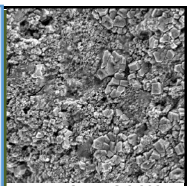
JEBAT, 2024, Vol 7, No 2, 94-97
https://doi.org/10.54987/jebat.v7i2.1050

HIBISCUS PUBLISHER

JOURNAL OF ENVIRONMENTAL BIOREMEDIATION AND TOXICOLOGY

Website: http://journal.hibiscuspublisher.com/index.php/JEBAT/index



JEBAT VOL 7 NO 2 2024
SEM of *V. Subterranea* leaf

Biogas Production From Date Palm Fruit Waste as an Alternative Energy Source in Jigawa State, Nigeria

Abdulhadi Yakubu[1]*, Aliyu Abdulhamid Omar[2], Zainab Abbas Abdulhadi[3] and Garba Uba[4]

[1]Department of Public Health, College of Health Sciences, Jigawa State Polytechnic, P.M.B. 7040, Dutse, Nigeria.
[2]Department of Science Laboratory Technology, Faculty of Science, Sa'adu Zungur University, P.M.B. 049, Bauchi, Nigeria.
[3]Department of Microbiology and Biotechnology, Faculty of Science, Federal University Dutse, P.M.B. 7156, Dutse, Nigeria.
[4]Department of Science Laboratory Technology, College of Science and Technology, Jigawa State Polytechnic, P.M.B. 7040, Dutse, Nigeria.

*Corresponding author:
Abdulhadi Yakubu,
Department of Public Health,
College of Health Sciences,
Jigawa State Polytechnic,
P.M.B. 7040, Dutse,
Nigeria.
Email: ayakubu.slt@jigpoly.edu.ng

HISTORY

Received: 18th Aug 2024
Received in revised form: 19th Nov 2024
Accepted: 24th Dec 2024

KEYWORDS

Date palm
Fruit waste
Codigestion
Biogas yield
Sustainable production

ABSTRACT

This research was conducted to produce biogas from Date Palm fruit waste, which is abundant in the study area. The Date Palm fruit waste, which acts as a substrate, was collected from the Nigerian Institute for Oil Palm Research (NIFOR) Dutse substation in Jigawa State, Nigeria. Three different anaerobic digesters, along with their corresponding control digesters, were set up for a period of forty-two (42) days. For the anaerobic digestion process, a 15-litre cylinder with a working volume was used, equipped with air-tight lids and provision for gas collection. The digesters were fabricated at the Federal University's Research Centre in Dutse and were maintained at 37 °C in the University's Botanical Garden. They were shaken manually approximately 2-3 times a day to maintain homogeneity of the contents. The result shows the highest biogas concentration at 0.5 w/w (2000 g/mL), which is 10.5 g, while the lowest biogas concentration (3.4 g) was recorded in an aerobic digester containing a 2:1 wastewater ratio with 200 mL of cow dung as slurry. On the other hand, the control anaerobic digester produced a very small amount of biogas from the respective digester, which contains only slurry and water. It is therefore recommended that date palm fruit waste be utilized for the production of biogas as a substitute for fossil fuel, in line with the United Nations Sustainable Development Goals.

INTRODUCTION

Global energy demands are currently met by non-renewable fossil fuels, which are believed to have negative environmental impacts, including global warming, climate change, and depletion of the ozone layer, caused by the burning of fossil fuels. These pose a serious threat to the environment [1]. Date fruits (*Phoenix dactylifra L.*) are of great importance in human nutrition owing to their rich content of essential nutrients, which include carbohydrates, salts, minerals, dietary fiber, vitamins, fatty acids, amino acids, and protein. Carbohydrates are the primary chemical components of dates, primarily comprising glucose, fructose, and small amounts of cellulose and starch. The high nutritional and high sugar content of date palm wastes make them excellent sources for microbial fermentation potential in bioenergy production [2]. The waste of the palm oil industry could become a promising source of renewable energy due to its abundant organic matter, including significant amounts of amino acids, free organic acids, and carbohydrates. In countries like Iraq, small quantities of date waste are used in making animal feed. More than 9,000,000 trees by-product dates are discarded due to their industrial processes and unsuitable texture [3]. To produce biogas from digestible materials through anaerobic digestion, the decomposition of organic wastes occurs in four simultaneous processes (**Fig. 1**): hydrolysis, acidogenesis, acetogenesis, and methanogenesis [4]. Suitably controlling these stages, maintaining an equilibrium between their rates, leads to maximizing the gas generation.

According to the research activities gathered from the literature, many researchers have proposed various methods for biogas production from agricultural and industrial wastes. [4] reported that date palm fruits contain moisture ranging from 10 to 22%, total sugars 71.2e81.4%, protein 1.72e4.73%, lipid 0.12e0.72%, and ash 1.89e3.94%, on a dry weight basis. Date palm fruits and their residues contain many essential components that support the growth of microorganisms. Methane with a yield of 570 L/kg VS from Zahdi date biomass, a by-product of the syrup (Dibs) industry in Iraq, was collected by Jaafar [3]. The date palm tree, as well as the processing of its fruit, generates

https://doi.org/10.54987/jebat.v7i2.1050

huge quantities of biomass waste worldwide. Date seeds, which make up to 14% of the date weight, are another major component of waste biomass originating from the date palm tree. Waste dates and date flesh constitute the third large stream of date palm-based biomass waste, amounting to about two million tons per year [5]. Annually, in Dutse and its neighbouring states in Nigeria, several tons of date fruits, stalks, stems, and seeds are produced, which become unsuitable for human and animal consumption and are therefore dumped without any treatment, causing environmental problems such as the emission of gases into the atmosphere, contributing to the global warming phenomenon. The main aim of this research is to attempt the biosynthesis of gas from date palm fruit waste. The production of biogas from these wastes will be economically and environmentally important to the Dutse environs.

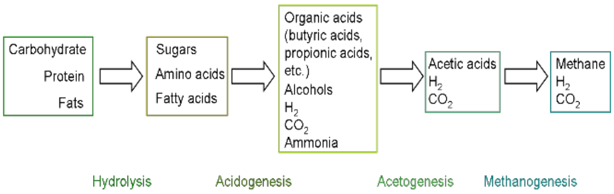


Fig. 1. Methane fermentation complex.

MATERIALS AND METHODS

Substrate

Different forms of dried date palm fruit waste were collected from the Nigerian Institute for Oil Palm Research (NIFOR) at the Dutse substation. Each date palm fruit waste was air-dried and then milled sufficiently to pass through a sieve.

Anaerobic Digestion

A 15-litre cylinder with a working volume was used for anaerobic digestion, equipped with air-tight lids and provision for gas collection. The digester was placed in a water bath to maintain a constant temperature, and two Erlenmeyer flasks were connected with rubber tubes for gas collection. The digesters were fabricated locally at the Federal University, Dutse, Nigeria, Research Centre and were maintained at 37°C in the laboratory. They were manually shaken 2-3 times every day to keep the contents homogenized.

Starter culture

Fresh cow dung served as the primary starter culture, naturally containing bacteria that produce methane. It was collected from the Dutse abattoir and used as inoculum. This starter was used to inoculate the Date palm fruit waste..

Substrate pretreatment

Following milling and passing through a sieve with a mesh size of approximately 5 mm, the substrate size was reduced to 2-5 mm. The milled substrate was then pretreated with NaOH at different concentrations (0.5, 0.75, and 1.0%), followed by soaking at 3, 6, and 9 days. The pH of the soaked substrate was adjusted to 7 using HCl, while the C: N ratio was adjusted to approximately 30:1, as described by Al Juhaimi et al. [1].

Substrate Testing

In the first experiment, the digesters were fed with 2000g of wastewater mixture adjusted to a total solids (TS) content of 8.5% (w/w). The corresponding volatile solids content ranges from 7% to 7.9%, depending on the component of the waste. 500 ml of cow dung slurry was added as inoculum. Simultaneously, control digesters were operated, which had all other conditions the same as those in the test digesters, but no waste was added. These digesters will yield biogas generated solely by the cow dung inoculum. Moreover, biogas volumes were transformed to correspond to normal temperature. In the second experiment, the digester was fed 3,000 g of a wastewater mixture adjusted to a Total solids (TS) content. Once started with cow dung, the digester was subsequently maintained at room temperature and periodically shaken to allow a bacterial culture to develop in it, which would be adapted to date palm waste, as explained by Lattieff [6].

RESULT AND DISCUSSION

To describe the anaerobic digestion performance of date palm fruit wastes, four different substrates with their corresponding inoculum, as well as a control digester, were used within the same period of time at constant temperature, as shown in **Tables 1** and **2**.

Table 1. The concentration of biogas produced using date palm waste as substrate.

Volume of water (mL)	Volume of cow dung (slurry) (mL)	Mass of date palm waste (g)	Retention time (d)	Biogas yield (g)	Gas intensity
2000	2000	500	42	10.5	Fast
2000	1000	400	42	7.9	Fast
2000	500	300	42	3.4	Slow

Biogas Yield at Different Substrate Mixing Ratios

The performance of anaerobic digestion using date palm fruit waste was assessed under three different substrate-to-water mixing ratios with corresponding volumes of cow dung slurry, as presented in **Table 1**. All digestion experiments were carried out over a constant retention time of 42 days at room temperature. The highest biogas concentration of 10.5 g was recorded in the digester with a mixing ratio of 1:1 (2000 mL of water and 2000 mL of slurry). This mixture exhibited the fastest gas production rate, which indicates that the balance between solids and moisture has favored microbial activity and enhanced hydrolysis efficiency. A moderate biogas concentration of 7.9 g was obtained with a 2:1 water-to-slurry ratio (2000 mL water and 1000 mL slurry). However, the gas yield decreased significantly to 3.4 g in the digester with a 4:1 water-to-slurry ratio (2000 mL of water and only 500 mL of slurry), which also exhibited a slower gas production rate.

These results demonstrate a clear correlation between the solid mixing ratio and biogas yield, consistent with prior findings that the total solid concentration directly affects the efficiency of anaerobic digestion [6]. A higher proportion of solids (as in the 1:1 mixture) provided more degradable organic matter, which served as substrate for microbial metabolism. However, if the solid concentration is too high, it may lead to poor mass transfer, reduced microbial contact with the substrate, and possible accumulation of volatile fatty acids (VFAs), which inhibit methanogenesis. On the other hand, increasing the water content (as in the 4:1 mixture) resulted in a dilution effect, reducing the substrate availability per unit volume and thereby decreasing biogas production. Despite providing adequate moisture for hydrolysis, excessive dilution limits microbial energy yield, resulting in longer digestion times and reduced gas production.

Gas Intensity and Digestion Dynamics

The qualitative classification of gas intensity—categorized as "Fast" or "Slow"—supports these findings. The digesters with 1:1 and 2:1 ratios both exhibited "Fast" biogas production, characterized by visible bubbling and measurable increases in gas volume early in the retention period. In contrast, the 4:1

digester displayed a "Slow" rate of production, possibly due to a longer lag phase or less favorable microbial growth conditions. This result aligns with earlier research [4] suggesting that, in batch systems, the biogas yield increases with substrate loading up to a certain threshold, after which further increases may result in reduced efficiency due to system overload or inhibition [7]. Furthermore, the 42-day retention time appeared sufficient for complete digestion across all samples, although peak production rates varied according to the substrate concentration. A plateau in gas yield after this period suggests that optimal degradation had been achieved under the given experimental conditions [8]. On the other hand, the control anaerobic digester produced a very small amount of biogas from the respective digester, which includes only slurry and water. This insignificant amount of biogas was due to the absence of substrate (Date palm fruit waste) in the control digester. This suggests that the presence of date palm fruit waste can enhance fermentation activity in the digester, thereby increasing biogas production, as shown in Table 2.

In comparison to other agricultural wastes, date palm fruit waste demonstrated a moderate biogas yield, producing 10.5 g over a 42-day retention period at an optimal 1:1 substrate-to-water ratio. A lower yield was observed at higher dilution ratios due to reduced organic content and microbial activity [9]. On the other hand, banana peels yielded significantly higher methane yields, ranging from 18 to 25 m³/ton within a 25–to 30–day period, which is attributed to their low lignin and high sugar content, making these substrates more biodegradable [10,11]. When pretreated, sugarcane bagasse, although fibrous and lignin-rich, showed an improved biogas output, enhancing methane yield by up to 166%, but the process required 30–45 days of digestion [9]. Similarly, corn stalks yielded 15–22 m³/ton, often with co-digestion to improve microbial efficiency [12], whereas rice husks exhibited the lowest yields (<10 m³/ton) due to their high silica and lignin content, necessitating longer retention times of over 45 days [13]. Thus, while date palm waste is viable, its performance is outpaced by softer fruit wastes, such as banana peels, which have fiber-rich residues that require enhancements to match their efficiency.

Combustion Test

A combustion test was conducted after 42 days of anaerobic digestion to determine the flammability and quality of the biogas produced from date palm fruit waste under different substrate-to-water ratios and control conditions (**Table 2**). This important step assesses the practical energy potential of the biogas, extending beyond its volume. The production of flammable gas indicates a sufficient methane content, typically above 45–50%, which is essential for combustion applications, such as cooking or electricity generation [13].

The biogas produced was readily flammable as seen in the first digester setup (2000 g of date palm waste, 2000 mL of water, and 500 mL of cow dung), which demonstrates that the optimal 1:1 solid-to-liquid mixing ratio provided favorable conditions for methanogenic microbial activity. The produced volume and quality of biogas in this setup align well with previous findings, which indicate that a balanced solid-to-liquid ratio improves microbial access to substrate, accelerates hydrolysis, and boosts methane yield [14]. The second setup, which used a 2:1 water-to-substrate ratio, generates a small volume of gas that was found to be non-flammable, although it produces an audible ignition sound upon testing. This indicates the presence of combustible gases, such as hydrogen or carbon monoxide, but at a likely low concentration too low for sustained burning. Similar output was observed in a previous research that shows that suboptimal substrate dilution can hinder methanogenesis while still allowing minor gas formation during acidogenic or acetogenic stages [12]. The third digester setup, which served as a control (no date palm waste) and included only cow dung slurry (2000 mL water, 500 mL slurry), resulted in the production of the least gas (2.4 g) and also showed no visible flame, indicating a low methane content. Additional control digesters with even less cow dung slurry (1500/400 mL and 1000/300 mL water/slurry combinations) produced only 2.0 g and 1.09 g of gas, respectively, and were characterized by slow to very slow gas intensity. The findings in this study reinforce the notion that cow dung, while a viable inoculum, is not a sufficient substrate for meaningful biogas generation in the absence of a carbohydrate-rich co-substrate, such as date palm waste. Similar findings from other studies, which used different residues such as rice husk or sugarcane bagasse, also support this conclusion, where the presence of lignocellulosic biomass is crucial for driving higher biogas yields when combined with manure [15].

Table 2. The amount of biogas produced by the control digesters without using substrate (date palm fruit waste).

Volume of water (mL)	Volume of cow dung (slurry) (mL)	Retention time (d)	Biogas yield (g)	Gas intensity
2000	500	42	2.4	Slow
1500	400	42	2.0	Slow
1000	300	42	1.09	Very slow

A schematic illustration of the process of biogas generation from date palm fruit waste in anaerobic digesters is shown in **Fig. 1**. The system shows the combination of organic substrate (date palm waste) and cow dung slurry as a nutrient inoculum. In the control setup using slurry alone, the system produced 3.4 g of biogas, while in the optimized mixture with both substrate and slurry combined, a yield of up to 10.5 g of biogas was achieved demonstrating the enhanced methane potential of date palm waste as a co-digestion substrate.

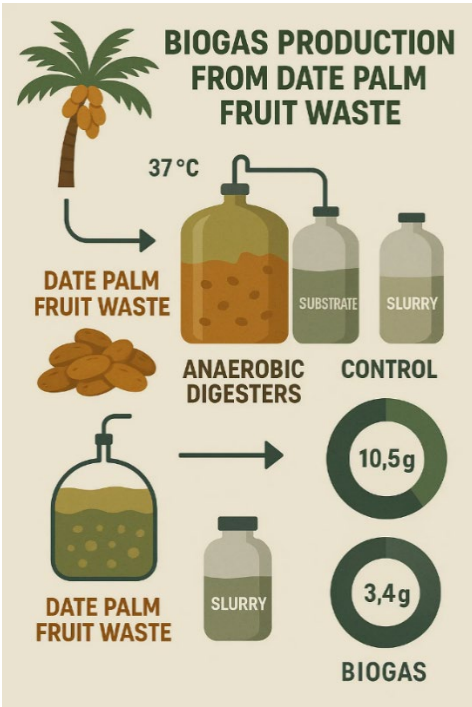


Fig. 1. Biogas production from date palm fruit waste using anaerobic digestion. Image generated using SORA ChatGPT.

CONCLUSION

The results obtained after forty-two (42) days of anaerobic fermentation of the substrates, along with water and cow dung as a slurry, indicated the presence of biogas. This biogas was able to generate a flame when ignited using a lighter. This shows the presence of gas in the digester. However, the amount of gas concentration produced was also measured. The highest biogas concentration, at a 0.5 w/w (1:1) ratio of wastewater, was found to yield 10.5 g, while the lowest biogas concentration (3.4 g) was recorded in an aerobic digester containing a 2:1 wastewater ratio with 200 ml of cow dung as slurry. During anaerobic digestion at 0.25 w/w (1:4), the reactor's response to produce biogas was slower than that of the other samples. It is therefore concluded that biogas can be generated in an anaerobic digester using date palm fruit waste as substrate and cow dung as slurry.

ACKNOWLEDGEMENT

The authors acknowledge the Tertiary Education Trust Fund (TETFund), Abuja, Nigeria, and Jigawa State Polytechnic, Dutse, Nigeria, for their sponsorship.

CONFLICT OF INTEREST

Authors have nothing to declare

REFERENCE

1. Al-juhaimi FY, Hamad SH, Al-ahaideb IS, Al-otaibi MM, Ghafoor K, Abbasi T, et al. Biogas Production through the Anaerobic Digestion of Date Palm Tree Wastes - Process Optimization. Bioresour Technol. 2014;9:3323–33.
2. Djaafri M, Kalloum S, Kaidi K, Salem F, Balla S, Meslem D. Enhanced Methane Production from Dry Leaflets of Algerian Date Palm (Phoenix dactylifera L .) Hmira Cultivar , by Alkaline Pretreatment. Waste Biomass Valorization. 2019;0(0):0.
3. Jaafar KA. Biogas Production by Anaerobic Digestion of Date Palm Pulp Waste. Al-Khwarizmi Eng J. 2010;6(3):14–20.
4. Abdul E, Assirey R. Nutritional composition of fruit of 10 date palm (Phoenix dactylifera L .) cultivars grown in Saudi Arabia. Integr Med Res. 2015;9(1):75–9.
5. Chergui D, Akretche-kelfat S, Lamoudi L, Al-rshaidat M, Boudjelal F, Ait-amar H. Optimization of Citric acid production by Aspergillus niger using two downgraded Algerian date varieties. SAUDI J Biol Sci. 2021;
6. Lattieff FA. A study of biogas production from date palm fruit wastes. J Clean Prod. 2016;139:1191–5.
7. Makkawi Y, El Y, Salih M, Nancarrow P, Banks S, Bridgwater T. Fast pyrolysis of date palm (Phoenix dactylifera) waste in a bubbling fl uidized bed reactor. Renew Energy. 2019;143:719–30.
8. Souli I, Liu X, Lendormi T, Chaira N, Ferchichi A, Lanoisellé J louis. Anaerobic digestion of waste Tunisian date (Phoenix dactylifera L .): effect of biochemical composition of pulp and seeds from six varieties. Vol. 0, Environmental Technology. Taylor & Francis; 2020. 1–39 p.
9. AL Juhaimi F, Hamad S, Al-Ahaideb I, Al-Otaibi M, Ghafoor K, Abbasi T, et al. Biogas Production through the Anaerobic Digestion of Date Palm Tree Wastes - Process Optimization. Bioresources. 2014 Apr 21;9:3323–33.
10. Suhartini S, Nurika I, Paul R, Melville L. Estimation of Biogas Production and the Emission Savings from Anaerobic Digestion of Fruit-based Agro-industrial Waste and Agricultural crops residues. BioEnergy Res. 2021 Sept 1;14(3):844–59.
11. Damaris OK. Batch Anaerobic Digestion of Banana Plant Residues for Methane Production [Internet] [Thesis]. University of Nairobi; 2022 [cited 2025 July 21]. Available from: http://erepository.uonbi.ac.ke/handle/11295/161463
12. Vasileiadou A. From Organic Wastes to Bioenergy, Biofuels, and Value-Added Products for Urban Sustainability and Circular Economy: A Review. Urban Sci. 2024 Sept;8(3):121.
13. Oyedeji S, Patel N, Krishnamurthy R, Fatoba P. Agricultural Wastes to Value-Added Products: Economic and Environmental Perspectives for Waste Conversion. In: Advances in biochemical engineering/biotechnology. 2024.
14. Biogas Production From Anaerobic Co-Digestion of Date Palm Leaves and Cow Dung Using Batch Digester - ProQuest [Internet]. [cited 2025 July 21]. Available from: https://www.proquest.com/openview/bbf6322deffefef2d408ed0d5082b5e1/1?pq-origsite=gscholar&cbl=2026366&diss=y
15. Awasthi S, Mishra A, Pal DB. Energy Production from Sugarcane Bagasse and Rice Husk. In: Pal DB, Rai AK, Siddiqui S, editors. Sustainable Clean Energy Production Using Waste Biomass: Sustainable Energy Production and UtilizatioN. Singapore: Springer Nature; 2024. p. 157–81. Available from: https://doi.org/10.1007/978-981-97-0840-6_7