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Original Research

Characterization of Mahogany and Gmelina Sawdusts

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Abstract: In this study, mahogany and gmelina sawdusts were characterized by proximate and ultimate analyses, SEM, EDXRF, FTIR, XRD and TGA. The physiochemical properties showed high ash content of 15.84 and 15.35%, low volatile matter (1.73% and 1.92%), low moisture content (4.95% and 3.98%). Other results are fixed carbon (76.98% and 77.8%), carbon contents (47.37% and 47.60%), and hydrogen (2.3% and 3.2%), low nitrogen content (1.0% and 0.98%), and negligible sulfur content (0.4% and 0.3%), the calorific value are 319.24 and 327.43 kJ/g. The morphology of the samples depicts a wide variety of shapes and sizes after subjection to high temperature. The EDXRF result for mahogany are MgO, Al_2O_3, SiO_2, K_2O, CaO, and SnO_2, for gmelina are MgO, SiO_2, K_2O, CaO, SnO_2, other trace elements. Functional groups of carboxylic acids, alcohols, ketones, aldehydes, carboxyl were present while detected phases are quartz and calcite for the samples. The TGA analysis revealed the degradation at 205°C and 230°C, and the devolatilization stage at 205-575 °C, 230-638 °C and the carbonization at 575-835 °C and 638-835 °C for mahogany and gmelina respectively. This finding demonstrates that sawdust has the potential for various applications.

Keywords: Carbonization; Characterization; Environment; Gmelina; Sawdust.

Introduction

Waste products from the exploitation and wood processing are known as sawdust materials. It is produced as a tiny, uneven chip or powdery substance wasted during the cutting, sawing, edging, trimming, and smoothing of wood [1]. Sawdust is typically abandoned or kept in uncontrolled spaces, and a significant source of environmental pollution, between 15% and 20% of overall production is from the sawmill sector and the waste sawdust utilization is not optimized [2]. Utilizing sawdust as a biomass fuel and in chemical production could ease waste disposal issues and thereby lower pollutant emissions [3]. Cellulose (35-60%), hemicellulose (15-35%), and lignin (15-30%) are the three main chemical components of sawdust [1]. It is reported that sawdust burns with a lot of smoke, it has a low bulk density, low heat release and inhaling the fine wood dust is linked to a potential health problem [1, 4]. However, sawdust is abundance and competitively low price among other lignocellulose materials [5]. Mahogany (*Swietenia mahagnoni*) and Gmelina (*Gmelina arborea*) sawdusts are the most common waste in Nigerian timber markets, local furniture industries and from wood processing and exploitation.

Sawdust is used as a fuel source in thermal operations, in the production of compost, as an adsorbent to remove pollutants like dyes, heavy metals, and pharmaceuticals, as an insulating and building material, as well as in cement bonded boards manufacturing [1, 6]. Additionally, it is used in procedures such as combustion, carbonization, pyrolysis, gasification, fermentation, biochemical, and transesterification into biofuel products (charcoal, briquettes, pellets, and biogas) [7]. Example, the production of bio-oil from pyrolysis by depolymerized lignocellulosic biomass in a single oxygen-starved reactor [8]. In another study, Mahogany Sawdust was converted into activated carbon using the hydrothermal-pyrolysis method and characterized by proximate analysis FTIR, XRD, and FESEM [5].
This study is aimed at the investigation of the physicochemical properties and the characterization of carbonized mahogany and gmelina sawdusts using proximate and ultimate analyses, SEM, EDXRF, FTIR, XRD and TGA analysis.

Materials and Methods

Sample preparation
The mahogany and gmelina sawdusts were collected from Baga road timber market, Maiduguri. To eliminate the contaminants associated with sawdust, it was washed multiple times with distilled water. It was then oven-dried for 24 hours at 70 °C, then for an additional night at 105 °C to get a constant weight, when sieved to a mesh size between 60 and 80. The samples were kept for future studies in sealed sample containers. Sawdust was pyrolyzed in a stainless steel fixed bed reactor with an internal diameter of 25 mm and a height of 400 mm. The setup for the experiment's schematic diagram is shown in Figure 1.

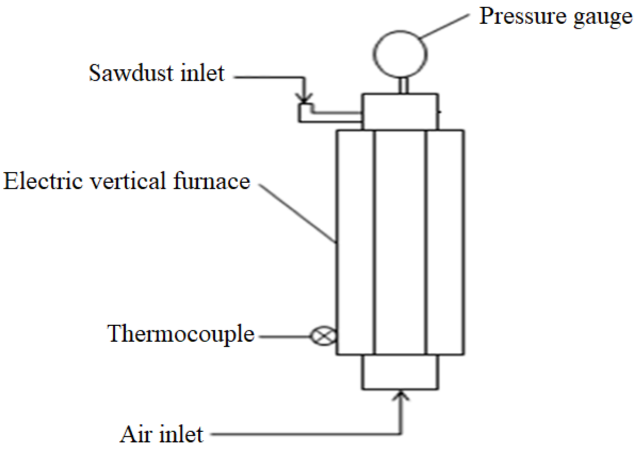

Figure 1: Schematic diagram of the experimental setup.

Characterization
The ultimate analysis was deduced based on ASTM standard D3176-15 (LECO CHN analyzer) and the proximate analysis was examined based on ASTM Standard D7582-12 and coal calorific value was determined using a bomb calorimeter (Model: IKA C2000) as reported by [9]. SEM JEOl 6060 was used to analyze the morphology of the prepared sample. Elemental analysis is carried out with Energy Dispersive X-ray Fluorescence Spectrophotometer (EDXRF) analytical system (Model-XR300.50KV). Fourier transform Infra-Red (FTIR) studies were analyzed using Perkin Elmer spectrometer, Shimadzu UV1800 spectrophotometer (UV–Vis). The X-ray diffraction (XRD) method for composition analysis was performed with an X'Pert Philips PW3040 diffractometer using Cu Kα radiation (2θ range = 20-80°; step = 0.05° 2θ; time per step = 0.2 s). Thermogravimetric analysis of sawdust was done using a thermogravimetric analyzer (Mettler Toledo equipment), at a rate 10 °C min^{-1} up to 1000 °C under constant N_2 flow rates of 50 mL/min.

Results and Discussion

Physicochemical Properties

Proximate study validates the presence of low volatile matter and low moisture content in the two samples. For thermochemical conversion, more volatile matter is preferable; however, more ash reduces the energy value of the biomass, slows down burning, and creates fouling issues. Fixed Carbon (FC) is the content of a sample that is remaining after volatile matter is burnt to leave carbon in its free state [9]. A biomass with low moisture of less than 10% indicates the suitability of the samples for pyrolysis [3] and in this study, the moisture content of mahogany and gmelina were 4.95 and 3.98%. The ash contents were 15.84 and 15.35% meanwhile, high ash content influences the burning rate and results in a fouling problem [10].

Table 1: Proximate and ultimate results.

	Proximate analysis	
Property	**Mahogany**	**Gmelina**
Moisture content (%)	4.95	3.98
Ash (%)	15.84	15.35
Volatile matter (%)	1.73	1.92
Fixed carbon (%)	76.98	77.81
	Ultimate analysis	
Property	**Mahogany**	**Gmelina**
C	47.37	47.60
H	2.30	3.20
O	37.20	38.00
N	1.00	0.98
S	0.4	0.30

The ultimate analysis result showed the carbon contents (47.37% and 47.60%), and hydrogen content of 2.3% and 3.2%, the carbon and hydrogen are the major combustible constituents of a fuel [9]. A research revealed the ultimate analysis result of sawdust considered as having high amount of carbon (48.87%) and it is reported to be suitable for biochar production [10]. Low nitrogen content (1.0% and 0.98%), and negligible sulfur content (0.4% and 0.3%) implied that the SO_x and NO_x formation will be low during pyrolysis with lesser corrosion during operation [3]. Categorizing of a forest species for its potentiality as fuelwood, a 20.0 kJ/g heat calorific value as a standard is set [7] hence, the calorific value of mahogany and gmelina of 319.24 and 327.43 kJ/g showed the suitability of the samples as fuel, the two sawdust samples showed slightly different property but within the same range. The calorific value of bio char briquette made from Gmelina arborea sawdust is 32.82 MJ/kg, making it an excellent alternative energy source in home and industrial use [1].

Surface Morphology

The morphology of mahogany and gmelina is shown in Figure 2 at magnification of 100 and 200 X. After being exposed to high temperatures, the morphology of the samples reveals a wide range of shapes and sizes, this illuminates the usual porosity and durability of channels in the biomass. High temperature also plays a significant effect in pore structure [1]. Devolatilization of sawdust following pyrolysis led to the development of the pores, and the improvement of the porous structure [2, 10]. A random distribution of small particles shows many mineral phases while the coarse particles are ascribed to the presence of kaolinite, Fe and/or Ti [9]. Big blocks are observed with regular channel arrays suggesting that the original structure was preserved even after calcination and larger pores in gmelina are seen compared to mahogany sample.

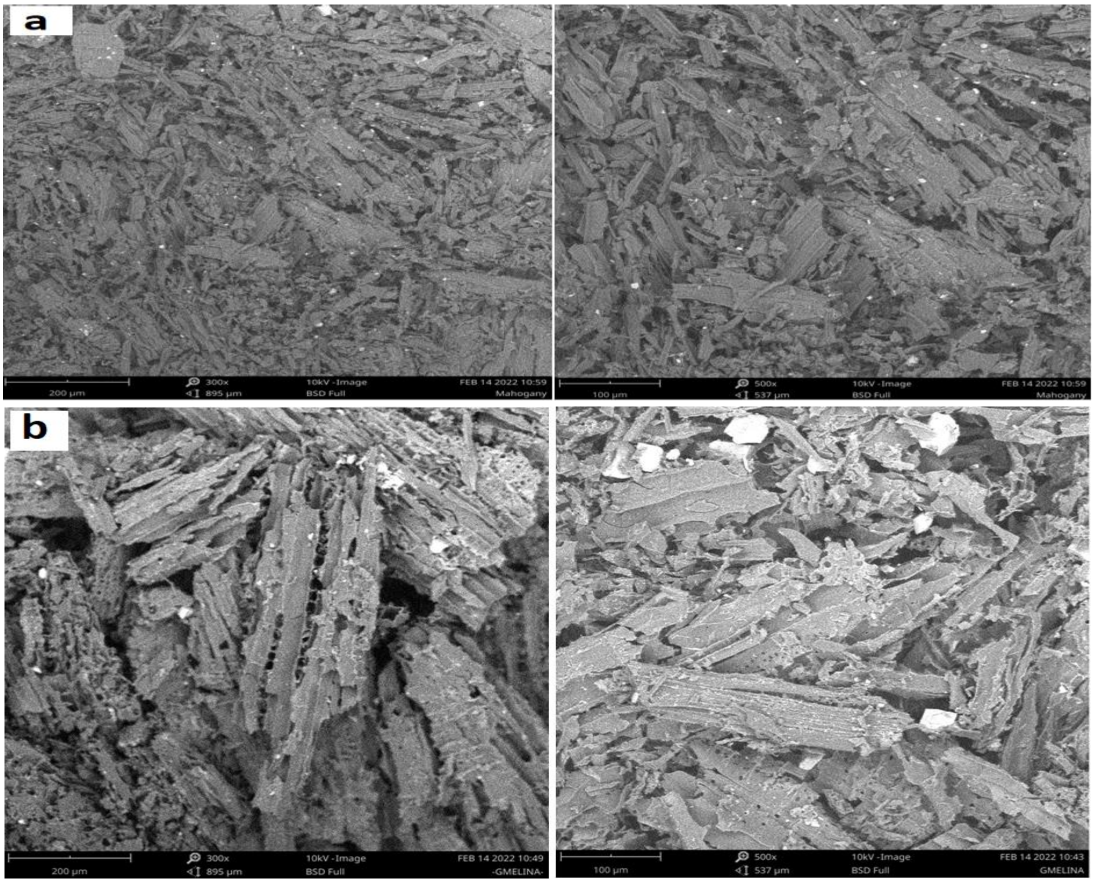

Figure 2: Morphology of (a) mahogany and (b) gmelina samples at 100 and 200 magnifications.

Chemical Composition

The chemical composition result shows that the highest peaks correspond to a greater quantity of the corresponding element in the sample. It is observed in Figure 3 that the peaks of some elements with respect to the other elements are higher in the composition of the materials.

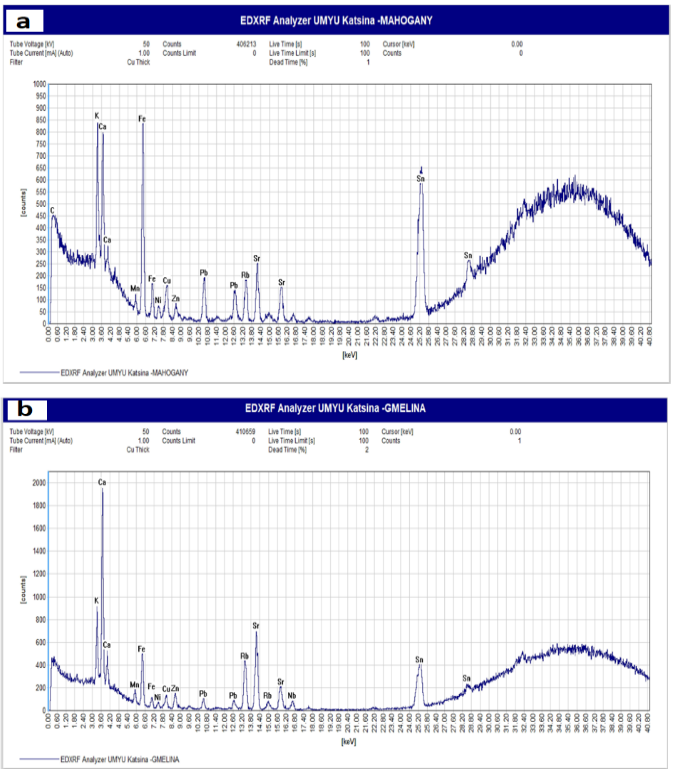

Figure 3: EDXRF result of (a) Mahogany and (b) gmelina.

The major metal oxides/elements that are found in the carbonized gmelina sawdust are MgO, SiO_2, K_2O, CaO, SnO_2, while for mahogany, MgO, Al_2O_3, SiO_2, K_2O, CaO, and SnO_2, were found. The other metal oxides/elements are present in traces as shown in Table 2.

Table 2: The metal oxides/elements and traces elements.

Element	Gmelina (%)	Mahogany (%)
Fe_2O_3	0.18631	0.3409
NiO	0.00096	0.00364
CuO	0.00484	0.01244
ZnO	0.02475	0.01156
Ga_2O_3	0.000269	0.00060
GeO_2	0.00017	0
Ta_2O_5	0.00556	0.0003
WO_3	0.01220	0.01136
MgO	2.03	1.99
Al_2O_3	0.761	1.299
SiO_2	2.906	4.157
P_2O_5	0.4075	0.2587
SO_3	0.1768	0.3450
Cl	0.0641	0.0307
K_2O	6.207	6.266
CaO	10.396	3.6484
TiO_2	001387	0.0304
V_2O_5	0.00008	0.00123
Cr_2O_3	0.00021	0.00029
MnO	0.2089	0.1003
BaO	0.00321	0.00882
As_2O_3	0	0.0008
Rb_2O	0.597	0.253
SnO_2	1.326	1.381
Y_2O_3	0	0.002251
CdO	0	0.17
PbO	0.01653	0.0291
Bi_2O_3	0.03075	0
Ag_2O	0.00063	0.00057
I	0.000566	0.00054

These major metal oxides/elements can be separated and utilize for various applications. For example, CaO was used as an absorbent in the in-situ capture of CO_2 and to increase the purity and percentage composition of H_2 in the producer gas [11]. SiO_2 is used as the electrode material for super-capacitors (SC), the SC is a material for energy storage system due to its fast charge/discharge rates, long-term cycling stability and low maintenance cost [12]. A recent study focuses on the production of glasses in the SiO_2-P_2O_5-CaO-K_2O system from waste as raw materials in the proportion CaO (42.1 wt%) and P_2O_5 (29.2 wt%), as well as other oxides such as Na_2O (3.9 wt%), SiO_2 (1.7 wt%), K_2O (2.7 wt%) and MgO (1.4 wt%) [13].

Functional groups

Figure 4 shows the presents of functional groups in the spectrum range of 4000-400 cm^{-1} for the mahogany and gmelina sawdust samples. It can be observed that the mahogany and gmelina sawdusts presented similar peaks at the low and high wavenumbers depicting the presence of similar functional groups on the samples. Table 3 shows the functional groups on the sawdust samples and their vibrational forms.

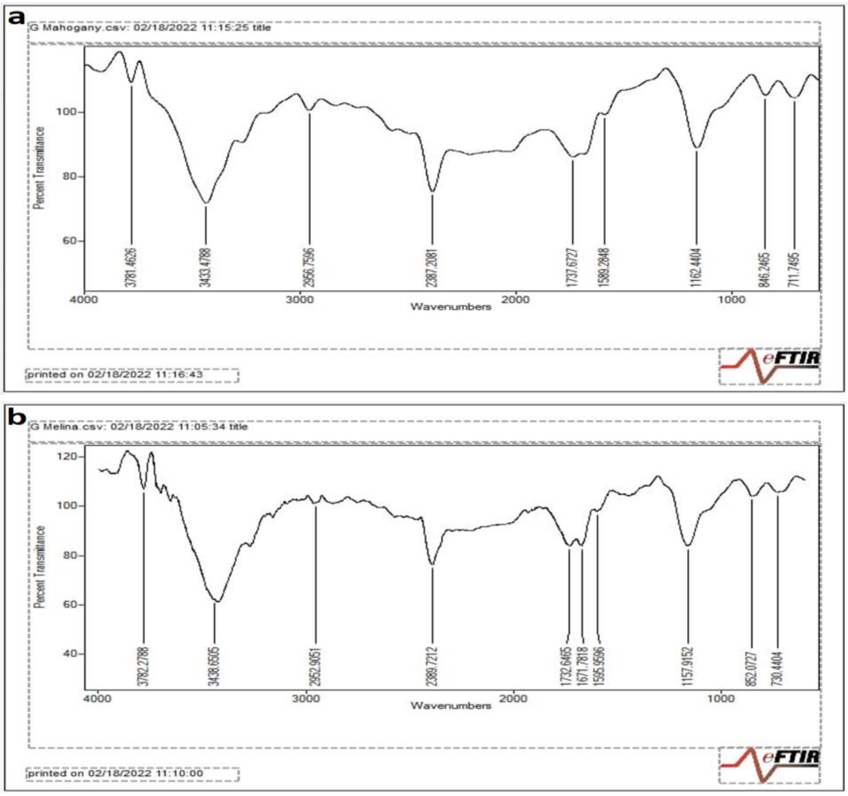

Figure 4: FTIR Spectrum of (a) mahogany and (b) gmelina samples.

It can be observed that similar functional groups that are present on mahogany and gmelina samples are similar this finding depicts that the samples can be utilize for similar application example, in the development of adsorbent for water treatment.

Table 3: Functional groups on the FTIR peak positions and functional groups.

Mahogany Peak position (cm⁻¹)	Gmelina Peak position (cm⁻¹)	Bond	Functional group	References
3781	3782	O—H	Alcohols	[14]
3433	3438	O—H	Phenols and alcohols	[10]
2956	2952	C–O	Saturated hydrocarbons	[10, 15]
2387	2398	O—H	Alcohols	[16]
1737	1733	C –O	Carboxylic acids, ketones and aldehydes, carboxyl in xylan and hemicelluloses	[2, 10, 17]
	1671	C–O	Carboxylic acids	[2, 10]
1599	1595	C–C	Lignin aromatic vibrations	[2, 10, 17]
1162	1157	C-C	Alcohols, esters and ethers	[10]
846	852	C–Cl	Aryl halide	[2]
711	730	C – H	Aromatic	[18]

Mineralogy

The XRD peaks were studied and analyzed using highscore software for phase identification of samples diffraction. According to the XRD pattern shown in Figure 5, the two detected compounds are quartz and calcite for the mahogany and gmelina sawdusts. Quartz is a mineral with the chemical formula SiO_2, and the most important silica polymorph in nature used as high-purity quartz crystals or sands, and refractory materials [19]. One of the most thermally stable mineral is calcite, it exhibits semiconductor properties at a particular temperature, making it a viable choice for use in charge-modulated CO_2 capture systems [20]. In soil treatment as an alkaline amendment agent, calcite can elevate acidic soil pH [21].

Different spectrum was displayed for calcite and quartz as the mineral phases in co-combustion of reclaimed asphalt binder and wood sawdust material [22].

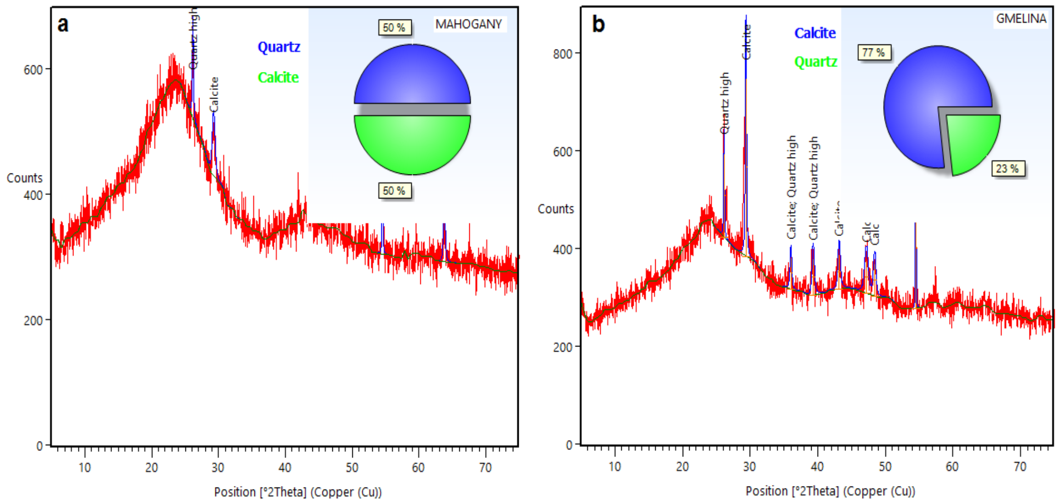

Figure 5: XRD pattern of (a) mahogany and (b) gmelina sawdust.

Moreover, the deformation of crystalline carbon into an amorphous structure is shown by the amorphous halo centered at 2θ = 23^{O} of the plane (002) in similar trend to a literature [14]. Hemicellulose and lignin are amorphous displaying wide unspecific peaks while cellulose is found at both the amorphous and crystalline regions [2, 23] also, the sharp and finer peaks indicate crystalline particles [16].

Thermal Behavior

The technique for analyzing organic and inorganic samples to identify various characteristics including moisture, volatiles, and carbonization is thermosgravimetric analysis [1], further it determines the thermal degradation behavior of sawdust [10]. Figure 6 shows the thermal decomposition (TG) and the Derivative Mass Loss (DTG).

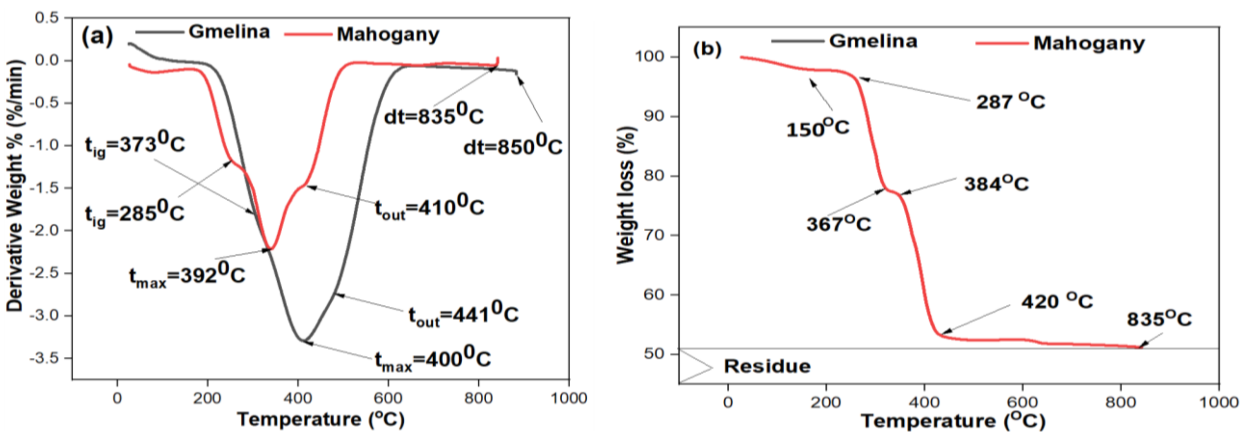

Figure 6: Plots for (a) DTG profile and (b) TG profile of the mahogany and gmelina sawdust.

It was revealed that cellulose is crystalline and degrades between 315 and 400 °C, hemicellulose is amorphous and degrades between 200 and 315 °C, and lignin is a highly cross-linked molecule that degrades over a large temperature range between 180 and 900 °C [10]. Figure 6a shows three stages of degradation, the first stage is the drying stage ranged at 205 °C and 230 °C, the second stage is the devolatilization stage at 205-575 °C and 230-638 °C and the final stage termed carbonization at 575-835 °C and 638-835 °C for mahogany and gmelina respectively. Similar categorization was reported [24]. The

Temperature Profile Characteristics (TPC) was deduced for ignition T_{ig}, peak loss, T_{max}, and burnout temperature T_{out}.

The curves exhibited by the mahogany and gmelina sawdust shown in Figure 6b are the same which indicates the similarity in the composition. The temperature between 100 °C and 300 °C showed the evaporation of moisture and low-molecular-weight compounds [17], while the further increase in temperature showed a severe decline in the weight decrease of the mahogany and gmelina sawdust from 287 °C up to 420 °C. This severe loss is the significant weight loss that revealed the decomposition of undergraded cellulose and lignin. The temperature from to 420 °C to 835 °C was due to the rapid carbonization of the sawdusts. The approximate weight loss was around to 50.7% at 835 °C and a temperature for lignin degradation. Similar finding of the TG plot was reported [2]. The remaining organic residue, known as char, can then be further processed for a variety of uses, such as the creation of carbon nanotubes, solid fuel, bio-adsorbents, soil conditioner/enhancer, and a number of cosmetic goods [1, 3, 23, 24].

Conclusion

A green, clean, and sustainable environment can be ensured by converting low-value trash, such as sawdust, into more valuable resources that can helps the world's waste management system. The characterization of the mahogany and gmelina sawdust by physiochemical properties, morphology, chemical composition, functional groups, mineralogy, and thermal behavior in this study categorizes the sawdust samples as a potential fuel and for many other uses. Various applications such as adsorption, the in-situ capture of CO_2, activated carbon production, electrode materials for super-capacitors, production of glasses, carbon nanotube production, soil conditioner/enhancer, and several cosmetic products can be realized from the sawdust.

Disclosure Statement

The author(s) did not report any potential conflict of interest.

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