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Research Article

Characterization of Lignocellulosic Biomass Samples in Omu-Aran Metropolis, Kwara State, Nigeria, as Potential Fuel for Pyrolysis Yields

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Abstract. This study deals with a preliminary investigation of biomass samples' physicochemical, structural composition, and thermal properties to aid the appropriate selection of biomass utilized for pyrolysis operation. The proximate, ultimate, structural composition and thermal analyses were conducted using seven lignocellulose biomass samples obtained in Ajase market, Ajasse Ipo, Kwara State, Nigeria, and Omu-Aran, Kwara State, Nigeria. Results showed that the average moisture contents (MC) ranged from 0.12 to 0.44%, and volatile matter (VM) ranged from 73.70 to 83.82%. Fixed carbon (FC) varied from 12.79 to 22.80%, and Ash contents varied between 01.20 to 5.52%. Similarly, the average carbon contents ranged from 45.11 to 50.00%. Hydrogen contents ranged from 5.38 to 6.15%, nitrogen contents varied between 0.20 to 1.24%, and oxygen contents from 43.79 to 48.51%. Also, sulphur contents varied between 0.01 to 0.19%, while the biomass species' average cellulose, hemicellulose, and lignin contents ranged from 28.34 to 45.80%, 25.83 to 34.01%, and 21.96 to 49.63% respectively. The high percentage of VM, C, H, HHV, ignitability index, cellulose, and hemicellulose content recorded in the biomass samples would enhance devolatilization reactivity, ignitability, and burn gases in the reactor, as well as a good production of hydrocarbons content during the pyrolysis process. Also, the low ash content would prevent harmful chemical deposits in the reactor during the pyrolysis process. It can be deduced that shea butter wood was best suited for biofuel generation, closely followed by sugarcane bagasse and palm kernel shell. At the same time, corn cobs possessed the least properties for the pyrolysis process.

Keywords: Lignocellulose biomass; Proximate analysis; Ultimate analysis; Structural composition; Heating value; Thermal properties

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1. Introduction

Energy plays a vital role in most human activities; it is the premise of industrial civilization. However, without energy, the modernization of our life and cities would not have been actualized (Onokwai *et al*., 2019). Previously, the demand for energy sources was minimal because it was primarily utilized for cooking, heating, and transportation. However, the increase in population growth rate and technological advancement necessitated more energy demand. This high energy demand warranted the quest for different energy sources, though some have an advanced effect (Maksimuk *et al*., 2021; Nnodim *et al*., 2022). For instance, fossil fuels constitute the primary energy resource used to generate power for technological development and advancement since the industrial revolution. Nevertheless, there were consequential effects. Studies have shown that the volume of pollutants produced by fossil fuels is the sequel to their usage on the high side. This constitutes a health hazard to the public and the environment. Therefore, researchers proceeded to generate energy via alternate renewable sources to overcome the 'Energy Crisis.' Among renewable energy sources, biomass energy offers a practical solution (Onokwai *et al*., 2019; Onokwai *et al*., 2019) because it offers about 13%. Share in the global energy mix in 2016, which is the most significant renewable energy source (Okonkwo *et al*., 2019).

More attention has been drawn to biomass, among other renewable sources of energy known to mankind, due

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to its ability to produce biochar, bio-oil, and biofuel, which reduce the energy crises beclouding mankind and environmental hazards caused by the utilization of fossil fuel for electricity generation. Biomass can be generally considered the collection of a composite mix of biological materials that include proteins, lignin, fats, and carbohydrates in starch, hemicellulose, and cellulose (Oladejo *et al*., 2020). Nwosu *et al*. (2015) reported a variation of similar lignocellulose biomass due to geographical location. The intrinsic component of the biomass, soil type, and climatic conditions where the biomass samples are sourced and cultivated.

The degradation of biomass into bio-oil, biochar, and syn-gas involve a completely thermochemical conversion process, such as pyrolysis, liquefaction, gasification, torrefaction, and carbonization (Akintola *et al*., 2019). Banerjee *et al*. (2021) optioned that improper determination of the physicochemical properties of lignocellulose biomass samples would lead to low quality and quantity of pyrolysis yields. Rajamma *et al*. (2009). emphasized the need to investigate biomass's thermal degradation and decomposition behaviour before selecting them for thermochemical conversion to enhance their yields.Thermogravimetric analysis (TGA) helps to determine the weight loss of the biomass samples as a function of temperature (Balogun *et al*., 2021) and a distinct characteristic such as the thermal behavior of biomass (Gajeraa *et al*., 2020). Ozyuguran *et al*. (2018) opined that HHV is not only utilized for the design and operation of biomass conversion system but also aid the selection of biomass as fuel for the thermochemical conversion process. Furthermore, the disposal of ash obtained from the thermochemical conversion process of lignocellulose biomass contaminates underground water resources due to heavy metal leaching due to poor. Hence, this leads to respiration health problems and reduces the soil's fertility (Bonfim and De-Paula, 2021).

However, different researchers have characterized some of the biomass samples under investigation. This shows a lack of information on the physicochemical and thermal properties of biomass sourced in Omu-Aran metropolis, Kwara State, Nigeria. This study investigates the characterization (proximate, ultimate, structural composition, and thermal analysis) of lignocellulose biomass to ascertain their energy potential. For use as a fuel for optimum pyrolysis yields and reducing environmental pollution during the pyrolysis process.

2. Materials and Methods

2.1 Source of Materials

Seven lignocellulose biomass samples, namely shea butter wood, bamboo, palm kernel shell, corn cobs, lemon grass, and obeche wood, were sourced locally from the sawmill and palm oil mill. The local farm in Omu-Aran, Kwara State, Nigeria ($8^0 08' 18.85'' N$ Latitude and $5^0 06' 9.36'' E$ Longitude) while Sugarcane bagasse and Sugarcane straw were obtained from Ajasse Ipo, Kwara State, Nigeria ($8^0 13' 60'' N$ Latitude and $4^0 49' 0'' E$ Longitude).

2.2 Pretreatment

The biomass samples were pretreated by cleaning, crushed, and sieved to various particle sizes with a diameter (d_p) of 0.1-0.2mm, 0.2-0.4mm, 0.4-0.6mm, 0.6-0.8mm, and 0.8-1.0mm to enhance densification (Osueke *et al*., 2019; Kshirsagar and Kalamkar, 2020). The crushed samples were sun-dried for five days (5h/day) to remove the surface and residual water. Also, it later separated from contaminants such as stones and other foreign objects (Gautam and Chaurasia, 2020), before storing them in zip-locked polyethylene bags at ambient temperature for characterization and pyrolysis experiment.

2.3 Physicochemical Analysis

2.3.1 Proximate Analysis of Sun-Dried Powered Biomass

Carbolite muffle furnace (Model: CWF1223-230SN+&02-3216P1) in Biochemistry Laboratory, Landmark University, Omu-Aran was used to determine the proximate analysis (MC, FC, VM, Ash). According to ASTM E 1358 – 97 standards, the moisture content was determined. About 0.5 g of oven-dried biomass samples were transferred into an empty crucible. The mass of the crucible plus biomass was weighed and recorded. The samples were heated in a muffle furnace at 105°C for 2hrs. The Volatile matter (VM) was determined using ASTM E872-82 by weighing an empty crucible and then placing 1g of each biomass in a muffle furnace, maintained at 900°C for 8 min all through. Finally, the weight was measured and recorded. Deploring ASTM standard ASTM D1102-84, the biomass ash content (AC) was evaluated using a muffle furnace. 1g of biomass sample was measured into a silica crucible and later transferred into a muffle furnace, maintained at 105^{o}C for an hour. The crucible was transferred into the desiccator to cool down to room temperature. After that, the crucible was transferred into a muffle furnace charged at 585^{o}C for 3 h. The fixed carbon (FC) was determined by difference, which is FC=100-(MC%+VM%+AC%) as suggested by (ASTM E 1358 – 97, 2006; ASTM D1102-84, 2007; ASTM E872-82, 2006)

2.3.2 Ultimate Analysis of Sun-Dried Powered Biomass

Carbon, Hydrogen, and Nitrogen contents were determined using LECO CHN 2000 Elemental Analyzer based on ASTM D5373-21 standard. 0.5g of the sample was measured into a crucible charged into a GenLab oven maintained at 105^{o}C for 1 h and encapsulated in a thin foil to fit into the LECO CHN 2000 Elemental Analyzer. After that, the sample was transferred into the purge chamber of the furnace, maintained at 1300^{0}C for 7 min. The sulphur content was determined using ASTM D4239-11 by placing 2 g of the biomass in a flame photometer and maintaining it at a temperature greater than 1000°C, after that, the sulphur detector detected the sulphur present. Finally, the Oxygen component was determined by difference (100-C%+H%+N%+S%+Ash%) as suggested by (ASTM D5373-21, 2016; ASTM D4239-11, 2011)

2.4 Structural composition analysis of sun-dried powered biomass

The extractive content in the biomass was determined by first adding 100 mL of acetone used as a solvent for extraction into a 2 g of oven-dried raw biomass (A) placed into a cellulose thimble. The boiling and rising of the mixture were carried out at 70°C for about 20 min. The sample was dried in a Genlab oven for 2 h and maintained at a temperature range of 105-110°C until a constant weight was attained (B). The number of extractives was determined using Eqn. (2) as proposed by (Mansor *et al*., 2019).

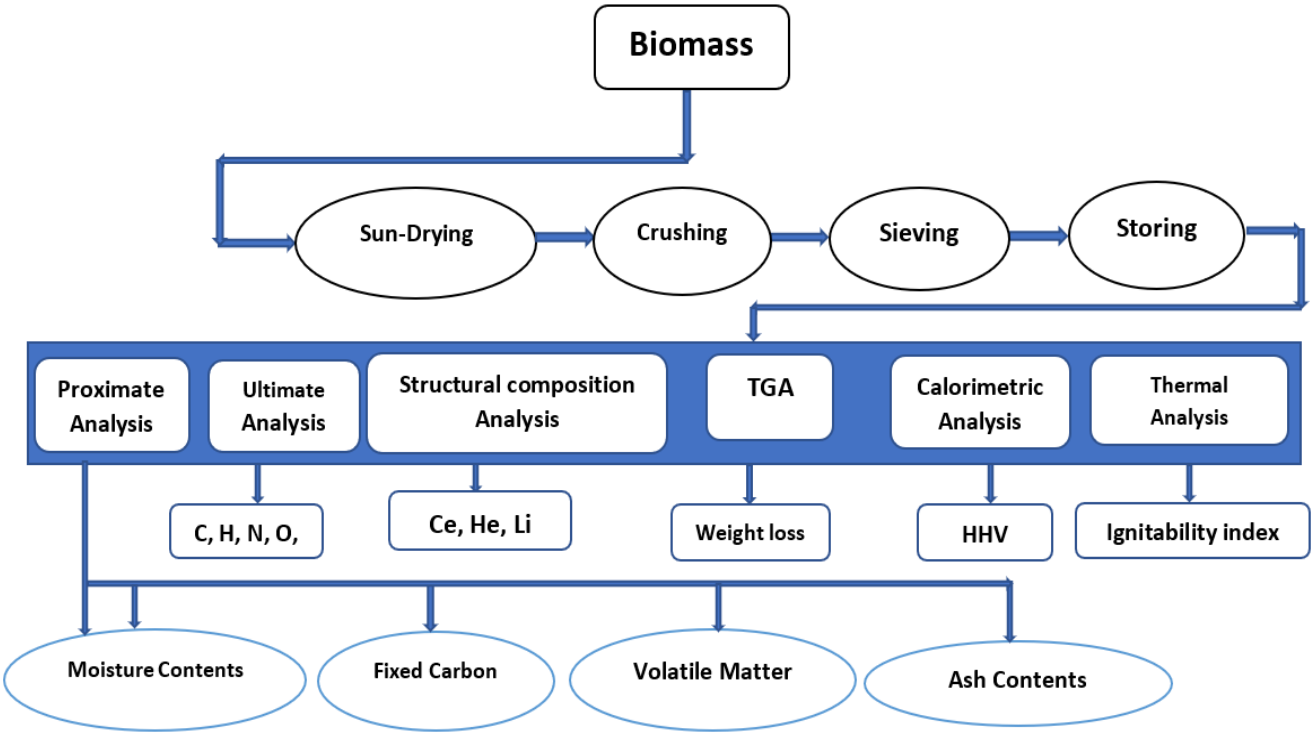

Fig. 1. Pretreatment and Characterization of Biomass Processes

The hemicellulose content was obtained by adding 150 mL of 500 mol/m^3 sodium hydroxide (NaOH) into an extractive free (B) biomass sample. The mixture was boiled with distilled water at a temperature of 80°C for 3.5 h. After that, the sample was filtered via vacuum filtration and then washed with deionized water until neutral pH was attained, freeing the sample from Na+. The sample was finally oven-dried to a constant weight (C) at 105-110°C. The amount of hemicellulose content was determined using Eqn. (3) as proposed by (Adeleke *et al*., 2020). The lignin content was determined by adding 3mL of 72% sulphuric acid (H_2SO_4) into an extractive free (B) biomass sample. The sample was kept at atmospheric temperature for 6 h, then stirred very well at 30 min intervals to ensure complete hydrolysis, then boiled at a temperature of 100°C for 1 h. After that, the sample was filtered via vacuum using a filtering crucible and then washed with deionized water until there was no more detection of SO^{4+} via titration process with 10% of BaCl solution. The sample was finally oven-dried to a constant weight (D) at 105-110°C. The final weight is recorded as lignin content. The cellulose content is obtained by difference, assuming that the biomass sample consists of extractives, hemicellulose, lignin, and cellulose only.

2.5 Thermogravimetric analyses (TGA) of sun-dried powered biomass

The biomass samples' thermal degradation and decomposition behaviour were investigated using a thermogravimetric analyzer (Model: TGA 55). Approximately 3 mg of each biomass was loaded into the crucible. The samples were heated in the TGA analyzer from 30 ^{0}C to 800 ^{0}C at a steady heating rate of 10^{0}C/min under an inert environment of a continuous nitrogen flow rate of 80ml/min (Merdun and Laouge, 2020).

2.6 Heating value analysis of sun-dried powered biomass

The higher heating value (HHV) was obtained using the ASTM D2015-00 standard. 2g of biomass sample was measured into a crucible and then placed in a high-pressure oxygen atmosphere metallic cylinder (bomb) at a current temperature (25°C). The results were then displayed on the Mohan Brothers bomb calorimeter (Plate 5g). The LHV was calculated from HHV using eqn. (1) as proposed by (ASTM D2015-00, 2000; Merdun and Laouge, 2020).

$$LHV\ (MJ/kg) = HHV - (0.218 \times H) \quad (1)$$

Where LHV = lower heating value of fuel in MJ/kg; HHV= higher heating value of fuel in MJ/kg, and H = weight % of hydrogen in fuel

2.7 Evaluation of Ignitability index (I_I)

The pretreatment of the biomas processes and it characterization is presented in Fig. 1. The fuel ratio and ignitability index of the sun-dried biomass samples were determined using Eqn. (2) respectively, as reported by (Adeleke *et al*., 2020).

$$I_1 = {}^{(HHV - 81FC)}/_{VM + MC} \quad (2)$$

Where, HHV = Higher heating value; FC = Fixed carbon; VM = volatile matter; MC = Moisture contents, I_I = Ignitability index

3. Results and Discussion

3.1 Proximate Analysis

The average values of the proximate analysis of lignocellulose biomass samples are presented in Table 1. The percentage of moisture contents (MC) ranged from 0.12 to 0.44%, volatile matter (VM) ranged from 73.70 to 48.80%, fixed carbon (FC) varied between 13.60 to 22.50%, and ash contents varied between 1.20 to 3.52%. The VM (88.04%) obtained for obeche wood (Table 1) in this study is moderately higher than the 81.42% reported by (Adeleke *et al*., 2020) for woody biomass. The proximate analysis obtained from corncob (Table 1) shows that the VM (79.87%) is approximately equal to 77.14%, as reported by (Kartal and Ozveren, 2021). Similarly, the value FC (15.39%) in this study is within the same range reported by [59], whose values are 17.0%. The moisture contents in all the lignocellulose biomass (Table 1) are less than 0.5% due to excessive drying of the biomass in an oven at a temperature of 105°C for 1h before characterization. These results are similar to those (Ayeni *et al*., 2018; Gautam and Chaurasia, 2020) who reported approximately zero percent for moisture contents on an oven-dried basis. The low moisture contents were recorded to make them suitable for the pyrolysis process since less energy would be needed to vaporize the biomass in the reactor and enhance the thermal energy generated and conversion efficiency during the process. Obeche wood (88.04%) has the highest volatile matter, closely followed by sugarcane bagasse (83.82%) and shea butter wood (82.92%). At the same time, the palm kernel shell possesses the lowest volatile matter. The high volatile matter of Obeche wood, sugarcane bagasse, and shea butter wood would increase the heating value, devolatilization reactivity, ignitability, and burn gases in the reactor, thereby leading to a high bio-oil and non-condensable gases yields (Kpalo *et al*., 2021). Bamboo has the highest ash content (5.52%), making it unsuitable for pyrolysis. An increase in the percentage of ash content would reduce the amount of bio-oil yield due to catalytically cracking of the bio-oil into non-condensable gases (NCG) and low biochar yield. Also, the low ash contents in shea butter wood, sugarcane bagasse and plam kernel shell help reduce harmful chemicals (e.g., slag, fouling, corrosion, etc.). During the pyrolysis process, the reactor further minimizes extensive maintenance of the pyrolysis plant (Nagarajan and Prakash, 2021). Hence, making them favourable for the pyrolysis process. The high fixed carbon (FC) present in palm kernel shell and lemon grass would enhance the time to yield biochar and bio-oil due to the high energy released. The variations in the results, when compared with previous studies, are due to geographical location, the intrinsic composition of the biomass, soil type where the biomass is sourced and cultivated (Acevedo *et al*., 2019).

3.2 Ultimate analysis

Table 2 shows the average values of the ultimate analysis of lignocellulose biomass, whose carbon contents ranged from 40.35 to 51.23 %; hydrogen contents ranged from 5.02 to 6.15%. Nitrogen contents varied between 0.10 to 2.95%, oxygen contents from 42.66 to 54.08% and sulphur contents varied between 0.01 to 0.60%. The biomass carbon, hydrogen, nitrogen, oxygen, and sulphur contents of each biomass sample are presented in Table 2. Comparing this study with various research, the carbon contents (45.11%) of bamboo obtained in this study closely agreed with the values of (Gautam and Chaurasia, 2020) 45.9-46.3%. Similarly, the hydrogen contents of 5.91% in this study fall in the same range as 5.74% reported, as shown in Table 2. The value obtained from corncobs whose carbon, hydrogen, nitrogen, oxygen, and sulphur contents are 47.18, 6.03, 0.22, 46.34, and 0.23%, respectively. Sugarcane bagasse has a high carbon and low oxygen, nitrogen, and sulphur contents, making them more useable for the pyrolysis process. Their low nitrogen and sulphur, and nitrogen contents make them more suitable for pyrolysis due to their high tendency to emit harmful gases that might enhance the formation of NOx and SOx into the atmosphere when burnt Nagarajan and Prakash, 2021). The biomass samples' low sulfur and nitrogen contents indicate that they can produce environmentally friendly fuel due to their low emission of SOx and NOx gases that plants can utilize during photosynthesis.

3.3. Structural composition analysis

The average structural composition analysis (Table. 3) shows that the biomass species' cellulose, hemicellulose, and lignin contents ranged from 12.95 45.80% to 11.72 36.72%, 7.12 49.63%, respectively. The values of cellulose, hemicellulose, and lignin contents obtained for woody/forestry biomass (Table 3) fall within the range of values for hardwood reported by (Nwosu and Muzakir, 2015; Roger *et al*., 2021), whose values are (Ce: 45.4%, He: 26.0%, Li: 23%). The cellulose (Ce) value of sugarcane bagasse (Table 3) agreed well with the report of (Nwosu and Muzakir, 2015). Similarly, the hemicellulose and lignin contents correlated very well.

Table 1
Proximate Analysis (Oven-Dried basis)

Sample	MC (%)	VM (%)	FC (%)	Ash (%)
Bamboo	0.41 ± 0.04	80.40 ± 0.90	13.04 ± 0.12	5.52 ± 0.02
Obeche wood	0.37 ± 0.05	88.04 ± 0.4	9.08 ± 0.04	2.51 ± 0.02
Shea butter wood	0.29 ± 0.03	82.92 ± 1.17	15.89 ± 0.45	0.90 ± 0.01
Corncob	0.44 ± 0.06	79.87 ± 0.90	16.19 ± 0.43	3.50 ± 0.02
Palm kernel shell	0.30 ± 0.02	73.70 ± 0.50	22.80 ± 0.25	3.20 ± 0.01
Sugarcane bagasse	0.28 ± 0.03	83.82 ± 1.05	14.88 ± 0.23	1.30 ± 0.02
Lemon grass	0.48 ± 0.05	66.87 ± 1.12	23.95 ± 0.10	9.88 ± 0.02

**MC-Moisture contents; Volatile matter; FC-Fixed carbon

All the biomass samples considered exhibit higher cellulose and hemicellulose over lignin composition, except palm kernel shell, whose lignin contents are slightly higher than their cellulose and hemicellulose contents. This implies that the biomass is suitable for the pyrolysis process because increased cellulose and hemicellulose contents increase the pyrolysis rate. Hence, it degrades mostly volatile products, e.g., bio-oil and NCG yields. At the same time, the palm kernel shell is more suitable for biochar yields since an increase in lignin contents reduces the pyrolysis rate, which retard the decomposition of volatile products. Hence, it favours the yield of biochar production.

3.4 Heating Value analysis

The HHV and LHV varied from biomass to biomass because their fuel characteristics differed (Table 4). The highest HHV and LHV recorded were 21.80 and 20.49 MJ/kg for shea butter wood, while corncob has the lowest HHV and LHV at about 18.11 and 16.78 MJ/kg.

Results obtained from Palm kernel shell (Table 4) show that the HHV closely agreed with the report the 18.84 MJ/kg reported Umar *et al*. (2020) but moderately lower than 20.71 MJ/kg reported by Tortosa-Masia *et al*. (2000). In the case of sugarcane bagasse, the HHV is slightly higher than 17.70, 17.70 and 17.32 MJ/kg reported by Channiwata *et al*. (2002), Munir *et al*. (2000) and Suarez *et al*. (2000), respectively. Similarly, the HHV and LHV reported for bamboo, obeche wood, and shea butter wood in this study, as shown in Table 4, are in consonant with what Chukwuneke *et al*. (2019) and Oyebanji *et al*. (2022) reported for mahagany wood (HHV: 21.26MJ/kg and LHV: 20.27MJ/kg). Lophira alota wood (HHV: 21.20MJ/kg and LHV: 18.08MJ/kg), respectively. Results obtained from lemon grass is fairly higher than 17.7MJ/kg reported by Gravalos *et al*. (2016) for plant leaves/weeds. The increase in the HHV and LHV of shea butter wood, obeche wood and palm kernel shell were attributed to their high fixed carbon (FC) and carbon contents which is the primary source of heat (Kpola *et al*., 2021; Umar and Sulaiman *et al*., 2021; Sawadogo *et al*., 2018). While the decrease in HHV and LHV recorded for corncobs resulted from their high ash and moisture contents (Akinola and Fapetu, 2015; Oladejo *et al*., 2020).

Furthermore, shea butter wood, sugarcane bagasse, obeche wood is more suitable for the pyrolysis process as its low ash. Moisture contents and high fixed carbon and carbon contents would enhance their hydrocarbon contents, increasing their heating value and rapid decomposition of the biomass in the reactor

Table 2
Ultimate Analysis

Biomass	C (%)	H (%)	N (%)	O (%)	S(%)
Bamboo wood	45.11 ± 0.36	5.91 ± 0.03	0.28 ± 0.01	48.51 ± 0.28	0.19 ± 0.001
Obeche wood	47.69 ± 0.13	5.70 ± 0.03	0.57 ± 0.02	46.00 ± 0.13	0.04 ± 0.01
Shea butter wood	50.00 ± 0.82	6.00 ± 0.03	0.20 ± 0.02	43.79 ± 0.24	0.01 ± 0.001
Corncob	47.90 ± 0.91	6.10 ± 0.02	0.51 ± 0.01	45.30 ± 0.23	0.19 ± 0.01
Palm kernel shell	48.9 ± 1.12	5.38 ± 0.02	0.22 ± 0.01	45.03 ± 0.15	0.02 ± 0.001
Sugarcane bagasse	47.31 ± 0.20	6.15 ± 0.06	0.45 ± 0.01	45.99 ± 0.19	0.10 ± 0.01
Lemon grass	41.12 ± 0.16	5.29 ± 0.01	1.75 ± 0.01	51.68 ± 0.21	0.06 ± 0.01

**C-Carbon; H-Hydrogen; N-Nitrogen; O-Oxygen-S-Sulphur

Table 3
Structural Composition Analysis

Sample	Cellulose (%)	Hemicellulose (%)	Lignin (%)
Bamboo wood	40.96 ± 0.92	25.83 ± 0.52	21.96 ± 0.24
Obeche wood	44.14 ± 0.21	26.86 ± 0.19	24.78 ± 0.25
Shea butter wood	45.80 ± 0.14	30.43 ± 0.23	28.42 ± 0.32
Corncob	41.62 ± 0.14	34.01 ± 0.41	17.45 ± 0.48
Palm kernel shell	28.34 ± 0.14	25.34 ± 0.41	49.63 ± 0.42
Sugarcane bagasse	43.99 ± 0.93	29.49 ± 0.12	27.80 ± 0.45
Lemon grass	40.14 ± 0.10	25.78 ± 0.21	20.65 ± 0.24

Table 4
HHV and LHV of Oven-dried Biomass

Sample	HHV(MJ/kg)	LHV(MJ/kg)
Bamboo wood	19.80±0.37	18.51±0.73
Obeche wood	20.10±0.76	18.5±0.34
Shea butter wood	21.80±0.69	20.49±0.44
Corncob	18.11±0.24	16.78±0.14
Palm kernel shell	19.98±0.44	18.70±0.25
Sugarcane bagasse	18.60±0.57	17.31±0.52
Lemon grass	17.23±0.35	16.08±0.25

HHV: Higher heating value; LHV: Lower heating value

3.5 Thermogravimetry analysis (TGA)

Fig. 2 depicts the thermogravimetry analysis (TGA) profile from the thermal reaction of bamboo, corncobs, sugarcane bagasse, obeche wood, palm kernel shell, and shea butter wood and lemon grass under an inert environment (nitrogen flow rate, 1mL/min) at a steady heating rate of 10°C/min in the temperature range of 30 to 850°C. The TGA curve (Fig. 2) helps determine the purity, thermal stability, drying, thermal degradation, weight loss, and structural composition of the biomass when subjected to heating at different temperatures. This is necessary because cellulosic, hemicellulosic, and lignin contents in the biomass exhibit various decomposition behaviour. TGA, known as pyrolytic decomposition of biomass, undergoes three phases over a broad temperature range preheating phase (moisture evaporation), volatile devolatilization, and carbonization (Ozyuguran and Yaman, 2017; Efomah and Gbabo, 2015).

In the first stage, known as the preheating stage (moisture evaporation) phase, passive pyrolysis of the biomass occurred at about 85-120°C, resulting in drying and decomposition of a low quantity of volatile components. Occurred due to the emission of free water and chemically bonded water known as the water of constitution (Umar *et al*., 2021), which was extended up to a temperature of 180°C. Approximately 1-3% weight loss was recorded, similar to what (Umar *et al*., 2021) reported for lignocellulose biomass. The fluctuations of the TG curve were due to the biomass utilized to carry out the experimental runs, which had been oven-dried and possessed low moisture content (Akinola and Fapetu, 2015). During the second stage, known as the volatile devolatilization stage (180-470°C), thermal degradation of hemicellosic and cellulosic polymers coincided, leading to the formation of an excessive number of small-molecule gas and liquids phase components with a relatively large molecular weight. A greater percentage of tar was precipitated Menares *et al*., 2020). Active pyrolysis occurred during this process.

Also, the highest weight loss was recorded for sugarcane bagasse at about 60% (180-470°C), while bamboo possessed the lowest weight loss of 27% (180-480°C). These losses in weight were attributed to the degradation of light volatile compounds below 100 °C. The last phase, known as the carbonization stage, begins at the end of the second stage up to an asymptotic value of thermogravimetry (TG). Shows no significant weight loss due to secondary reactions such as cracking and repolymerization, leading to slow decomposition (conservative minor devolatilization) of the lignin contents at a temperature of about 470-900°C (Merdun and Laouge, 2021).

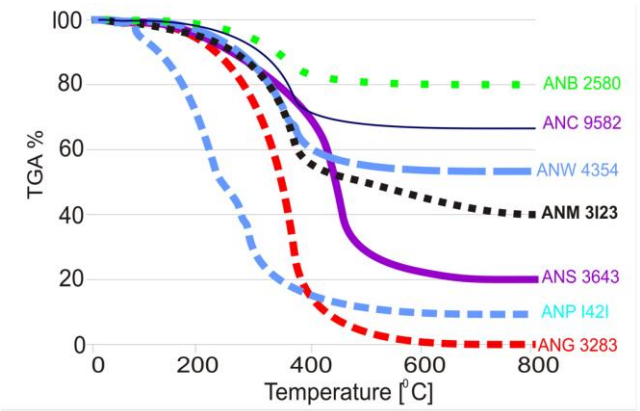

Fig. 2. TGA of weight loss at a heating rate 10°C/min

Hence, this leads to the formation of solid residues (Char). During this process, the passive pyrolysis process occurred. The overall weight losses are B (25%), C (38%), G (98%), M (60%), P (95%), S (90%) and W (80%). These results are supported by the works done by Baffour-Awuah *et al*. (2021); Okokpujie *et al*. (2019) Isah *et al*. (2020). Sugarcane bagasse (G) possessed the highest weight loss after undergoing exothermic thermal decomposition at different pyrolysis temperatures, closely followed by Palm kernel shell. At the same time, bamboo had the least weight loss percentage. Hence, Sugarcane bagasse is more suitable for the pyrolysis process among the samples reviewed next to palm kernel shell, shea butter wood, and lemon grass, respectively, as the rate of weight loss, is proportional to the energy released.

Bamboo (ANB 2580); Corncobs(ANC 9582); Lemon grass (ANW 4354); Obeche wood (ANM 3123); Shea butter wood (ANS 3643); Palm kernel shell (ANP 1421); Sugarcane bagasse (ANG 3283)

3.6 Ignitability Index (I_I)

The ignitability index (I_I) is essential in rating a biomass's quality. It helps to evaluate the tendency of the biomass to burn or ignite during the pyrolysis process. Biomass with high I_I enhances rapid decomposition of the biomass in the pyrolysis plants. The ignitability values ranged from 0.2 for corn cob to 0.32 for palm kernel (Fig. 3). Palm kernel shell possessed the highest ignitability index, closely followed by sugarcane bagasse, while corn cob has the least ignitibility index.

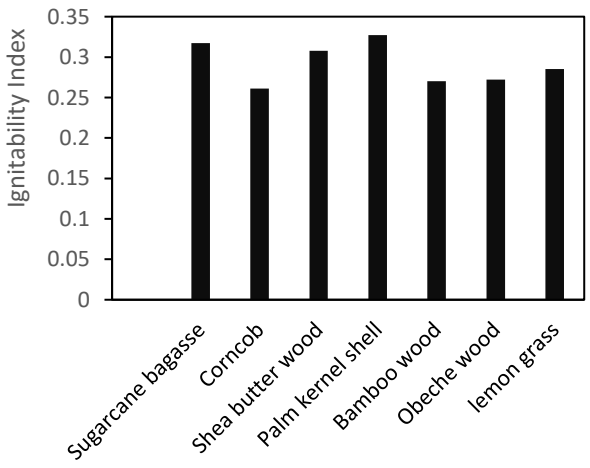

Fig. 3. Ignitability index

The increase in ignitability index recorded for palm kernel shell, sugarcane bagasse and shea butter are attributed to their high HHV and low moisture content. Hence, palm kernel shea, shea butter wood, and sugarcane bagasse are more suitable for pyrolysis.

4. Conclusion

The energy potential of seven lignocellulosic biomass samples has been investigated based on proximate, ultimate, structural composition, and thermal analyses. When compared with previous studies, the variations of the results for each biomass weree attributed to geographical location, the intrinsic composition of the biomass, soil type where the biomass is cultivate,d and climatic conditions where the biomass is sourced. The low moisture contents recorded in the biomass samples would reduce the energy needed to vaporize the biomass in the pyrolysis plant. In contrast, an increase in the volatile matter and carbon contents recorded for shea butter wood, sugarcane bagasse and palm kernel shell would enhance the heating value, devolatilization reactivity, ignitability, and burn gases in the reactor. While the low ash content recorded for shea butter wood, Obeche wood and sugarcane bagasse would prevent harmful chemical deposits in the reactor during the pyrolysis process. The low sulfur and nitrogen contents of shea butter wood, palm kernel shell and coconut shell ndicate that they can produce environmentally friendly fuel due to their low emission of SOx and NOx gases that plants can utilize during photosynthesis. The high Carbon and Hydrogen contents of shea butter wood, sugarcane bagasse, and palm kernel shell indicate that a good hydrocarbons content would be released during the pyrolysis process. Likewise, their low oxygen contents would increase the HHV and LHV of the biomass, thereby leading to a stable yield of bio-oil and NCG. The high lignin contents of palm kernel shell would decrease the pyrolysis rate, thereby increasing the biochar yield. At the same time, the high cellulose and hemicellulose contents recorded for shell butter, sugarcane bagasse, and obeche wood would increase the pyrolysis rate. Hence, this leads to a high yield of bio-oil and non-condensable gases. Sugarcane bagasse (98%) possessed the highest weight loss after undergoing exothermic thermal decomposition at different pyrolysis temperatures, closely followed by Palm kernel shell (95%). In comparison, bamboo (25%) had the least weight loss percentage. Hence, Sugarcane bagasse is more suitable for the pyrolysis process among the samples reviewed next to palm kernel shell and shea butter wood respectively, as the rate of weight loss, is proportional to the energy released. Among the seven lignocellulose biomass samples investigated, shea butter wood possessed the most suitable energy generation, closely followed by sugarcane bagasse and palm kernel shell, while corn cobs were found to be least suited for the pyrolysis process.

The energy potential for seven lignocellulose biomass for use as fuel have been determined, which would help researchers in selecting appropriate biomass for conversion process. Hence, Shea butter wood and Palm kernel shell are recommended for pyrolysis process due to their high energy potential.

Data Availability: The authors confirm that the data supporting the findings of this study are available within the article. The corresponding author can provide raw data supporting this study upon reasonable request.

Authors contributions: Onokwai, Okokpujie, Ajisegiri, Oki conceived the theory, formulation, and methodology. Onokwai, Okokpujie, Oki sourced and analyzed the data. Onokwai, Ajisegiri, Akinlabi prepared and edited the manuscript. The results were discussed and commented on by all the authors. Onokwai, Okokpujie, Adeoye handled the submission and review processes.

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