FUDMA Journal of Sciences (FJS)
ISSN online: 2616-1370
ISSN print: 2645 - 2944
Vol. 7 No. 6, December, 2023, pp 328 - 332
DOI: https://doi.org/10.33003/fjs-2023-0706-2138

EXPLORING THE SUITABILITY OF FRUIT AND VEGETABLE WASTES FOR BIOMETHANE AND ELECTRICITY GENERATION

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ABSTRACT

The exploration of sustainable energy sources, such as biomethane, has become essential due to the increasing global population and demand for food and energy. This study aims to investigate the potential production of biomethane and electricity generation from fruit and vegetable waste. The fruit and vegetable waste used in this research was collected from student hostels at the College of Nursing and Midwifery, Sahaf Restaurant, Mima Restaurant, Mama Ojo Restaurant, Dan Sadi Restaurant, and IBC Restaurant in Malumfashi. The research involves laboratory analysis of the fruit and vegetable waste samples, focusing on their nutrient composition, biomethane potential, and electrical potential. Proximate analysis was used to determine the nutrient characterization, while the Baserga model was used to predict the biomethane potential. Proximate analysis revealed a total solid content of 95.92%, a volatile solid content of 86.5%, a crude protein content of 0.14%, a nitrogen-free extract of 76.96%, a crude fiber of 6.1%, and a crude fat of 3.3%. According to the Baserga model, a significant biomethane yield of 864.4 L/kg volatile solids, with a methane content of 57%, can be expected. The findings also indicate that complete degradation of fresh organic matter from fruit and vegetable waste can generate 748m^3/ton of gas. Furthermore, the study predicts an electricity potential of 1601 kWh/ton of fresh fruit and vegetable waste. Based on these findings, the study recommends the use of fruit and vegetable waste as biomass for energy production to address landfilling issues and promote a more sustainable waste management approach.

Keywords: Anaerobic Digestion, Biomethane, Fruit, Vegetable wastes

INTRODUCTION

The surge in global population and the resulting increase in demand for food and energy have spurred a search for sustainable energy sources. One promising alternative to fossil fuels, which contribute significantly to greenhouse gas emissions, is biofuels like biogas, biomethane, bioethanol, and biodiesel (Jeswani et al., 2020). Biomethane, in particular, has emerged as a renewable bioenergy source that can help meet global energy needs while mitigating the economic and environmental burdens associated with traditional fuels (Alengebawy et al., 2023). The suitability of feedstock for biomethane production relies on its ability to generate biogas. Biomethane is an attractive renewable energy option that can replace fossil fuels and contribute to carbon-neutrality goals, thus supporting a circular bioeconomy (Noussan et al., 2024). Fruit and vegetable waste, among other feedstocks, can be used to produce biomethane (Matobole, Seodigeng, & Rutto, 2021).

Globally, large quantities of fruit and vegetable waste are generated, with approximately 40 to 50 percent of all fruits and vegetables produced annually being wasted (FAO 2020). When these waste materials are disposed of in landfills, they decompose and release methane gas (CH4), a greenhouse gas that is 28 times more potent than CO2 in terms of its impact on global warming over a 100-year period (Sahoo et al., 2023). This underscores the importance of proper management of fruit and vegetable waste. Using this waste as feedstock in the anaerobic digestion (AD) process presents a compelling opportunity to generate renewable energy and address environmental concerns (Zhu et al., 2023).

Assessing the biomethane potential (BMP) is crucial for the successful operation and optimization of biomethane plants. This involves evaluating the potential methane production from various organic wastes, which is essential for effectively utilizing biomethane (Oliveira et al., 2022). The first step in assessing the suitability of organic waste for AD feedstock is characterizing its nutrients, which provides insights into nutrient distribution and viability for biomethane production (Herman et al., 2022). Given the wide range of potential feedstocks, comprehensive characterization is necessary to predict their performance in a digester and integrate fruit and vegetable waste into the renewable energy landscape (Rincón-Catalán et al., 2022). Understanding the biomethane potential and nutrient characterization of organic wastes is crucial for maximizing their potential as prime bioenergy sources and advancing the circular bioeconomy.

Various studies have explored the biomethane potential of fruit and vegetable waste and highlighted the importance of comprehensive characterization to optimize biogas production. For example, a study conducted in Pakistan assessed the potential of fruit waste and domestic vegetable waste for biomethane production through anaerobic digestion, finding a higher percentage of biomethane gas released from these waste streams under optimal conditions (Khalid et al., 2016). Another study emphasized the importance of selecting appropriate operating process parameters, such as temperature, pH, and organic loading rate, to optimize biogas production (Maile et al., 2016). Additionally, research in Austria and Karaj, Iran, focused on the biomethane potential of organic waste fractions and the impact of nutrient characterization on biogas production (Rosenfeld et al., 2020). These studies collectively highlight the significance of understanding the biomethane potential of fruit and vegetable waste as a promising avenue for renewable energy production and the transition to a more sustainable and circular bioeconomy. Therefore, this study aims to explore the biomethane potential from fruit and vegetable waste.

MATERIALS AND METHOD

Sample Collection and preservation

Fruit and Vegetable wastes were collected from various sources, including student hostels at the College of Nursing and Midwifery, Malumfashi, Sahaf Restaurant, Mima Restaurant, Mama Ojo Restaurant, Dan Sadi Restaurant, and IBC Restaurant, for laboratory analysis. Proper sample storage and preservation are critical to avoid contamination, modification, or loss of analytes during storage, which can create changes in the sample content. To avoid this, the samples collected were stored at a very low temperature of 4℃ to retain their bioactive components before laboratory analysis (Dave et al., 2022).

Sample Preparation for the Laboratory Analysis

The first step in assessing whether an organic waste product is suitable for use as an AD feedstock is to analyze its nutrient composition (Longjan & Zahir, 2018). Tampio et al., (2019) reported that understanding the distribution of nutrients in food waste as a feedstock is crucial to verify their appropriateness and performance as biomethane. The nutritional makeup of the substrate utilized in biogas production, according to Nwokolo et al., (2020), is important. In this study dust, coarse particles, and other impurities that could impair the test findings were removed by rinsing the substrates with deionized water. The samples for the analysis were shade dried to remove surface moisture. This was done to preserve the bioactive components of the sample in order not to be altered by the effect of solar insolation. Following that, the samples were mechanically homogenized into powder with a mortar and pestle, and the fine particles were sieved for proximate analysis (Mohammed et al., 2020). The sieved Fruit and Vegetable wastes samples were sent to Central Laboratory Umaru Musa Yar'adua University for standard AOAC analysis (Association of Official Analytical Chemists [AOAC] 2005) to determine their nutrient characteristics. These characteristics include Total Solids (TS), Volatile Solids (VS), Crude Fiber (CrF), Crude Protein (CrP), Crude Oils, Nitrogen-free extracts (NFE), ash, and moisture content. Physicochemical properties such as volatile solids, moisture content, particle size, nutrient content, and biodegradability, are significant for building and operating digesters because they influence biogas production and process balance during AD (Mohammed et al., 2020, Tagne et al., 2021).

Theoretical Biomethane Estimation

The Baserga (1998) model for biomethane estimation was applied to calculate the theoretical biomethane potential of the Fruit and Vegetable wastes after laboratory analysis. This model calculates the theoretical biomethane potentials of food waste substrate based on its nutrient composition, requiring the CrF, CrP, crude oils, ash, and moisture content of the samples as input variables. According to the model, all of the organic content in the sample can be transformed into biogas (Longjan & Zahir, 2018). The full set of constants and equations for the model are presented below:

Table 1: Baserga Model Digestibility constant

Digestibility Factors:		
Crude Fibre	(CrFd)	74.3%
Crude Protein	(CrPd)	65.09%
Crude Fat	(OAHd)	67.51%
NFE	(NFEd)	69.97%
Gas Yield Conversion Factors:		
Carbohydrates	(GYCf)	790l/kg
Proteins	(GYPf)	700l/kg
Fat	(GYOf)	1250l/kg
Methane content of Biogas:		
Carbohydrates	(MCf)	50%
Proteins	(MPf)	71%
Fats	(Mof)	68%

Source: Adapted from Longjan and Zahir, 2018

Calculated parameters

$NFE = 100 - (CrP + CrF + OAH + Ash + Moisture) \ldots\ldots$ (1) (AOAC 2005)

$VS = (CrP + CrF + OAH + NFE) \ldots$ (2) (AOAC 2005)

Baserga Equations

$$\text{Digestible Carbohydrate}\left(\frac{g}{kg}DMB\right) DC = ((CrF \times CrFd) + (NFE \times NFEd)/10 \quad (3)$$

$$\text{Digestible Crude Protein}\left(\frac{g}{kg}DMB\right) DP = (CrP \times CrPd)/10 \quad (4)$$

$$\text{Digestible Crude Fat}\left(\frac{g}{kg}DMB\right) DO = (OAH \times OAHd)/10 \quad (5)$$

And:

$$\text{Digestible Carbohydrate}\left(\frac{kg}{kg}VS\right) DCv = DC/(VS \times 10) \quad (6)$$

$$\text{Digestible Crude Protein}\left(\frac{kg}{kg}VS\right) DPv = DP/(VS \times 10) \quad (7)$$

$$\text{Digestible Crude Fat}\left(\frac{kg}{kg}VS\right) DOv = DO/(VS \times 10) \quad (8)$$

And:

$$\text{Gas Yield Carbohydrate}\left(\frac{l}{kg}VS\right) GYC = DCv \times GYCf \quad (9)$$

$$\text{Gas Yield Protein}\left(\frac{l}{kg}VS\right) GYP = DPv \times GYPf \quad (10)$$

$$\text{Gas Yield Fat}\left(\frac{l}{kg}VS\right) GYO = DOv \times GYOf \quad (11)$$

$$\text{Total Gas Yield}\left(\frac{l}{kg}VS\right) TGY = GYC + GYP + GYO \quad (12)$$

And:

$$\text{Methane Share for Carbohydrate (\%)} MC = GYC \times MCf / TGY \quad (13)$$

$$\text{Methane Share for protein (\%)} Mp = GYP \times MPf / TGY \quad (14)$$

$$\text{Methane Share for Fat (\%)} MO = GYO \times MOf / TGY \quad (15)$$

$$\text{Total Methane Content (\%)} TMC = MC + MP + MO \quad (16)$$

And:

$$\text{Gas Yield}\left(\frac{m^3}{tonne}\right) of\ Fresh\ Matter = (TGY \times VS)/100 \quad (17)$$ (Baserga, 1998).

RESULT AND DISCUSSION

Proximate Analysis

Table 2 presents the proximate analysis results using the standardized [AOAC] 2005 procedure. The nutrient characterization analysis reveals the following percentages: total solids (TS) is 5.92%, volatile solids is 86.5%, crude protein (CrP) is 0.14%, nitrogen-free extract (NFE) is 76.96%, crude fiber (CrF) is 6.1%, crude fats (OAH) is 3.3%, moisture content is 9.42%, and ash content is 4.08%. These findings align with the results reported by Charles & Oluwatosin (2022) in Nigeria, who found a moisture content of 21%, crude protein content of 6%, ash content of 8%, crude fiber content of 20%, volatile solid content of 86%, nitrogen-free extract (NFE) content of 58%, and total solid content of 79% in plantain peels. However, these findings contradict those of Feiz et al. (2019), who reported that food waste substrates for biogas production contain total solids (TS) between 21.6% and 29.8% and volatile solids (VS) between 74.2% and 84.9%. This analysis demonstrates that fruits and vegetables have the necessary components for biogas production through anaerobic digestion.

Table 2: Proximate Analysis Result

Waste Sample	Parameters in %							
	TS	**VS**	**CrP**	**NFE**	**CrF**	**OAH**	**Ash**	**Moisture**
Fruits and Vegetables	95.92	86.5	0.14	76.96	6.1	3.3	9.42	4.08

Source: Authors Computation 2023

Theoretical biomethane

Table 3 presents the theoretical biogas yield and methane content of Fruit and vegetable wastes, which were calculated using the Baserga model for biomethane estimation. The model required the CrF, CrP, crude oils, ash, and moisture content of the samples as input variables, and it predicted the biogas potential based on the nutrient composition of the food waste substrate. The biomethane yield and methane content were found to be 864.4L/kg volatile solids (VS) and 57% (Baserga, 1998), respectively. This finding corresponds to that of (Mekonnen Tura & Seifu Lemma, 2019), who reported a biogas production of 105.5mL/1000g from the mixtures of Fruit and vegetable wastes.

Table 3: Theoretical biomethane yield and methane share of Fruit and Vegetable wastes

Feedstock	Biomethane yield/kgVS	Methane Content (%)
Fruits and Vegetables	864.4	57

Source: Authors Computation 2023

Gas yield potential per ton fresh Fruit and Vegetable wastes

The model was also used to predict the total gas yield obtainable from complete degradation of fresh organic matter of Fruit and Vegetable wastes, result shows that has a gas yield of 748m^3/ton

This aligns with previous research findings indicating that FW possesses significant potential as a bioenergy feedstock, attributed to its elevated biogas potential and yield. As illustrated by Suhartini et al. (2019), there is notable potential for FW to be harnessed as a source of electricity, whether through a single-digestion or co-digestion anaerobic digestion process. The electricity potential from single and Co-digestion of FW and FW: Tofu Solid Waste at (50:50) mixing ratio were 473.8 kWh/ton and 307.2 kWh/ton, respectively.

Electrical Potential

According to Suhartini et al., (2019), Electrical potential estimation was calculated with the assumption that 1m^3 biogas has a calorific value of 22 MJ. With the assumption of an electrical conversion efficiency of 35%, 1 m^3 biogas will yield 2.14 kWh (electricity)

The total calorific value of 1-ton fresh Fruits and Vegetable wastes is given by;

The total biogas yield is 748m^3

22MJ x 748 m^3 = 16456MJ/ton

The total electricity that could be harnessed from 1-ton fresh Fruit and Vegetable wastes is given by;

The total biogas yield is 748m^3

1m^3 biogas will yield 2.14 kWh (electricity)

2.14kwh x 748m^3 = 1601 kWh/ton

CONCLUSION

This study emphasizes the crucial role of feedstock characterization in evaluating the potential of organic waste for bioenergy production. Proximate analysis is vital as it reveals the composition of the waste, including its moisture, volatile solids, crude protein, fiber, fats, nitrogen-free extract, and ash. The study confirms that the waste exhibits a high volatile solid content, which enhances its suitability for anaerobic digestion and biogas production. The significant nitrogen-free extract and ash content also indicate the presence of beneficial organic and inorganic nutrients that support anaerobic digestion. Additionally, the waste's high moisture and biodegradability make it a suitable substrate for anaerobic digestion. Furthermore, the study findings advocate for incorporating the waste as biomass for energy production to address landfilling challenges. Further research is recommended to determine the total carbohydrates in the waste and explore sustainable methods for managing food waste and recycling nutrients.

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