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NUTRIENT CHARACTERIZATION, BIOGAS AND ELECTRICITY GENERATION POTENTIALS OF ROOT AND TUBER WASTES

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ABSTRACT

Rapid population growth and increasing food demand have led to a significant rise in organic waste generation, which has had a negative impact on the environment. However, these wastes can be utilized as substrates for anaerobic digestion (AD) biogas production, providing a sustainable and environmentally friendly waste management solution. The aim of this study was to evaluate the nutrient composition, biogas potential, and electricity generation capacity of root and tuber waste as a feedstock for biogas production. Waste samples were collected from various restaurants in Malumfashi. The nutrient composition of the waste samples was analyzed using standardized AOAC methods, and the biogas potential was estimated using the Baserga model equations. The results revealed that the waste samples had a total solid content of 94.70%, a volatile solid content of 87.60%, a crude protein content of 0.10%, a nitrogen-free extract of 5.1%, a crude fiber content of 5.04%, a crude fat content of 7.1%, and an ash content of 5.3%. The estimated biogas yield from complete degradation of fresh organic matter from roots and tubers was 501m^3/ton, with a methane content of 52%. Based on the calorific value of biogas and the efficiency of electrical conversion, the estimated electrical potential was determined to be 1072 *kWh/ton*. The study recommends the utilization of root and tuber waste as a valuable resource for biogas generation and renewable energy production. Additionally, further research should be conducted to determine the specific biogas production outputs of root and tuber wastes.

Keywords: Anaerobic Digestion, Biogas, Roots, Tuber Wastes, Municipal Solid Waste

INTRODUCTION

The energy crisis and the issue of municipal solid waste management (MSWM) are significant global challenges. Rapid urbanization has resulted in a substantial increase in the generation of municipal solid waste (MSW), exceeding 2 billion tons per year globally, posing a threat to the environment (Mrosso et al., 2023). The global production of MSW is escalating annually, surging by 8% (Procházková et al., 2019). This upward trend is primarily attributed to consumerism and the urbanization process (Mrosso et al., 2023). As nations and cities urbanize, waste is expected to reach 3.40 billion tonnes by 2050, more than doubling population growth over the same period (Kaza et al., 2018). Developed countries create 521.95 – 759.2 kg of waste per person per year (kpc), compared to 109.5 – 525.6 kpc in developing countries (Savalia & Dungrechiya, 2022). The annual volume of waste generated in sub-Saharan Africa (SSA) increased from 81 million tonnes to 174 million tonnes per year between 2012 and 2016 and is projected to reach 269 million tonnes in 2030 (Adedara et al., 2023).

Nigeria alone generates more than 32 million tons of solid waste annually, of which only 20-30% is collected (Ogundele et al., 2018). In most urban centers across Nigeria, approximately 50 percent of Municipal Solid Waste (MSW) consists of organic matter, with many areas having an even higher proportion of up to 80 percent (Amber et al., 2023). According to Dickson et al. (2023), the average volume of municipal solid waste in the city of Abuja, Nigeria, was estimated to be 0.658 kg per capita per day. All of this waste can be converted into renewable and sustainable energy through the production of biogas by anaerobic digestion (AD), offering a solution to waste disposal and management.

Biogas is a flammable gas formed by the biological decomposition of organic matter in the absence of oxygen (Sawyerr et al., 2019). The gas consists mainly of methane and carbon dioxide, along with other trace components such as hydrogen, hydrogen sulfide, and halocarbons (Indrawan et al., 2018). Biogas is widely recognized as a carbon-neutral bioenergy source that reduces anthropogenic greenhouse gas emissions, mitigates global warming, and supplements the energy supply (Moustakas et al., 2020). Biogas can be produced from various feedstocks, including root and tuber waste. Research has shown that cassava tuber slurry, with urea supplementation, efficiently produces biogas with a methane content of 62.3% (Felix & Aisien, 2020). Root tuber waste, such as yam, cassava, and sweet potato, has greater potential for biogas production compared to other substrates under investigation (Chebet & Twizerimana, 2022). Additionally, a study on cassava wastewater demonstrated enhanced biogas production with zeolite and biochar additives, highlighting the potential for biogas production from cassava waste (Achi et al., 2020).

Whereas, many studies have researched the energy potential of root and tuber waste through anaerobic digestion (AD), it is important to consider nutrient characterization when determining the suitability of a feedstock for biogas production. Nigeria is the largest producer of root and tuber crops globally (Awah & Amanze, 2014), with an average annual production of 121 million tonnes in 2021, growing at a rate of 4.38% from 1972 to 2021 (World Data Atlas, 2021). The increase in population growth, combined with the low cost of living in Nigeria, has led to a significant rise in root and tuber crop production. In Nigeria, 95% of root and tuber crops produced are consumed domestically (Karya & Otsanjugu, 2019). This has resulted in a substantial increase in root and tuber waste generation. The decomposition of this waste emits methane gas, which is 28 times more potent than carbon dioxide over a 100-year time frame. It also pollutes underground and surface water through leachates and contaminates the air (Abubakar et al., 2022). Landfills, the third-largest source of anthropogenic methane emissions, require proper measures for methane mitigation and recovery (Bian et al., 2021).

Therefore, using root and tuber waste for biogas production offers a promising opportunity for sustainable waste management and renewable energy generation for combined heat and power. However, the potential use of this waste depends on its nutrient composition. Understanding the distribution of nutrients in the waste is crucial for assessing its suitability for biogas generation and predicting its performance in a digester (Longjan & Zahir, 2018). The initial assessment of the suitability of root and tuber waste as biogas feedstock can be based on its nutrient availability. Therefore, the objective of this study is to evaluate the nutrient availability for biogas production and determine the biogas potential of root and tuber waste. The research focuses on understanding the nutrient distribution in the feedstock, which is crucial for determining its suitability for biogas generation and predicting its performance in a digester. By analyzing the nutrient composition of root and tuber waste, the study aims to identify its suitability and potential for biogas and electricity generation.

MATERIALS AND METHOD

Sample collection and preparation for Laboratory Analysis

Roots and tuber waste was collected from various restaurants in Malumfashi, including Sahaf, Mima, Mama Ojo, Dan Sadi, and IBC. The collected waste was decontaminated by rinsing it with deionized water to remove dust, coarse particles, and other contaminants that could affect the test results. After rinsing, the waste was air-dried to eliminate surface moisture. To obtain representative samples, the waste was mechanically homogenized into a powder using a mortar and pestle. The fine particles were then sieved and sent to the Central Laboratory at Umaru Musa Yar'adua University for standard analysis according to AOAC (Association of Official Analytical Chemists) guidelines (Hirut et al., 2020).

Waste nutrient characterization

The nutrient composition of the samples, including total solids (TS), volatile solids (VS), crude fiber (CrF), crude protein (CrP), oils, nitrogen-free extracts (NFE), ash, and moisture content, was analyzed using standard AOAC methods (AOAC, 2005). The analyses performed on the samples were determined based on the AOAC methods, which are widely used for nutrient analysis of organic waste materials. The AOAC methods have been used in several studies to assess the biogas potential and nutrient composition of various organic waste materials.

Total solids and moisture content

Total solids refer to the dry matter content of a sample after all moisture has been eliminated. To determine the total solids content, the sample was dried in an oven at 105°C until a constant weight was achieved. The weight of the residue represents the total solids content in the sample. The moisture content was calculated by subtracting the weight of the total solids from the initial weight of the sample (Van Wychen & Laurens, 2015).

Volatile solids and ash content

Volatile solids refer to the components of a sample that are lost on ignition at 550°C. To determine the volatile solids content, the sample was first dried to a constant weight in an oven at 105°C. After drying, the sample was weighed and placed in a furnace, where it was ignited at 550°C for four hours. The residue obtained after ignition represents the ash content of the sample, while the difference in weight between the initial dry mass and the residue represents the volatile solids content (Van Wychen & Laurens, 2015).

Crude fibre

Crude fibre is a complex carbohydrate that consists of true cellulose and insoluble lignin. The Crude Fibre (CrF) content of a sample is determined by loss on ignition of the dried residue remaining after digestion of a sample with 1.25% H_2SO_4 and 1.25% NaOH solutions. To determine the CrF content, the sample is placed in a flask and the H_2SO_4 solution is added. The contents are then boiled for 30 minutes and left to rest for one minute. The contents are then filtered, and the residue is transferred to a flask with a boiling NaOH solution for 30 minutes and left to rest for one minute. The residue is then washed, dried, and weighed (Longjan and Zahir, 2018).

Crude protein

The amount of protein present in a sample, known as crude protein, is determined by its nitrogen content. This is analyzed using Kjeldahl's method, which involves assessing the total nitrogen content of the sample after it has been digested in sulfuric acid with a mercury or selenium catalyst. This method is commonly employed for the evaluation of protein content in various organic waste samples, and it is a standard procedure for nutrient analysis in the assessment of biogas potential (Longjan and Zahir, 2018).

Crude fat

Crude fat (OAH) refers to the mixture of fat-soluble materials present in a sample, including the free lipid content. The analysis of crude fat involves extracting the fats from the sample using petroleum ether and evaluating the percentage of the weight before the solvent is evaporated. This method is commonly used for the assessment of the lipid content in various organic waste materials, including food waste, animal manure, and slaughterhouse waste (Longjan and Zahir, 2018).

Nitrogen-free extracts

The nitrogen-free extracts represent the non-nitrogen soluble organic compounds in a sample, which include carbohydrates such as starch and sugar. The value of nitrogen-free extracts was calculated by subtracting the sum of the crude fiber, crude protein, crude oil, and ash from the total solids content (AOAC 2005). This approach is commonly used to assess the carbohydrate content and nutrient composition of organic waste materials, including those used for biogas production. Several studies have employed similar methods to evaluate the biogas potential and nutrient characteristics of various organic waste samples, such as maize cob, slaughterhouse waste, and municipal solid waste, for anaerobic digestion and biogas production.

Biogas Potentials

The theoretical Biogas potentials of the feedstock were determined using the Baserga model (Baserga, 1998), which calculates the theoretical Biogas potential of a substrate based on its nutrient composition. The model requires input data such as crude fiber (CrF), crude protein (CrP), crude oils, ash, and moisture content of the samples. The model assumes that all the organic content in the sample is converted to biogas.

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

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

$VS = (CrP + CrF + OAH + NFE)$ *(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).

RESULTS AND DISCUSSION

Nutritional Composition

The nutrient composition of root and vegetable waste samples was analyzed and is presented in Table 2. The analysis revealed that the samples had a total solid content of 94.70%, indicating the proportion of non-volatile components. The volatile solid content, which represents the organic matter that can be converted into gas, was measured at 87.60%. The crude protein content, a measure of nitrogenous compounds, was determined to be 0.10%. Additionally, the nitrogen-free extract, which includes carbohydrates excluding crude fiber, had a concentration of 5.1%. The crude fiber content, representing indigestible components, was found to be 5.04%. The crude fat content, indicating lipid concentration, was measured at 7.1%. Finally, the ash content, reflecting the inorganic residue after complete combustion, was determined to be 5.3%. These findings are consistent with those reported by Bislava et al. (2021) in their study on Yam peel meal (YPM) and Irish potato peel meal (IPPM). The latter reported similar physicochemical characteristics in Yam peel meal (YPM), with a total solid (TS) content of 95.00%, crude protein (CrP) of 4.38%, crude fiber (CrF) of 7.20%, fat of 2.28%, ash content of 1.60%, and nitrogen-free extract (NFE) of 78.87%. Similarly, the analysis of Irish potato peel meal (IPPM) yielded a total solid content of 96.40%, crude protein of 9.72%, crude fiber of 12.50%, fat of 1.10%, ash of 1.10%, and nitrogen-free extract of 71.96%. These results provide valuable insights into the nutrient composition of food waste samples, which can be used to assess their suitability for biogas production and other renewable energy applications.

Table 2: Nutrient characterization result

Parameters	Percentage
Total Solids (TS)	94.70
Volatile Solids (VS)	87.60
Crude Protein (CrP)	0.10
Nitrogen Free Extract (NFE)	77.00
Crude Fibre (CrF)	5.10
Crude Fats (OAH)	5.04
Ash Content	7.10
Moisture Content	5.30

Source: Authors Computation 2023

Biogas potential

The Baserga model equations were used to determine the biogas potential of waste from roots and tubers. The results showed a biogas potential of 572 L/kgVS, with a methane content of 52%. These findings were compared to a study by Kefas & Undiandeye (2022), who reported a biogas potential of un-ensiled potato peel waste as 216.99 mL/gVS, and 261.06 mL/gVS for silage. Assessing the biogas potential is crucial for identifying promising feedstocks for biogas production and contributing to the development of sustainable and renewable energy sources.

Table 3: Theoretical Biogas

Feedstock	Biogas yield/kgVS	Methane Content (%)
Roots and Tuber	572	52

Source: Authors Computation 2023

Gas yield potential per ton Root and Tuber wastes

The model was also employed to predict the total gas yield obtainable from the complete degradation of fresh organic matter of roots and tubers, resulting in a gas yield of 501 m^3/ton. This finding is significant as it highlights the potential of roots and tuber waste as a valuable feedstock for biogas production. The gas yield values are crucial for evaluating the efficiency of anaerobic digestion processes and optimizing biogas production from organic waste materials.

Electrical Potential

According to Suhartini et al. (2019), the electrical potential estimation was calculated based on the assumption that $1m^3$ of biogas has a calorific value of 22MJ. With an assumed electrical conversion efficiency of 35%, 1 m3 of biogas can yield 2.14kWh of electricity. The total calorific value of 1-ton fresh Root and tuber food waste is given by;

The total biogas yield is $501m^3$

22MJ x $501m^3$ = 11022MJ/ton

The total electricity that could be harnessed from 1-ton fresh roots and tuber food waste is given by;

The total biogas yield is $501m^3$

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

2.14kwh x $501m^3$ = 1072 kWh/ton

This finding when compared with the results reported by Amponsem et al. (2023), who estimated the methane yield for anaerobic digestion to be approximately 224021.24 m^3/yr and the electricity generation potential to be 601870.65 kWh/yr. These findings indicate that root and tuber waste can serve as suitable feedstocks for biogas production and electricity generation.

CONCLUSION

This study aimed to evaluate the potential of roots and tuber waste as feedstock for biogas production and electricity generation. The goal was to address the challenges of increasing energy and food demand, as well as municipal solid waste generation. The nutrient characterization of the waste samples revealed high levels of total and volatile solids, as well as significant concentrations of crude protein, nitrogen-free extract, crude fiber, crude fat, and ash. Using Baserga models, the estimated biogas yield was found to be 572 L/kgVS, with a methane content of 52%. The total biogas obtainable from the complete degradation of fresh organic matter from roots and tuber waste was found to be 501 m^3/ton. Based on the calorific value of the biogas and electrical conversion efficiency, the study estimated an electrical potential of 1072 kWh/ton. These results indicate that roots and tuber waste can be a valuable resource for sustainable biogas generation and renewable energy production. The study emphasizes the importance of utilizing organic waste, particularly roots and tubers, for biogas production to mitigate the environmental impact of escalating municipal solid waste. The findings align with the global need for innovative approaches to waste management and renewable energy sources. However, further research is recommended to explore the actual biogas production outputs of root and tuber waste and optimize the anaerobic digestion process. This research provides valuable insights into the potential of roots and tuber waste as feedstock for biogas production, highlighting its significance in the context of waste-to-energy initiatives and sustainable resource utilization.

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