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# Evaluation of Nigerian Oil Palm Frond Biomass Potential as a Feedstock for Bioenergy Generation

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## ABSTRACT

*Global energy consumption is rising quickly, the world must turn to renewable energy sources. One such renewable energy source that has attracted a lot of interest recently is bioenergy. A key agricultural crop in Nigeria, oil palm. However, the majority of the biomass produced by the oil palm is wasted or underutilised, which has negative environmental effects. This untapped resource could be a great source of fuel for the creation of bioenergy. The purpose of this research is to assess the potential of Nigerian oil palm fronds as a feedstock for the creation of bioenergy. This study used thermogravimetric analysis to reveal the physicochemical properties of the frond sample. According to the results of the proximate analysis, the amounts of volatile matter, fixed carbon, ash content, and higher heating value were 78.78wt per cent, 15.01wt per cent, 6.21wt per cent, and 17.63MJ/kg, respectively. Aluminium, potassium, silicon, sodium, calcium, magnesium, and chlorine were the main inorganic mineral elements found in the biomass ash, whereas phosphorus, sulphur, and iron were found in trace amounts. The feedstock is a potential material for thermochemical conversion to produce bioenergy, according to the results of the thermogravimetric and FTIR analyses, which identified characteristics indicative of energy feedstock biomass sample. This study will contribute to the existing knowledge and research on bioenergy production for sustainable and effective biorefineries that would produce different bioenergy products from Nigeria's palm oil resources.*

Keywords: ***Biomass; Palm Fronds; Biofuel; Thermogravimetric Analysis; Nigeria.***

**1.0 Introduction**

Due to the favourable tropical climate conditions needed for its growth, oil palm is a very significant crop in Nigeria and is primarily grown in the southern parts of the nation. With almost 3.5 million hectares of land dedicated to oil palm plantations, Nigeria is the fourth-largest producer of palm oil in the world [1][2]. Oil palm trees are primarily grown in Nigeria's southern region, where the tropical climate is perfect for the tree's development. The tree may yield up to 10 tonnes of fruit bunches per hectare each year for roughly 25 years during which it can reach a height of 20 meters [3]. The oil palm tree, which can produce up to 10 tonnes of fruit bunches per hectare yearly, is renowned for its tremendous productivity and longevity. Since it is a vital source of food and money for millions of Nigerians, the oil palm is significant both economically and socially in that country. [4][1][5].

The oil palm tree's byproducts, trunks and fonds, are also used in Nigeria for a variety of applications. The fronds are a significant source of feed for animals in Nigeria due to their high nutritional and fibre content. The fronds can be fed to pigs, rabbits, and other animals like cows, goats, and lambs. In addition, compost and organic fertilisers are generated from the fronds[5][1]. In Nigeria, oil palm fronds are also utilised as a raw material for weaving and other handicrafts. The fronds are woven into baskets, mats, and hats, which are sold in local markets and used in homes around the country. The fronds are also employed in building, including the thatching of roofs and the construction of walls. However, it can be difficult to dispose of oil palm fronds in Nigeria. If not correctly handled, a collection of discarded fronds can hinder plant development and lower soil productivity [6][7]. To dispose of the fronds, some farmers in Nigeria have turned to burning them, which adds to air pollution [8][9].

Even though the oil palm frond has a variety of uses, regulating its disposal is essential to ensuring that it is carried out sustainably and without harming the environment [10][11]. When oil palm fronds are dumped carelessly, they can degrade the soil, pollute streams, and pollute the air if they are burned [12]. One of the most important aspects of international efforts to mitigate climate change, improve energy security, and advance sustainable development is the generation of bioenergy from renewable sources. Palm fronds are a plentiful but underutilised resource for the production of bioenergy in Nigeria, one of the countries that produce the most oil palm worldwide. In this paper, we assess the potential of palm fronds from Nigeria as a feedstock for the creation of bioenergy.

According to studies, palm fronds can be converted by a variety of processes, including pyrolysis, fermentation, and gasification, to create bioethanol, biogas, and charcoal. [13][14]. The evaluation of palm oil fronds (POF) as a feedstock for bioenergy production in other parts of the world has been the subject of numerous research studies. This research has looked into a variety of topics related to POF's possible use and efficacy for bioenergy, including its chemical makeup, combustion characteristics, and potential environmental effects. During a study by [15][16], To determine POF's viability as a feedstock for bioenergy production, its chemical makeup was examined. The findings demonstrated that POF contained a high level of lignocellulose, making it an appropriate feedstock for biomass conversion. Additionally, the study discovered that POF had a low ash content, suggesting that it could only generate a little amount of ash during burning. The possibility of POF as a sustainable feedstock for bioenergy production in Malaysia was examined in another study by [17]. Using a thermogravimetric analyzer, the study examined POF's combustion characteristics and discovered that it has a heating value of 18.8 MJ/kg [18]. According to the study's findings, POF has a lot of potential for use in Malaysia as a renewable energy source for electricity generation [19][20]. Some research has evaluated the potential environmental effects of using POF for energy generation in addition to examining the potential of POF as a feedstock for bioenergy. For instance, [21] conducted a study to assess the possible greenhouse gas (GHG) emissions linked to Malaysia's usage of POF for power generation. According to the study, adopting POF as a feedstock might save GHG emissions by up to 4.6 million tonnes annually. The potential of POF as a sustainable and renewable energy source has continuously been shown by research studies on the subject of evaluating POF as a feedstock for bioenergy production [22][23].POF has been discovered to have favourable environmental effects in addition to its chemical makeup and combustion characteristics, making it a promising choice for supplying energy needs in an eco-friendly way[24][25]. Palm fronds are appropriate for use as a feedstock in the production of thermal and electrical energy due to their high energy content. Additionally, using palm fronds as a feedstock for the production of bioenergy has the potential to reduce waste and promote economic growth in nearby communities [26][27].

There is not enough research on the use of palm oil fronds as a bioenergy feedstock in Nigeria [28], despite their promise. The absence of thorough assessments of the physical, chemical, and thermal characteristics of palm oil fronds as well as an evaluation of their potential as a bioenergy feedstock in the Nigerian setting is the primary research gap of this work. To close this research gap and support Nigeria's efforts to establish a sustainable and renewable energy sector, the current study will undertake a thorough examination of the aforementioned factors.

## 2.0 Materials and Method

### 2.1 Material

Oil Palm fronds (Figure 1a), (6 to 8 cm) were collected from Caritas University Enugu, Eastern Nigeria Palm plantation and pre-sundried before being transported in plastic bags for onward laboratory analysis. The materials were further oven dried at 105$^{o}$C moisture content determination according to BS EN 14774-1 standard. The dried materials were then shredded in a rotor beater mill Retsch to particle sizes between 0.2 - 2 mm (Figure 1b) and stored in air-tight plastic bags.


(a) (b)

**Figures 1a:** Oil Palm Fronds **1b:** Shredded oil Palm Frond

**2.2 Feedstock Characterization**

**2.2.1 Volatile Matter and Ash Content Analysis**

Volatile matter and ash content on a dry basis was determined according to BS EN 15148 and BS EN 14775 respectively[29]. In the ash content analysis, the ceramic crucible was first ignited at 550$^{o}$C for 60min in an electric furnace to eliminate any organic materials present in it. Approximately 1.00g of the biomass sample was charged into the Ignited crucible after cooling and placed inside the furnace set at 550$^{o}$C for 60min. At the end of the process, the crucible and the resulting ash were weighed and the percentage of ash formation was computed accordingly. For the volatile matter determination, a crucible with a lid was used and ignited at 950$^{o}$C for 7min in the furnace. Similar to the ash content determination, approximately 1.00g of fresh sample was placed in the ignited crucible with lid and charged into the furnace set at 950$^{o}$C for 7min. subsequently, the volatile matter content was computed from the mass difference between the sample and the resulting mass at the end of the process. The fixed carbon was computed by subtracting the percentage compositions of ash and volatile matter from the bone-dry sample mass[30][31].

**2.2.2 SEM/EDX Analysis of Oil Palm Frond Ash**

The elemental composition of the ash was analysed using energy dispersive X-ray (EDX). The ash sample was placed on the carbon tape of the sample holder and positioned in the sample compartment of the X-ray. Scanning of the sample was conducted under low vacuum and the inorganic components present in the ash were recorded[32].

**2.2.3 Higher Heating Value (HHV) Determination**

Higher heating value (HHV) was determined using an oxygen bomb calorimeter Parr 6100 following BS EN 14918[33]. Nearly 1.00-2.00g of the sample was pelletised and placed in the metal crucible. Ignition wire in a U-shape was hung on the bomb cover and positioned appropriately with the tip of the wire touching the sample. The bomb cover was then fixed to the bomb container with the sample arrangement inside. Subsequently, the closed bomb was pressurised with purified oxygen until the pressure reached the desired set point. The pressurised bomb was inserted in a 2.0L container with water in it and the system was closed. The bomb calorimeter was set on until the process was completed. The value of heating value from the system display was read and recorded[34].

**2.2.4 Elemental Compositions of Biomass**

Elemental compositions of the biomass were determined using a CHNS analyser, LECO Corporation USA[32]. Biomass samples are first collected and prepared for analysis. The samples are typically dried, ground, and homogenized to obtain a representative sample. The CHNS analyzer is calibrated using standard reference materials with known elemental composition. This ensures accurate and precise measurement of the biomass elemental composition. The system uses high-temperature combustion to convert biomass into its constituent elements – carbon (C), hydrogen (H), nitrogen (N), and sulfur (S). The analyzer generates data on the elemental composition of the biomass sample. The data is then analyzed to determine the percentage of each element in the sample. The results are reported as a percentage of the total elemental composition of the sample. This information is critical in determining the suitability of biomass as a renewable energy source and for the optimization of processes that use biomass as a feedstock

**2.2.5 Thermogravimetric Analysis**

The thermogravimetric study was carried out in thermogravimetric analyser (TGA) Perkin Elmer Simultaneous thermal analyser (STA) 6000 (Figure 2) in a nitrogen atmosphere, flow rate 20 mL/min at temperatures between 30 – 1000$^{o}$C and heating rate of 10, 15 and 20$^{o}$C /min[35].

**Figure 2**: Photograph of DTA-TGA equipment. (STA Instruments).

### 2.2.6 Structural Composition Analysis

The structural composition of the biomass was determined according to NREL/TP-510-42618[36].

NREL/TP-510-42618 is a standard laboratory analytical procedure for determining the compositional analysis of biomass. The method involves three steps: extraction, hydrolysis, and analysis. The biomass sample was first extracted with ethanol, to remove the extractives, soluble sugars, and other low molecular weight substances. The remaining biomass sample is then hydrolyzed using acid or enzymatic hydrolysis to convert cellulose and hemicellulose into their respective monosaccharides. The solid fraction is analyzed for the acid-insoluble residue (AIR) content, which is the remaining lignin and ash content. The NREL/TP-510-42618 method was used to determine the structural composition of oil palm frond biomass. The information obtained from this method can be useful for optimizing the production of biofuels and other bioproducts from oil palm fronds.

### 2.2.7 Fourier Transform Infrared Spectroscopy (FTIR) Analysis

The nature of functional groups in the frond sample was evaluated by Fourier transform infrared spectroscopy (FTIR) using the PerkinElmer Spectrometer Spectrum RX1 instrument (Figure 3) using the potassium bromide (KBr) method. The translucent KBr discs (13 mm diameter) were made from homogenized 2 mg samples in 100 mg KBr using a CARVER press at 5.5 tons for 5 min. Spectra were recorded with the Spectrum V5.3.1 software within the wavenumber range of 400–4000 $cm^{-1}$ at 32 scans and 4 $cm^{-1}$ resolution[37][38].

All the experiments were repeated in triplicate and average values were recorded within the 3% standard deviation.

**Figure 3:** Photograph of FTIR Instrument

## 3.0 Result and Discussion

### 3.1 Proximate, ultimate and structural analyses

Proximate, ultimate and structural analysis results are shown in Table 1. Moisture content in the sample as received in the laboratory was 11.71 wt%. This property is an important parameter as it affects biomass quality, storage and handling especially if it is to be converted via thermochemical process. Initial moisture in the biomass takes up heat from the system and vaporizes and later condenses in the bio-oil which leads to a lower value of HHV. Volatile matter on a dry basis was found to be 78.78 wt% while the ash content and heating value recorded for the sample was 6.21 and 17.63 MJ/kg. These characteristics are similar to those of high-valued biomass reported in the literature. The high volatile matter in the sample indicates the easier conversion of the sample when subjected to thermochemical conversion. The result of the ultimate analysis revealed that the oil palm frond sample has 42.88 wt% carbon, 5.92 wt% hydrogen and 41.71 wt% oxygen. Similarly, the water-soluble extractives, cellulose, hemicellulose and lignin content recorded was 5.08, 41.22, 23.60 and 30.10 correspondingly.

**Table 1**: Proximate and Ultimate Analysis Oil Palm Frond Biomass

| **Properties** | **Value** |
|---|---|
| **Proximate analysis (wt%)** | |
| Moisture content (MC) | 11.71 |
| Ash content (AC) | 6.21 |
| Volatile matter (VM) | 78.78 |
| Fixed carbon (FC) | 15.01 |
| HHV (MJ/kg) | 17.63 |
| **Ultimate analysis (wt%)** | |
| Carbon (C) | 42.88 |
| Hydrogen (H) | 5.92 |
| Oxygen (O) | 41.71 |
| O/C | 0.97 |
| H/C | 0.14 |
| **Structural composition (wt%)** | |
| Extractives | 5.08 |
| Cellulose | 41.22 |
| Hemicellulose | 23.60 |
| Lignin | 30.10 |

**3.2 SEM / EDX Analysis**

The SEM image (Figure 2) showed that the ash particles had irregular shapes and sizes. It provided valuable insights into the surface morphology and composition of oil Palm frond ash, highlighting its potential as a feedstock for bioenergy generation. The EDX analysis of oil palm frond biomass ash as a potential feedstock for bioenergy generation showed promising results. Elemental mapping of the ash from the EDX analysis based on the scanning response intensity (Figure 4) showed mainly the presence of aluminium (Al), potassium (K), silicon (Si), sodium (Na), calcium (Ca), magnesium (Mg) and chlorine (Cl) while phosphorus (P), sulphur (S) and iron (Fe) are in trace amount. The investigation also revealed that the ash contained significant amounts of silica and potassium. The investigation also showed that the ash had a high carbon content, suggesting that it might be exploited as a source for producing bioenergy. The high carbon concentration of the ash might be used to create biochar, a useful soil additive that can also be burned. According to the analysis, biomass ash from oil palm fronds has a lot of promise as a feedstock for bioenergy production and other industrial uses, making it a valuable resource for sustainable development.

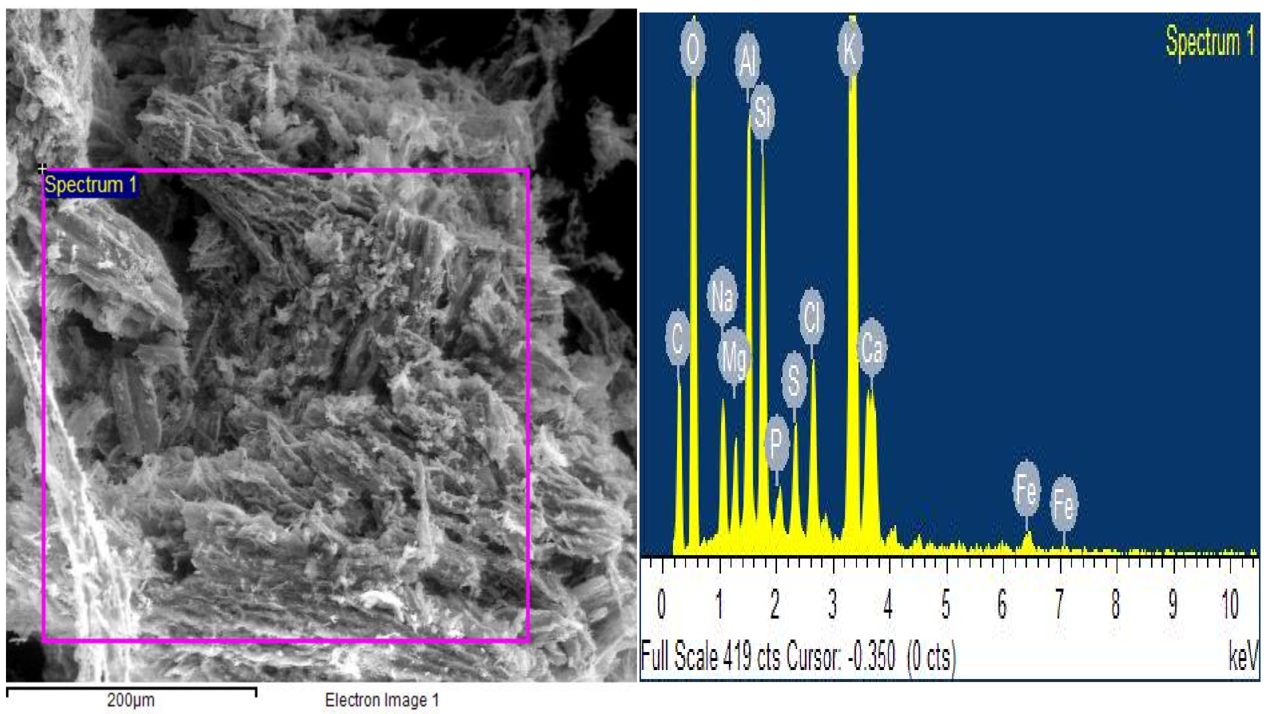


**Figure 4**: EDX-SEM analysis of oil palm frond ash

### 3.3 Thermogravimetric Analysis (TGA)

A helpful method for examining the thermal behaviour of biomass materials is thermogravimetric analysis (TGA). TGA analysis was used in this study of biomass ash from oil palm fronds to evaluate its thermal stability and combustion properties, which helped to determine its potential as a feedstock for bioenergy production. The findings revealed that the ash had a high degree of thermal stability and experienced a significant weight loss at temperatures above 600 °C. As a result, it seems that the ash would be suitable as a feedstock for high-temperature bioenergy production techniques like gasification or combustion. The oil palm frond biomass ash combustion behaviour also demonstrated that the burning of the ash was rapid and complete, with a high mass loss rate at temperatures above 500°C. This suggests that the ash could be used as a fuel to produce energy during combustion operations.

The thermogravimetric analysis (TGA) results in Figures 5a-d below also showed the thermal decomposition of various components in each oil palm frond. Three distinct regions concerning the decomposition temperature (<200$^{o}$C, 250-400$^{o}$C, and >400 $^{o}$C). The weight loss recorded on the TG curve under the 200$^{o}$C decomposition temperature could be attributed to the drying and devolatilization of extractives as identified in the structural analysis (Table 1). At 250-400$^{o}$C, a visible shoulder and maximum degradation peak were observed which correspond to the decomposition of hemicellulose and cellulose respectively. Beyond 400$^{o}$C, it signifies the decomposition of lignin. No noticeable peak was observed in the lignin decomposition region. Consequently, it can be deduced that the lignin content of oil palm frond has uniform thermal decomposition. The maximum degradation peak identified under each heating rate corresponds to the reaction intensity with values of 6.98 wt%/$^{o}$C, 10.49wt%/$^{o}$C and 13.16 wt%/$^{o}$C for 10, 15, and 20 $^{o}$C/min respectively. This suggests that increasing the heating rate favours rapid biomass decomposition, which in turn promotes volatile generation. This observation is an indication that the oil palm frond sample is a good candidate for thermochemical conversion, particularly pyrolysis and gasification. Based on the TGA analysis results, it can be concluded that oil palm frond biomass ash has good potential as a feedstock for bioenergy generation.

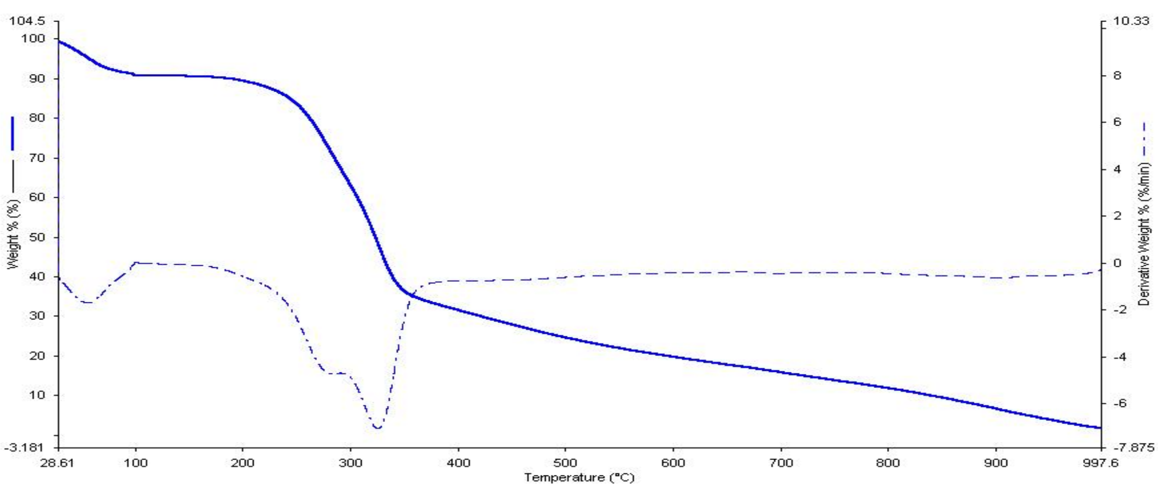


**Figure 5a:** TG and DTG of frond ash sample at 10 $^{o}$C/min under 20ml/min nitrogen flow

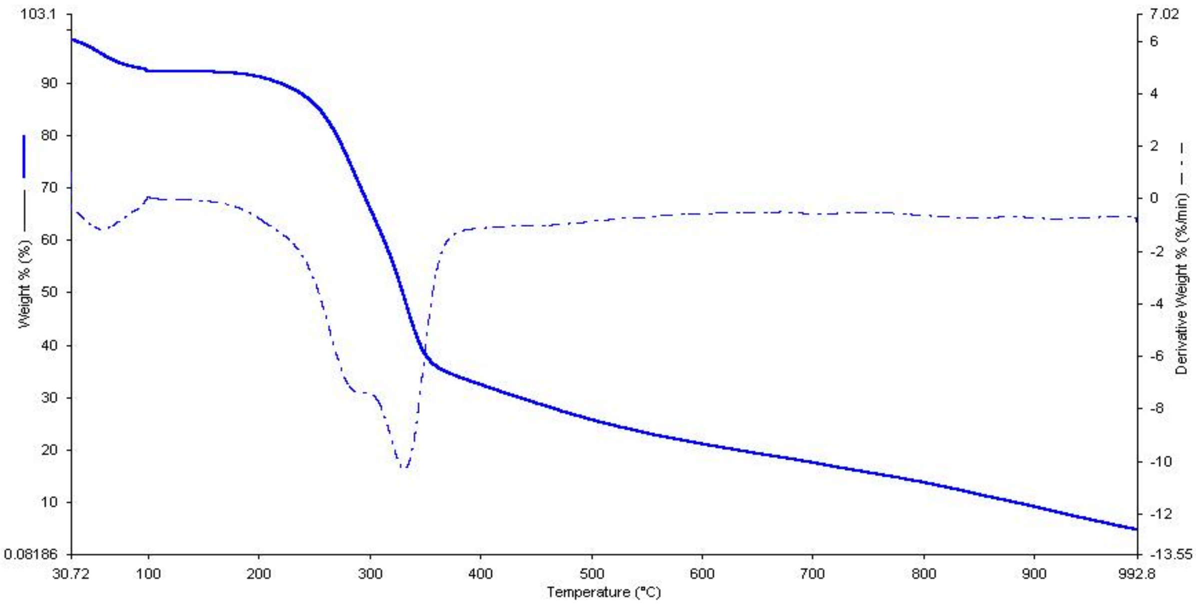


**Figure 5b:** TG and DTG of frond ash sample at 15 $^{o}$C/min under 20ml/min nitrogen flow

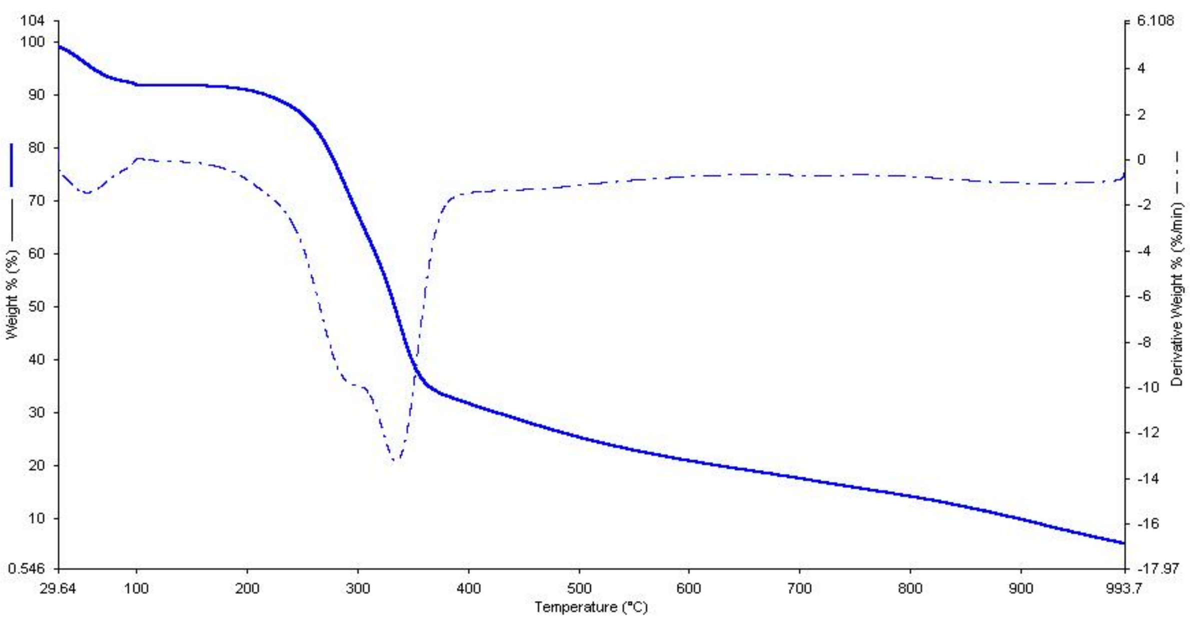


**Figure 5c:** TG and DTG of frond ash sample at 20 $^{o}$C/min under 20ml/min nitrogen flow

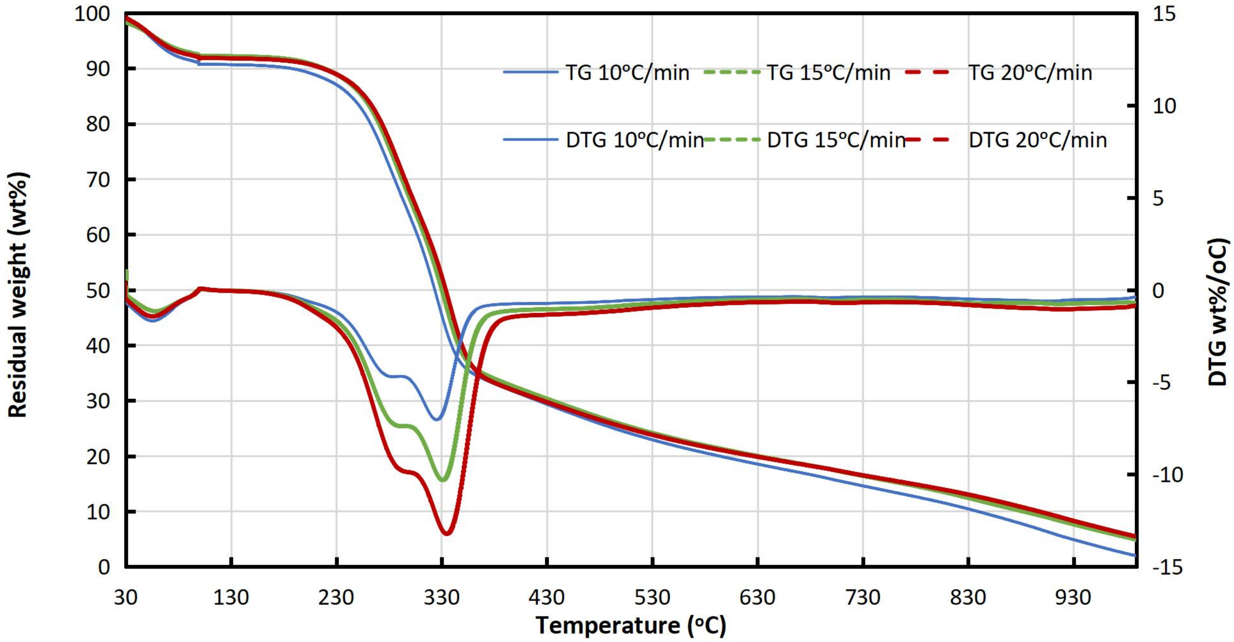


**Figure 5d**: Synthesized TG and DTG of frond ash sample at 10, 15, 20 °C/min under 20ml/min nitrogen flow

### 3.4 Fourier Transform Infrared Spectroscopy (FTIR) Analysis

An effective method for assessing the chemical makeup of the ash is the FTIR study of oil palm frond biomass ash potential as fuel for bioenergy generation. This research assisted in identifying the elements that were present in the ash, which may affect the feedstock's ability to burn during the production of bioenergy. By exposing the biomass ash to infrared radiation, the chemical functional groups in the sample determine how much of the radiation is absorbed by the ash. Information such as the presence of carbonates, phosphates, silicates, and other inorganic compounds can be found in the spectrum produced by the study. In order to determine potential pollutants in the feedstock, the chemical composition of the biomass ash from oil palm fronds was analysed using FTIR.

It was helpful to pinpoint certain components that can affect the effectiveness of bioenergy production, such as the presence of excessive potassium levels, which might cause corrosion and fouling of the combustion equipment. The averaged FTIR spectrum (Figure 6) shows various characteristic peaks for the biomass samples, with a region of high frequency between 4000 $cm^{-1}$ and 2300 $cm^{-1}$ and a region of low frequency between 1626 $cm^{-1}$ and 400 $cm^{-1}$ which indicates the possible presence of different alkyl, aromatic, alcohol, ester and carbonyl functional groups originating from the extractive, hemicellulose, cellulose and lignin components of all the biomass. In the high-frequency region, peaks in the samples between 3700 $cm^{-1}$ and 3421 $cm^{-1}$ could be attributed to a different hydroxyl group (alcohol/phenol) stretching vibrations. The band at 2937 $cm^{-1}$ could be a result of aliphatic saturated C-H stretching vibrations (asymmetric and symmetric methyl and methylene stretching groups) from extractives and lignin components of the biomass since fatty acid methyl esters and phenolic acid methyl esters have methyl and methylene groups. In the fingerprint region, the band at 1600 $cm^{-1}$ may be due to the ring-conjugated C=C bonds of lignin while the band observed at 1200 $cm^{-1}$ may be an indication of O-H bending in the cellulose and hemicellulose components of the biomass. The frequency at 1,050 $cm^{-1}$ may be ascribed to C-O, and C=C, and C-C-O stretching in cellulose, hemicelluloses and lignin while the bands between 800 and 600 $cm^{-1}$ may be attributed to aromatic C-H bending vibrations from the lignin in the samples. FTIR analysis of oil palm frond biomass ash potential as feedstock for bioenergy generation is a useful technique. It provided valuable information about the elemental and chemical composition of the ash, which would be useful in the optimization of the combustion process to increase the efficiency of bioenergy generation.

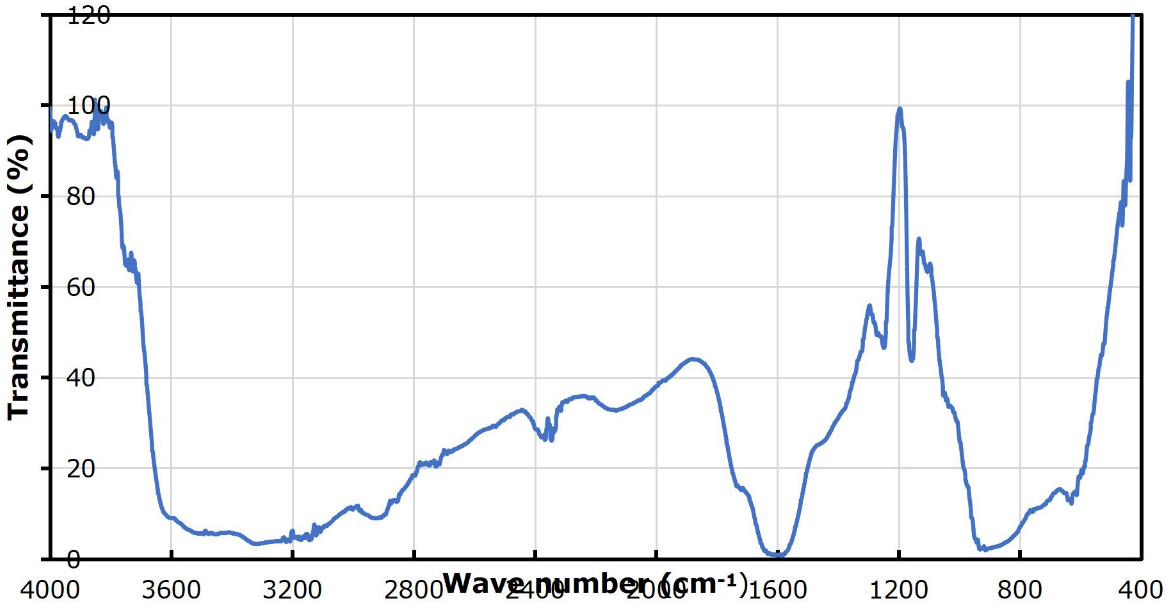


**Figure 6**: FTIR spectrum of Oil Palm frond Ash sample

## 4.0 Conclusion

In the eastern portion of Nigeria, oil palm fronds are one of the most common agricultural leftovers that go unused and have almost no uses. In this study, oil palm fronds were examined for their potential in the production of bioenergy. The results showed a feature typical of a biomass sample, indicating that the feedstock is a promising material for bioenergy production through thermochemical conversion. It offers several advantages. These advantages include the advancement of renewable energy sources, the decrease in reliance on fossil fuels, the promotion of environmental sustainability, and the opening up of waste management prospects. Additionally, the study can support the growth of the national economy, assist in making decisions that will increase energy security, and produce useful data on the quality and properties of biomass that may encourage the production of advanced biofuels. The study's conclusions may therefore help Nigeria by lowering its carbon footprint, boosting its energy security, and fostering more sustainably based economic activity. The potential use of Nigerian palm fronds as a feedstock for bioenergy production must be properly controlled to ensure sustainable and environmentally friendly procedures. Establishing rules and regulations that will direct the use of palm fronds in the production of bioenergy, may entail designing proper harvesting methods, encouraging conservation measures, and so on. Further study on the best pretreatment techniques for palm oil fronds is advised to improve their energy yield and quality and to shed light on the effects of various pretreatment procedures on the bioenergy produced from this feedstock.

**Declarations**

**Ethics approval and consent to participate**

Not applicable

**Competing interest**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

**Authors contributions**

**E M E, I Y M:** Conceptualization, Methodology, Original draft preparation, Performed experimental work, and Writing

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**Availability of data and material**

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