alcohol solution to obtain a high-alcohol solution. A very short column head was used because the operation must be carried out at a well-controlled temperature (78-80°C) in order to obtain alcohol at 78°C. The alcohol yield was then calculated based on the amount of initial substrate and the volume of pure alcohol obtained. The alcohol solution obtained by rectification was purified to obtain anhydrous alcohol. After distillation, 50 ml was taken for dehydration with magnesium sulfate. During this dehydration, an exothermic reaction was observed. After dehydration, 35 ml of anhydrous alcohol was obtained.

III. Analysis Parameters

The parameters measured for the physicochemical characterization of the alcohols obtained from banana, papaya, and pineapple peels include, in particular: temperature, pH, density, refractive index, electrical conductivity, alcohol yield, and alcohol content. Temperature, pH, and electrical conductivity were measured using the HANNA HI 70001 multiparameter meter. Density and refractive index were measured with a refractometer. The Brix degree was measured using an alcoholometer.

IV. Results And Discussion

Physicochemical Properties of Bioethanol Produced from Banana, Papaya, and Pineapple Peels

Boiled point

Table I presents boiling points of bioethanols obtained from banana, papaya, and pineapple peels and a mixture of the three (03) peels.

Tableau I: Boiling points of bioethanols obtained from banana, papaya, and pineapple peels and from a mixture of the three (03) peels

Parameters	Results (Mean ± Standard Deviation)			
	Banana	Papaya	Pineapple	Mixture (Banana, Papaya et Pineapple)
Bioethanols boiling points (°C)	78,56 ± 0,34	78,1 ± 0,14	78,56 ± 0,34	78,2 ± 0,28

The boiling point is around 78°C for all bioethanols. This confirms that ethanol is the major component of the mixture. This observation is consistent with the standard physicochemical data for ethanol and is in line with the results of numerous experimental studies, in which a boiling point of approximately 78.3 °C is used as an identification criterion [14; 15].

pH

Table II presents pH of bioethanols obtained from banana, papaya, and pineapple peels and a mixture of the three (03) peels.

Tableau II: pH of bioethanols obtained from banana, papaya, and pineapple peels and from a mixture of the three (03) peels

Parameters	Results (Mean ± Standard Deviation)			
	Banana	Papaya	Pineapple	Mixture (Banana, Papaya et Pineapple)
Bioethanols pH	7,00 ± 0,35	7,05 ± 0,21	7,05 ± 0,35	6,995 ± 0,13

The pH measured at 20°C is around 7, indicating a virtually neutral environment. These values are generally in line with standard ranges (6.0–7.0), reflecting a relatively balanced fermentation. These values are consistent with the characteristics typically observed for relatively pure ethanol after distillation. In fact, bioethanol generally has a pH close to neutral when the acidic compounds resulting from fermentation are partially removed during the distillation process. Similar values have been reported in several studies on bioethanol production from agri-food waste, where the pH of distilled ethanol generally ranges between 6.5 and 7.5 [16; 17]. However, values slightly above 7 could indicate the presence of buffering compounds or mineral residues from the substrate [18].

Density

Table III presents density of bioethanols obtained from banana, papaya, and pineapple peels and a mixture of the three (03) peels.

Tableau III: Density of bioethanols obtained from banana, papaya, and pineapple peels and a mixture of the three (03) peels

Parameters	Results (Mean ± Standard Deviation)			
	Banana	Papaya	Pineapple	Mixture (Banana, Papaya et Pineapple)
Bioethanols density (g.cm ⁻³)	0,759 ± 0,003	0,7885 ± 0,0007	0,790 ± 0,0014	0,789 ± 0,014

The measured densities range from 0.759 to 0.79, confirming the presence of an ethanol-rich mixture with good reproducibility, as evidenced by the low standard deviations. Indeed, the density of pure ethanol at 20°C is approximately 0.789 g•cm⁻³, while solutions containing a significant proportion of alcohol exhibit slightly lower or similar values depending on their composition [19]. The results obtained in this study therefore indicate a significant proportion of ethanol in the distillate. These results are consistent with those obtained in other studies on bioethanol derived from agri-food waste [20].

Alcohol yield

Table IV shows the alcohol yields of bioethanol produced from banana peels, papaya peels, pineapple peels and a mixture of the three (03) peels.

Tableau IV: Alcohol yields of bioethanol obtained from banana peels, papaya peels, pineapple peels and a mixture of the three (03) peels.

Parameters	Results (Mean ± Standard Deviation)			
	Banana	Papaya	Pineapple	Mixture (Banana, Papaya et Pineapple)
Bioéthanol Alcohol yields (%)	55 ± 2,2%	56 ± 1,41	66,33 ± 0,014	53,33 ± 0,014

The alcohol yields obtained range from 53.33% to 66.33%. They reflect the efficiency of the process of converting fermentable sugars into ethanol during fermentation followed by distillation. This yield falls within the range generally reported for bioethanol production from tropical fruit waste, where yields often vary between 40 and 65% depending on the nature of the substrate, fermentation conditions, and the efficiency of the distillation process [21].

Alcohol content

Table V shows the alcohol content of bioethanol produced from banana peels, papaya peels, pineapple peels, and a mixture of the three (03) peels.

Tableau V: Alcohol content of bioethanol produced from banana peels, papaya peels, pineapple peels, and a mixture of the three (03) peels.

Parameters	Results (Mean ± Standard Deviation)			
	Banana	Papaya	Pineapple	Mixture (Banana, Papaya et Pineapple)
Alcohol content of bioethanol (% v/v)	67,00 ± 0,71	40 ± 2,83	69,00 ± 0,71	33 ± 4,24

The alcohol content of the distillates ranges from 33% (v/v) to 69% (v/v). These values indicate that the resulting product is partially concentrated bioethanol, which is common after a single distillation. In practice, producing bioethanol for use as a fuel generally requires additional purification or rectification steps to achieve concentrations greater than 90% (v/v) [22]. These values remain below the standards required for bioethanol fuel ($\geq 95\%$ v/v according to ASTM D4806). Nevertheless, this type of bioethanol can be utilized for domestic energy purposes, particularly in alcohol stoves, as well as for certain pharmaceutical applications such as disinfectants, subject to additional testing. In fact, ethanol with a concentration between 20% and 70% is primarily used as an extraction solvent, antiseptic, industrial ingredient, or in baking. Common and characteristic applications of these concentrations include [23]:

- 60% (or 70% v/v): This is the standard concentration for antiseptics. Ethanol at this concentration is most effective at killing bacteria and viruses.
- 50%: Frequently used in cooking and baking for maceration, fruit preservation, and flavor extraction while retaining some of the fruit’s natural moisture.
- 20% to 40%: Found in the production of certain liqueurs, spirits, or mother tinctures, where alcohol is used to extract active ingredients (from plants) or to stabilize a mixture.

Confirmatory tests on the bioethanol produced

Potassium dichromate confirmation test

The images shown in Fig. 6 below illustrate the process for identifying the bioalcohols obtained. Following visual observation, the test revealed the presence of ethanol in the analyzed samples, as evidenced by the change in color of the reaction medium from orange to green at the end of the experiment. The experimental observations revealed a color change in the reaction medium, from orange to green, in all of the analyzed samples. This color transition reflects the reduction of dichromate ions (Cr^{6+}) to chromium (III) ions (Cr^{3+}), thereby confirming the oxidation of ethanol to acetic acid.



Fig.6: Bioethanol Identification test using potassium dichromate

This color change is characteristic of the reduction of orange-colored dichromate ions ($\text{Cr}_2\text{O}_7^{2-}$) to green-colored chromium (III) ions (Cr^{3+}) in the presence of an oxidizable alcohol such as ethanol in an acidic medium. Consequently, this test detects the presence of a primary alcohol in the distillates obtained, thereby providing qualitative confirmation of the presence of bioethanol in samples F0 through F4. The results obtained from the potassium dichromate test clearly demonstrate the presence of an oxidizable alcohol in all of the bioalcohol samples analyzed (F0 through F4). Indeed, the observed color change from orange to green is a classic qualitative indicator of the reduction of dichromate ions ($\text{Cr}_2\text{O}_7^{2-}$) to chromium (III) ions (Cr^{3+}) in a strongly acidic medium. This behavior is characteristic of primary alcohols, particularly ethanol, which undergoes gradual oxidation to acetaldehyde and then to acetic acid in the presence of a strong oxidizing agent such as potassium dichromate in a sulfuric acid medium [24]. Thus, the color change observed in all samples confirms not only the presence of an alcohol but, more specifically, that of an oxidizable primary alcohol, which is consistent with the expected nature of bioethanol derived from the alcoholic fermentation of sugars contained in fruit peels. These results corroborate the observations reported in the scientific literature, according to which the dichromate test is a reliable qualitative method for identifying primary alcohols in biological and agro-industrial matrices [25]. Furthermore, according to Skoog et al. [26], the sensitivity of this test is based on dichromate's strong oxidizing capacity in an acidic medium, which allows for the detection of even low concentrations of ethanol. Furthermore, the uniformity of the color change across the five fermenters (F0, F1, F2, F3, and F4) suggests that the fermentation process effectively led to ethanol production under all experimental conditions tested. This demonstrates the overall effectiveness of the alcoholic fermentation process applied to the substrates studied (banana, papaya, and pineapple peels), consistent with previous work on the conversion of lignocellulosic materials into bioethanol (Balat and Balat, 2009). However, it should be noted that this test remains strictly qualitative and does not allow for the quantification of the ethanol concentration in the samples. Ultimately, the potassium dichromate test conducted in this study constitutes an essential step in the qualitative validation of the bioethanol obtained. It confirms the success of the alcoholic fermentation process and demonstrates the conversion of fermentable sugars into ethanol under the action of yeasts.

Combustion Flammability Test

The images shown in Fig. 7 below illustrate the combustion of the samples, demonstrating the ability of the bioethanol produced to burn efficiently. The tests involved alcohol samples derived from banana peels (F1), pineapple peels (F2), and papaya peels (F3). All of the samples tested exhibited flammability. Combustion was characterized by the appearance of a pale blue flame, which is characteristic of the combustion of ethanol and other light alcohols. This color indicates clean combustion with limited soot emission, which is typical of low-molecular-weight alcohols [27].

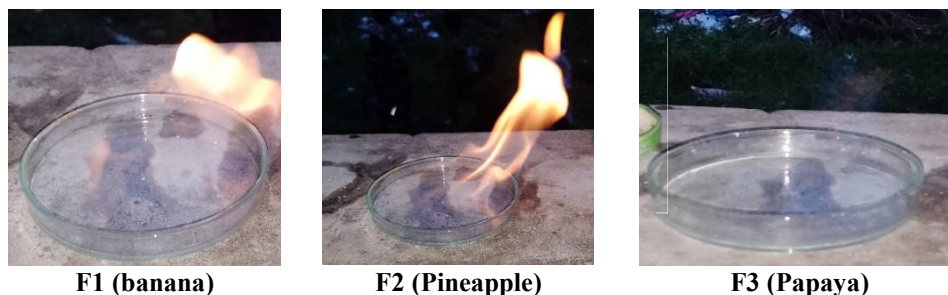


Fig. 7: Combustion of bioethanols produced by Ignition

The flammability observed in all samples confirms the presence of combustible organic compounds, primarily alcohols derived from the fermentation process. The pale blue flame is a characteristic indicator of ethanol, suggesting that it is the major component in the analyzed samples [28]. Furthermore, the relatively clean combustion observed indicates a low level of heavy impurities (such as hydrocarbons or aromatic compounds), which attests to the acceptable quality of the bioethanol obtained from banana, pineapple, and papaya peels. However, the possible presence of water or other volatile compounds may slightly affect the intensity and stability of the flame. Thus, this test provides additional qualitative evidence of the actual production of bioethanol, highlighting its potential for use as a renewable energy source.

Lucas test

The images shown in Fig. 8 below present the results obtained using the Lucas test. The tests were conducted on the following samples: alcohol derived from banana peels (F1), pineapple peels (F2), papaya peels (F3), a mixture of the three peels without yeast (F0), a mixture with yeast (F4), and a control consisting of absolute ethanol (F5). The tests were conducted at room temperature (cold). No cloudiness or visual changes were observed

in the various samples: the mixtures remained clear. The absence of turbidity observed in all test tubes indicates that no alkyl chlorides were formed under the experimental conditions. According to the principle of the Lucas test, this observation is characteristic of primary alcohols, which react very slowly, if at all, at room temperature [29].



Weigh out 10g of $ZnCl_2$



Negative test results in the samples

Fig. 8: Lucas test negative

This behavior can be explained by the reaction mechanism involved. The Lucas test favors an S_N1 -type nucleophilic substitution, which requires the prior formation of a carbocation. However, primary carbocations are highly unstable due to the absence of sufficient inductive and hyperconjugative effects to stabilize the positive charge [30]. Consequently, the reaction does not occur at low temperatures, which explains the absence of turbidity observed. The results obtained for samples F1 (banana), F2 (pineapple), and F3 (papaya) suggest that the alcohols produced by the fermentation of these substrates are predominantly primary alcohols, particularly ethanol, which is the main product of the alcoholic fermentation of sugars [31]. This observation is confirmed by the behavior of the control sample F5 (absolute ethanol), which also shows no cold reaction. Furthermore, the F0 (yeast-free) and F4 (yeast-containing) samples exhibit the same behavior, indicating that, regardless of the presence or absence of active fermentation, the alcoholic compounds formed or present remain predominantly primary in nature. This is consistent with the metabolic pathways of alcoholic fermentation, in which yeasts, particularly *Saccharomyces cerevisiae*, primarily produce ethanol (a primary alcohol). Thus, the results of the Lucas test confirm the primary nature of the alcohols obtained from banana, pineapple, and papaya peels, which is consistent with the literature on the fermentation of sugar-rich organic waste.

V. Conclusion

This study highlighted the potential for utilizing banana, papaya, and pineapple peels through fermentation for bioethanol production. The results show that fruit peels have good fermentation potential. Taken together, the results of this study demonstrate that tropical fruit peels—particularly those of pineapple, banana, and papaya—have high potential for bioalcohol production via alcoholic fermentation. Overall, the physicochemical parameters obtained in this study are comparable to those reported in the scientific literature, confirming the feasibility of bioethanol production from biodegradable waste such as fruit peels. Fruit peels exhibit excellent fermentative capacity, with temperatures, pH levels, and densities favorable for fermentation and high ethanol production. The alcohol contents confirm these trends: pineapple (69% v/v), banana (67% v/v), papaya (40% v/v), and mixed (33% v/v). Finally, potassium dichromate and combustion flammability tests were an essential step in the qualitative validation of the bioethanols obtained. They confirm the success of the alcoholic fermentation process and demonstrate the conversion of fermentable sugars into ethanol under the action of yeast. Finally, Lucas test results confirm the primary nature of the alcohols obtained from banana, pineapple, and papaya peels, which is consistent with the literature on the fermentation of sugar-rich organic waste. These results underscore the value of energy recovery from tropical biowaste based on a detailed understanding of fermentation parameters.

Competing Interests

Authors have declared that no competing interests exist.

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