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Original Research Article

Sustainability of Alternative Energy Sources: Thermo-Gravimetric Analysis of Energy Crops in Ekiti State, Nigeria

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Abstract: Ekiti State is a farming region with the ability to produce biomass reserves, which include yet refined crop cultivation product leftovers like sugar cane, corn cobs, palm husk shells, and okanagan wood, for use as fuel. The vast energy-generating potential of crops for use in industry and household applications is examined in this article. Biomass crops were subjected to a thermogravimetric examination to determine their unique thermal activity in an airtight and benign atmosphere with a temperature increase of 10°C per minute up to 800°C. The decrease in weight pattern was shown to be similar across all four waste specimens. Three reactive regions were identified during the nitrogen-rich environment assessment, which correlate to water loss, flammable generation, and char breakdown. Three response domains in an air system corresponded to the degradation, burning, and drying of char. The proximate and ultimate evaluation outcomes demonstrated that each of the bioenergy crop leftovers under investigation is fit for gas extraction and fuel combustion to meet power and thermal needs. The computational and experimental analysis revealed that Okanagan wood has the highest calorific value which indicates the highest heat values and considered the best for biomass energy production in Ekiti State for entrepreneurial venture.

Keywords: Airtight and Nitrogen Atmosphere, Bioenergy, Calorific Value, Crop residues, and Entrepreneurial venture.

I. INTRODUCTION

Global warming is the result of a steady increase in oxygen and carbon monoxide (CO_2) releases to the outside world, mostly from the burning of fossil fuels. The pursuit of alternative energy sources is essential to reducing CO_2 emissions and promoting a greener environment. In order to capture energy from some renewable sources, such wind and water power plants, biomass must be thermally utilized. Sustainable fossil fuels contribute to a reduction in greenhouse gases, as during a crop's growing period, an equal amount of CO_2 is collected from the atmosphere [1]. Biomass is a readily available, socially acceptable, and carbon-neutral energy source. It has the ability to meet the world's expanding demand for sustainable and renewable energy sources. Thus, by reducing greenhouse gas emissions and diversifying the world's energy sources, it is anticipated that humanity's transition from fossil fuels to renewable energy technologies (RET) will improve environmental sustainability. A biomass substitute that is both environmentally benign and economically feasible, as well as a source of income for the people of Nigeria, must be looked into immediately [2, 3].

The need for environmentally friendly energy sources with minimal carbon footprints has led to a search for new bioenergy resources. However, there are issues with transportation, storage, and lower energy densities when using biomass fuels. Energy density can be adversely affected by low density values, which raises the cost of storage and transportation. By densifying the biomass, pellets can be used as an alternative biomass source and their energy quality is increased while reducing the volume of biomass. They are mostly created from crop plants and a variety of biomass resources. As a way to ascertain the fuel's suitability for the combustion process and its transportation characteristics, it is important to evaluate its properties under all circumstances [4]. The most promising options for fuel from biomass include the use of woodland and agro-wastes, like straw and wood chips, in addition to the production of energy crops, including whole cereal plants, willows, and fodder grasses, for energetic uses [5, 6]. It is vital to analyze the carbon dioxide and oxide, overall gasoline content, and particles released during the breakdown of plant matter and burning of energy crops for generating hydrogen gas. The gas generated (H_2, CO, CO_2, CH_4, etc.) may be used in gas turbines, internal combustion engines, and other forms of machinery [7, 8].

The thermogravimetric analysis (TGA) method measures the sample's weight loss rate in relation to temperature and time, offering valuable insights into the thermal degradation processes involved in thermo-chemical conversion in different atmospheric conditions [9, 10]. Energy crops are trees that grow fast and some grasslands that are grown especially for energy generation. Non-edible plants are grown in difficult conditions in order to generate energy once food sources and energy-producing crops outnumber farmland usage [11, 12]. The main plant species used in the production of bio fuel include switchgrass (Panicum virgatum), miscanthus (Miscanthussp), canary grass (Phalaris arundinacea), alfalfa (Medicago sativa), and giant reed (Arundo donax). Global recognition of the significance of energy crops for the production of electricity or biofuels is currently underway [13, 14].

Residues from the agricultural industry might be a significant new supply, but their quality and seasonality have made them less appealing from an economic standpoint. Only a relatively small percentage of wastes are burned in industry, and the majority come from byproducts like bark or sawdust. Energy crops, virgin wood, agricultural residues, solid wastes, and commercial products are common fuels used in energy production [15]. The plant-based biofuels used in the commercial generation of steam can be essentially divided into three groups: agronomic fuels (bagasse, straw, grasses, stalks, etc.), wood and wooden fuels (hard and softwood, implosion lumber), and wastes (sewage sludge, waste from the paper and food sectors) [16]. The fuel's thermal value determines how much energy is given off upon burning. The amount of air required to burn a specific quantity of fuel and the amount of combustion gases produced throughout the operation are then determined by the fuel heating effectiveness. Provided that all the combustion processes are finished and that no excess oxygen stays behind, the ideal air desire equals the balanced air required. Excess air is needed during industrial biomass burning in order to drive the process almost to completion. However, the decrease of practicable surplus air in biomass burning is limited by the generation of hazardous pollutants [17].

A common food and commercial crop in many developing countries, including Nigeria, is maize (Zea mays). In addition to being grown for commercial purposes, maize contributes for about 11 million tons of agricultural production annually in Nigeria, where it is estimated that 49.7% of households grow it. On the other hand, the processing and growing of maize produce a lot of solid waste, or stover, which consists of the leaves, stems, and cobs, which make up more than half of the plant's bulk [18]. Nigeria currently lacks the technology necessary to convert corn cobs into energy. The biomass classification of maize cobs is lignocellulos; they are distinguished by the tight blending of cellulose (45% to 55%), hemicellulose (25% to 35%), and lignin (20% to 30%). As seen in Figure 1, high biomass-generated electricity from maize cob pellet conversion capacity might substitute for the current bulk fuel oil utilization by producing high-producing crops (about 3-5 tons/ha) [18, 19].

A transient manufacturing facility that is essential to the sugar market is sugar cane. There were 37 sugar mills in the nation, with an aggregate production of 1.3 million tons. Sugar cane plantation and yields is shown in Figure 2. Harvested sugarcane is delivered to the factory together with a variety of residues and by-products (bagasse and cane trash) for processing into sugar. Bagasse is used by some sugar mills in their combined heat pump boilers to provide heat and electricity for internal usage. About 70–80% of the cane waste is left in the field during the harvesting process, with the remaining 20–30% being transported to the mill together with the sugarcane stalks as extraneous matte [20].

Originating in West Africa, the oil palm (Elaeis guineensis) is one of the largest and most significant economic activity in Nigeria related to the production of palm fruit. Palm oil and palm kernel oil are produced by these fruits. The "Palm Belt," as seen in Figure 3, is an area of roughly 70,000 square miles that offers ideal growing conditions for wild palm oil. Palm kernel shells are biomass with the ability to process a raised calorific value, which when combined with other physical-chemical properties, turns them into a fuel that can be used in specific plants or, if no facility modifications are needed, combined with coal in a conventional thermos-electrical station for combustion [21].

Figure 4 illustrates why Okanagan Douglas Fir wood pellets are among the most desirable available compared to other wood pellets: they burn hotter, take more time, and are fresher. The bar for ultra-high-quality gasoline pellets has been set by this. Wax, plastic, chemicals, and reclaimed wood are not used in it. This product's extremely low ash content means that sanitation and upkeep of the stove, boiler, or furnace are reduced [22].

Wood biomass is a small byproduct of gasification or direct combustion of wood that can be transformed into energy, solid fuel by pelletizing, or liquid fuel by a variety of other processes. In Nigeria, biomass is consistently and extensively accessible as a sustainable energy source [23, 24].

Figure 1: Maize and Maize Cobs

Figure 2: Sugar Cane

Figure 4: Okanagan Wood

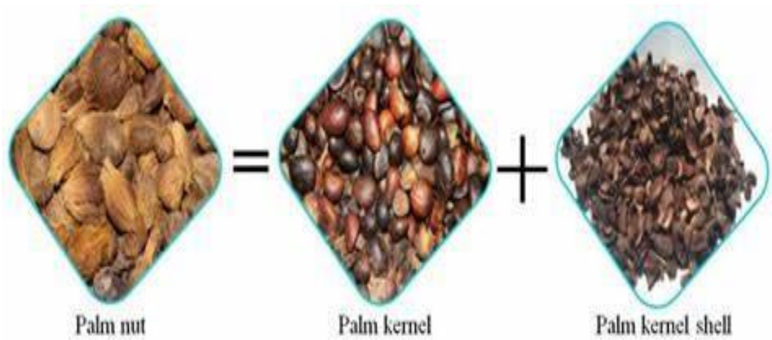

Figure 3: Palm Kernel Shell

Carbon-free, less expensive than fossil fuels, decreasing over-reliance on fossil fuels, providing a source of income for manufacturers, and reducing the amount of waste dumped in landfills are just a few benefits of biomass energy [25]. Energy plant cultivation could be a good substitute for wood from short-rotation forests, although several studies have described how these plants degrade thermally. Thermo-gravimetric analysis (TGA) is a method for examining how biomass materials behave thermally. The research focused on analysing the physical and chemical characteristics of maize cobs, sugar cane, palm husk shell, and okanagan wood, including its moisture content, carbon percentage, ash value, and volatile substance, due to its numerous advantages, availability, and long-term viability.

II. MATERIALS AND METHOD

The investigation requires sugar cane, kananagan wood, palm kennel shell, and maize cobs as its main natural components. Thermo-Gravimetric Analysis (TGA) is a technique used for investigation and assessment.

On four resource crops—corn cobs, sugar cane, palm kennel shell, and okanagan wood—the study project performs a thermogravimetric examination. As energy-rich crops are pyrolyzed using an aerobic process, it measures the extent of heat deterioration in each stage, recovers the reaction variables, and counts the vapor discharges and PMs. The identified physiochemical properties were analyzed and compared among their moisture content, carbon percentage, ash value and volatile matter for the four selected energy crops to determine the most viable and sustainable energy crop with the highest heat value. A biological fundamental scanner was utilized to ascertain the samples' CHNOS (carbon, hydrogen, nitrogen, oxygen, and sulfur) information, and an oxygen bomb calorimeter was employed to scientifically determine the matching net caloric values.

Samples of Okanagan wood, sugar cane, maize cobs, and palm kennel shells were gathered from the Ekiti State University Agricultural Research Farm in Ado, Ekiti State. Every sample was crushed into tiny particles (3-5 mm) before examination. The specimens were examined in order to identify the primary characteristics that influence the thermal transformation prior to thermogravimetric analysis (TGA). Using the oven draining procedure, the gravimetric estimation for each sample's water content was performed. With the use of an adiabatic oxygen bomb calorimeter, higher heating values (HHV) at a steady volume were measured. Conventional analytical techniques were followed to make scientific and proximate measurements. Every test was run threefold to guarantee consistency. The Thermo-Gravimetric Analyzer (TGA) in use is depicted in Figure 5.

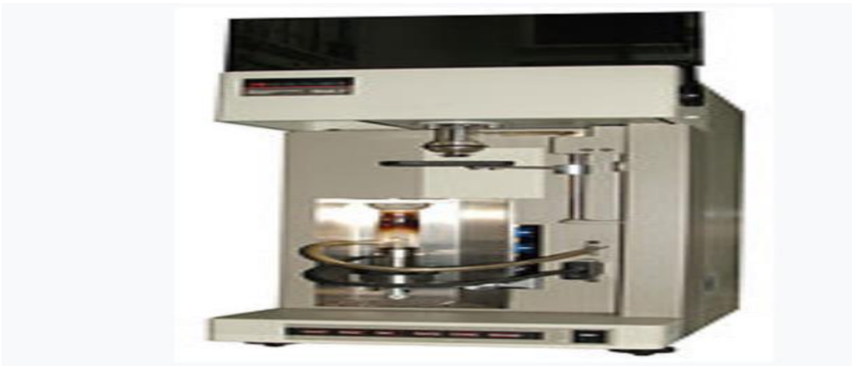

Figure 5: Thermo-Gravimetric Analyzer

TGA measures the thermal stability of materials including polymers. Changes in the weight of the specimens were measured as their temperatures increased. For analytical purposes, the following biomass-related parameters were measured and documented: evaporated water, decarboxylation throughout pyrolysis, solvent and plasticizer reduction, oxygenation, flammability, and breakdown.

A. Gas Emissions (GE) and Particulate Matter (PM) Analysis

An infrared analyzer (BI-NOS 100, ROSEMOUNT) was used to continually quantify the mucous membrane concentrations of carbon dioxide oxides (CO_2 and CO) at the TGA outlet. Applying a Flame Ionized Detector (FID, NGA 2000, ROSEMOUNT), all the compounds were examined. Every ten seconds, the demonstration's incertitude for measuring gas was documented, along with the chemical nature of the gas.

B. Thermo-Gravimetric Kinetic Approach

Equations 1, 2, and 3 were utilized to calculate the kinetics of the response variables. Here are the vitalization reaction's broad mechanics.

$$\frac{dx}{dt} = -kx^n \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

$$k = Ae^{-E/RT} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

$$L_n\left(-\frac{1}{w_o-w_f}\right)\frac{dw}{dt}=nL_n(A)-\frac{E}{RT}+\left(\frac{w-w_f}{w_o-w_f}\right) \quad \ldots\ldots\ldots\ldots\ldots 3$$

Equation 4 contains the simple linear expression for equation 3.

$yP + xQ + zR$ ………………. 4

Where x is the sample mass, n, the order of the reaction, and k, the reaction constant, represent the initial mass at the beginning of the process and, the mass that remains at the peak of it, respectively. w_f, the mass at any given moment; the shift in mass over time variation ratio; R, the universal gas constant; and A, the preexponential factor.

Where; $y=L_n\left(-\frac{1}{w_o-w_f}\right)\frac{dw}{dt}$, $x = 1/T$, $z = L_n\left(\frac{w-w_f}{w_o-w_f}\right)$, $P = L_n(A)$, $Q = -\frac{E}{R}$, $R = n$

Constants P, Q, R were estimated by multi-linear regression of the TGA data for each stage.

With the use of geographic applications, the possible uses for specific bioenergy agricultural waste were assessed. Both the low melting point and the high concentration of neutral and alkaline earth debris were impacted. At a temperature of 10°C/min, thermogravimetric examination was performed on palm kernel shell, Okanagan wood, corn cob, and bagasse in an environment with air and pure nitrogen. At temperatures lower than 150°C, humidity was removed. The first breakdown of bioenergy was seen between 200°C and 380°C in an atmosphere without oxygen and between 200°C and 350°C in an air atmosphere. Because the ingredients of Okanagan wood and palm kernel shell had larger ash contents than corncob and bagasse, the leftovers from the subsequent breakdown of biofuels in an inert setting constantly erupted over 400°C. The temperature ranges where the separation and char burning took place were 190–369°C and 340–500°C, respectively. Activated energy, timing factor, and reaction sequence were among the kinetic variables that were assessed during the thermal disintegration of palm kernel shell and palm oil fronds in TGA.

III. RESULTS AND DISCUSSION

Over the course of the assessment, the weight reduction and DTA signal were noted. The psychological, chemical, and caloric characteristics of biomass-derived energy were categorized. The estimation of condensation, prone to volatility matter, thermal value, dirt component, melting temperature, predetermined carbon material, and the final evaluation pertaining to the carbon, hydrogen, and oxygen makeup of the elements were all registered during the proximate analysis of the biomass-based fuel samples. The outcomes are listed in Table 1. Sugar cane had a moisture content of 13.17% when it was air dried, which is greater compared to 7.73% of palm oil shell, corn cob (7.77%), and okanagan wood (5.59%), which is the lowest. The ash level of Okanagan wood and the palm kenell shell is considerable, ranging from 3–4%. While Okanagan wood had an explosive content of 109.9%, palm kernel shell had a hazardous content of 81.03%. In both samples, the fixed carbon content was roughly 15%. The rice husk's proximity measurement matched the findings of S.J. Yoon *et al*., (2015). The moisture content of bagasse was 13.17%, while that of air-dried corn cob specimens was 7.77%. Each of the samples had minimal ash contents and comparable explosive matter, at roughly 74%. Bagasse had a fixed carbon content of 9.43% and maize cobs of 15.6%.

Table 1: Proximate and Elemental Analysis of Agriculture Residues.

Characteristics	MC	SB	PKS	OW
Moisture (%-air dry)	7.77	13.17	7.73	5.59
Volatile matter (%- air basic)	74.86	76.03	81.03	91.90
Ash (%-air basic)	1.77	1.36	4.10	3.20
Fixed carbon (%-air basic)	15.60	9.43	14.87	19.10

The analysis of the information gathered from the final examination of carbon, hydrogen, and oxygen is presented in Table 2. The biomass examined had a carbon content below 50 percent and a significant amount of oxygen in its chemical structure, which lowers the energy value. In Table 3, the main compositions were SiO2, CaO and K2O while Al2O3, Fe2O3, MgO appeared with small amount. When contrasted to crop residues, the SiO2 level of the corn cob sample was lower, but the K2O content was almost 29.58% of the ash. One important factor in ensuring a biomass gasifier operates effortlessly is the ash content, specifically the substantial proportion of alkaline oxide. According to the statistics, bagasse and maize cob had the greatest calorific values (17.36 MJ kg-1) out of all the materials that were evaluated. Table 4 showed the thermal degradation of biomass in nitrogen environment where bagasse has 10.4% water loss compared with corn cob of 7.2% at temperature range 209 to 381°C. The total weight loss was found high in bagasse with 17.8% whereas corn cob lost 14.6 %. Contrary to the increase trend, 20.8 % residual weight was 20.8% compared with 12.1% of bagasse. It implies that, weight loss in nitrogen environment favored corn cob than bagasse as clearly showed in Table 3. It was observed that, water loss content in corn cob with 9.9% is high compared with 9.2 % of bagasse. Thermal degradation of biomass in air environment where there is similar behaviour pattern of corn cob and bagasse in nitrogen environment is as presented in Table 5. The residue weight loss in thermal degradation is much high in residual weight of 3.7 % in corn cob than 1.7 % of 1.7 %.

Table 2: Results of Ultimate Analysis on MC, SB and PKS

Characteristics	Maize Cob	Sugar Bagasse	Palm Kernel Shell
Carbon (%-dry Basic)	49.50	49.80	49.65
Hydrogen (%-dry basic)	4.90	5.9	6.13
Oxygen (%-dry basic)	43.85	43.91	43.33
LHV	17.00	17.36	17.05

Table 3: Results of Ultimate Analysis on MC and SB

Characteristics of Maize Cob and Sugar Bagese							
Ash (% Mass)	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O
Maize Cob	51.88	1.3	4.27	4.17	1.85	0.37	29.58
Sugar Bagase	87.85	3.63	3.87	2.12	0.61	0.14	0.52

Table 4: Thermal Decomposition of Biomass in Nitrogen Environment

Samples	Water Loss (%)	Temperature range (ºC)	Weight loss (%)	Temperature range (ºC)	Weight loss (%)	Residual weight (%)
Corn Cob	7.2	209-351	56.6	351-800	14.6	20.8
Bagasse	10.4	230-381	58.7	381-800	17.8	12.1

Table 5: Thermal Decomposition of Biomass in air Environment

Samples	Water Loss (%)	Temperature range (ºC)	Weight loss (%)	Temperature range (ºC)	Weight loss (%)	Residual weight (%)
Corn Cob	9.9	214-340	75	340-465	9.075	3.7
Bagasse	9.2	190-369	77	369-490	11.484	1.7

The graph of the proximate analysis that characterized the residue contents are shown in Figure 6 to 9. Figure 10 is a graphical representation of the combined tested residues as depicted by the proximate analysis. As a result, the non-isothermal weight reduction (TG) profiles for the four biomass samples tested at 10°C min-1 in a nitrogen environment demonstrated comparable heating action. This study's goal was made concrete by the identification of three separate phases of losing weight. Figure 7 presents the DTA trends of the biomass thermally characterized in the air climate at a temperature rise of 10°Cmin-1 as well as the TG profiles of the biomass specimens heated by 10°Cmin-1 in an air setting. The graph clearly shown that Okanagan wood is the crop with the highest calorific heat content, followed by maize cob. It is deduced that the crop with the least heating value is sugarcane.

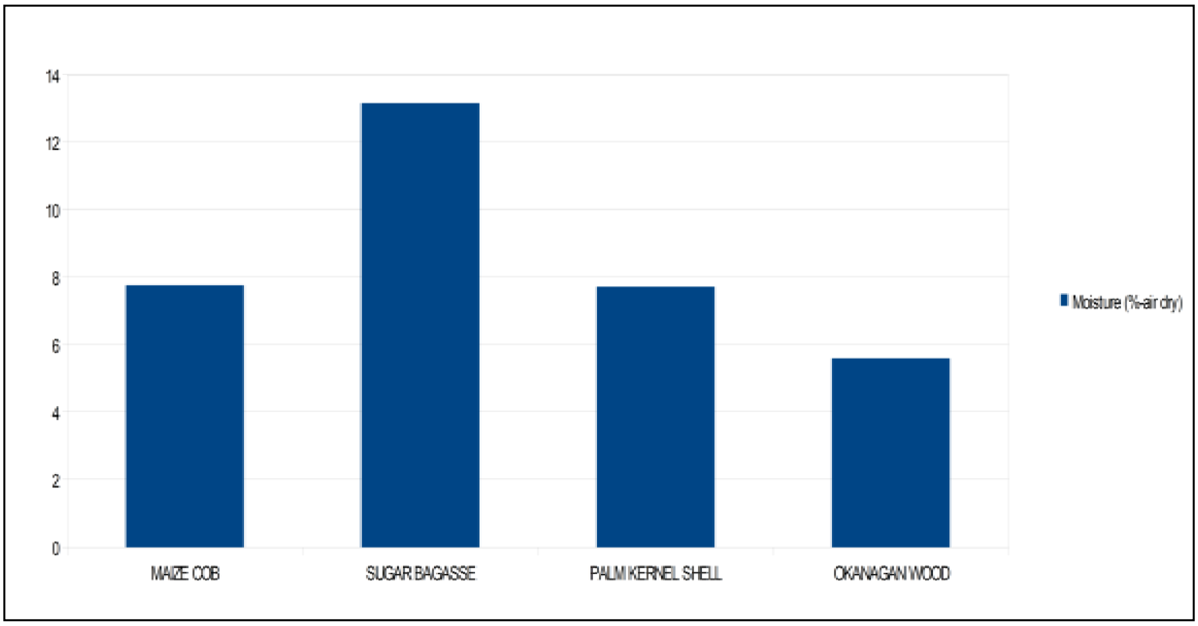

Figure 6: Moisture (%-air dry)

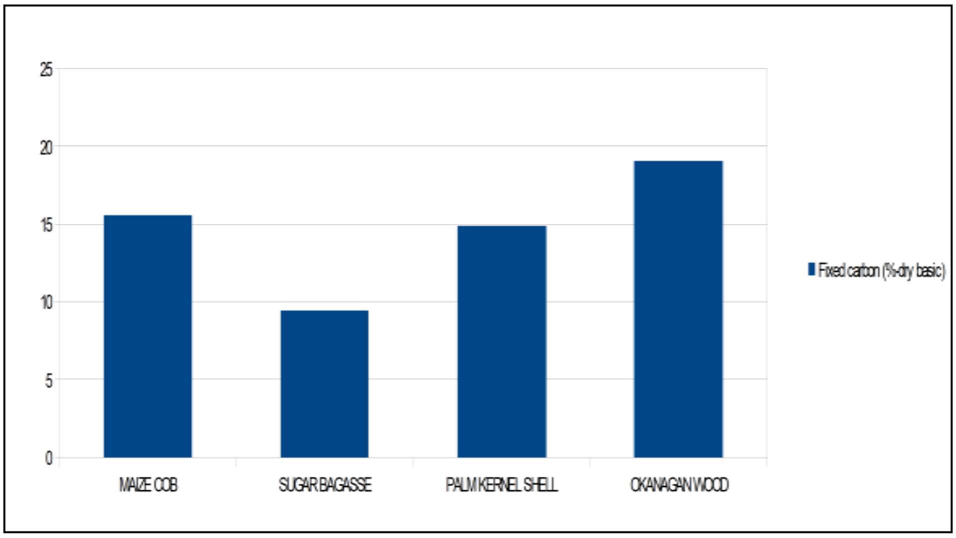

Figure 7: Fixed carbon (%-dry basic)

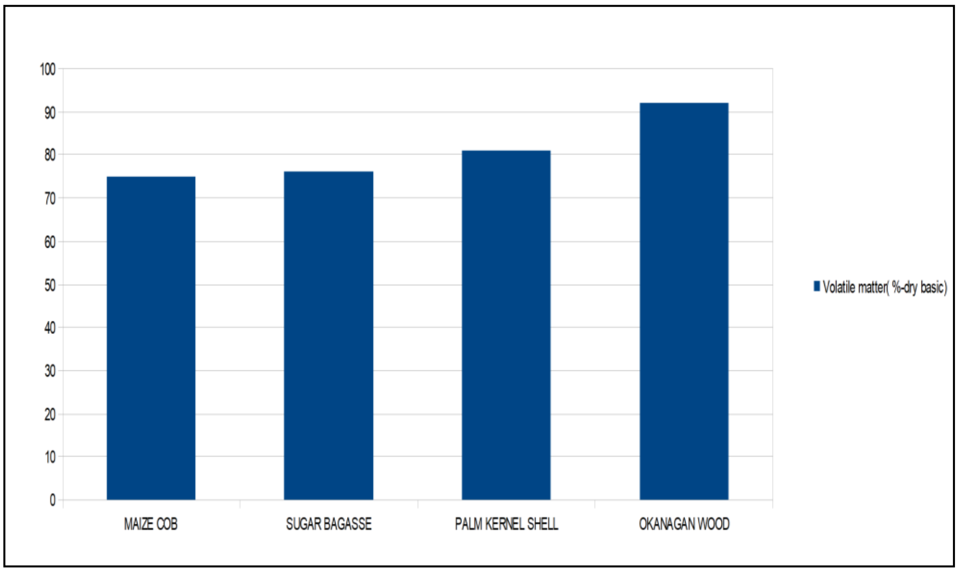

Figure 8: Volatile matter (%-dry basic)

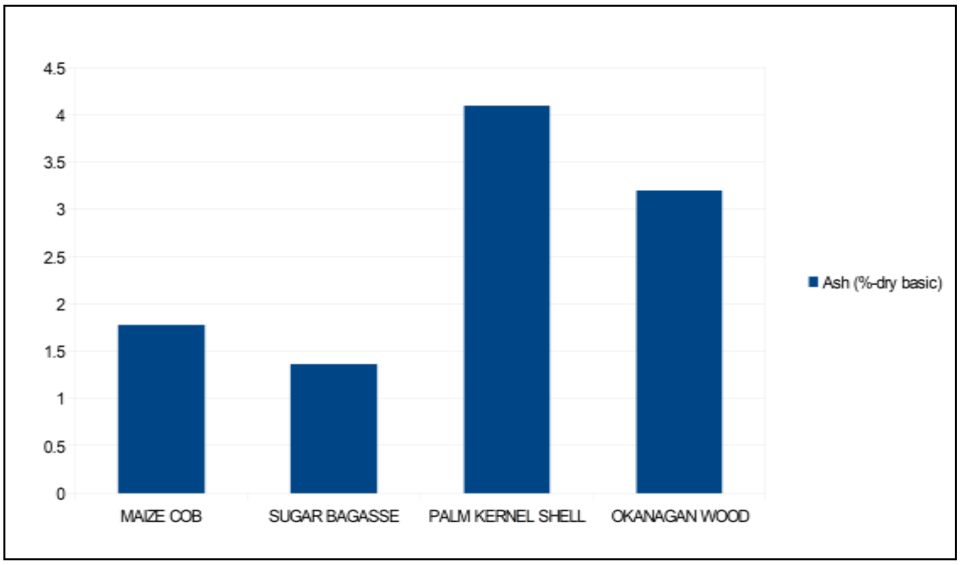

Figure 9: Ash (%-dry basic)

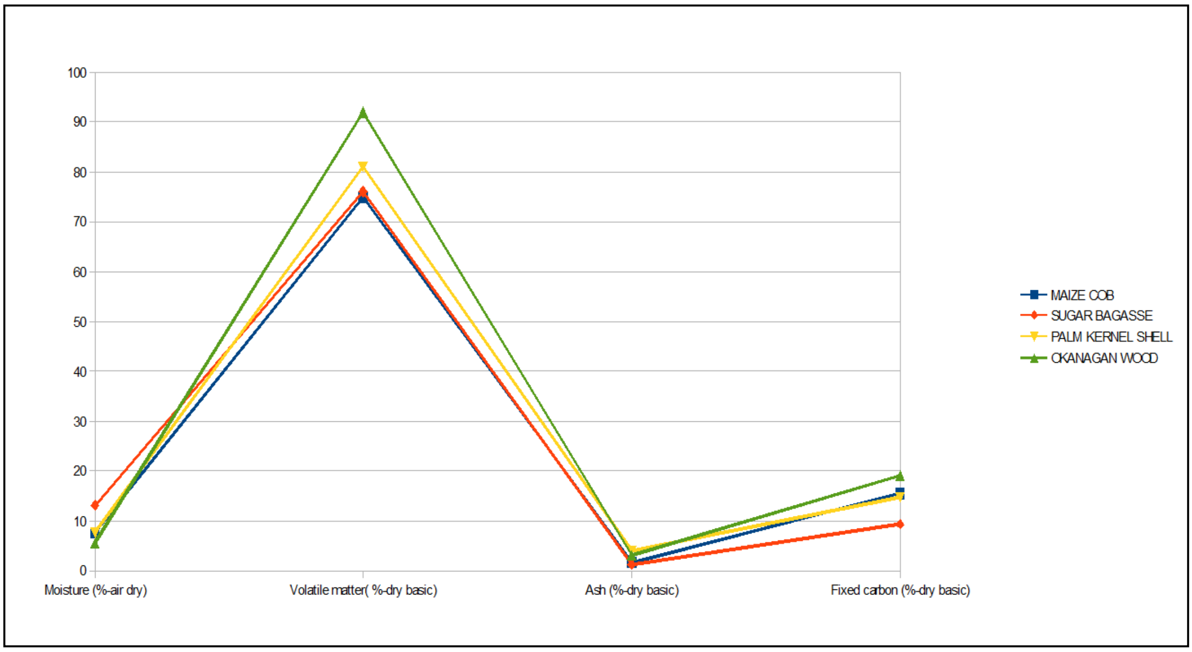

Figure 10: MC, SC, PKS and OW Calorific Heat Content

The biomass, which consisted of palm kernel shell and palm oil fronds, was thermally decomposed for the purpose of identifying the degradation zones and determining the kinetic characteristics, such as energy of activation, periodicity factor, and reactivity ordered. The break-down patterns indicated that for the two palm oil wastes, hemicellulose would breakdown at 280–300 °C and cellulose at 340–360 °C. There was no lignin breakdown seen, which was in line with previous research. In comparison to corn cob, sugar cane, bagasse, and Okanagan wood, PKS appeared to decompose at a faster pace. The breakdown patterns of palm oil wastes matched the kinetics of the initial-order actions well. The analysis identified the effect of frequency and activated energy as the two main variables, both of which are found to be smaller than the values documented in the published work.

IV. CONCLUSION

The purpose of this investigation is to provide information to Nigerians who wish to generate power from energy crops using biomass, specifically on which crop the specimen has the greatest value for heat production. This information will help the engines—steam or turbines—work more efficiently and effectively when producing electricity. All combustible crop wastes under investigation are suitable for conversion or burning to meet energy and heating needs, according to the proximate and ultimate assessments. Results from both the computational and experimental methods revealed that Okanagan wood has the highest calorific value which indicates the highest heat values (HHV) and considered the best for biomass energy production in Ekiti State. The following recommendations are made.

i. Okanagan trees should have its separate forestation plan in Ekiti state for the purpose of renewable biomass energy production for the state.
ii. Legislative laws should be made against deforestation of Okanagan and palm trees in Ekiti state.
iii. The Government of Ekiti state should encourage biomass energy production for the purpose of electricity generation.
iv. The populace of Ekiti state should be educated on the usefulness of the Okanagan tree in terms of biomass energy generation.

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