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Chemical Composition and Combustion Properties of Tropical Wood Species from Nigeria

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Research Article

Abstract

Ten different tropical wood species from Nigeria were collected and analyzed for bioenergy potential using their chemical compositions and thermal properties. The chemical compositions obtained were in accordance with those reported in literature, with ash levels from 4.73% to 7.33% and total extractibles ranging from 20.01% to 28.08%. Percentages of lignin obtained ranged from 27.37% to 28.89%, while the content of holocellulose ranged from 42.03% to 52.32%. Calorific values of the wood species were calculated using an elemental composition-based correlation equation, and values obtained ranged between 15.50 and 18.90MJ/kg. The fuel value index (FVI) values obtained for the sampled species revealed that acacia sp is the best species for use as fuelwood given its high calorific value and while Blighia sapida was found to be least suited for use as fuelwood.

Keywords
Bioenergy; Chemical composition; Fuelwood; Thermal analysis; Tropical wood.

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1. Introduction

Traditional biomass, especially fuelwood, remains a crucial source of energy, mostly in rural areas of developing countries. A 2018 report by the Food and Agricultural Organization of the United Nations revealed that in 2015, about 50% of all felled wood globally was deployed as fuelwood (FAO, 2018). The sustainability of fuelwood had developed gradually over the decades from the bleak forecast of global forest reserves depletion to a more promising perspective in recent times. This perspective includes appreciating the multiplex chains of supply and demand substitution, which have mitigated the anticipated depletion of forests in several countries of the world (Arnold *et al.*, 2006). New analytical instruments were deployed recently to determine fuelwood sustainability as a source of energy based on its availability globally (Ghilardi *et al.*, 2016) and contribution to global warming (Bailis *et al.*, 2015).

The conventional and modern approach commonly used to harness energy from fuelwood for cooking and heating purposes, has been combustion, especially in open fires. However, this approach has been causing apprehensions; due to its negative impact on human health (Naeher *et al*., 2007; Valerio, 2012) and low efficiency (Hoffmann *et al*., 2015). This approach also exposed a form of energy poverty that needs to be alleviated (Pachauri and Spreng, 2011). Fuel switching or stacking could help to gradually replace fuelwood in conventional applications, and move families up the energy ladder (Heltberg, 2004; Van der Kroon *et al*., 2013) to cleaner and safer sources of energy. For example, technological solutions such as advanced fuelwood cookstoves are developed to reduce fuelwood consumption (thus enhancing sustainability) and emission of deleterious smoke (Ruiz-Mercado and Masera, 2015). Gasification and pyrolysis are more thermo-chemical processes used to harness clean energy and high value chemicals from wood biomass. Gasification converts the fuelwood to a combustible gas, which can be used for heating or utilized as fuel for internal combustion engines, while pyrolysis, converts the fuelwood to bio-char and bio-oils for heating and transportation fuels, respectively (Panwar et al. 2012; Kan *et al.*, 2016; Tag et al. 2016; Ezhumalai and Kumar, 2017). The outputs from these thermo-chemical processes are influenced largely by biomass chemical composition, biomass types and biomass pretreatment methods (Ezhumalai and Kumar, 2017; Kan et al. 2016; Tag *et al.*, 2016). Fuelwood is adjudged to possess high chemical quality if it contains high extractives as well as low ash contents, which culminates to high calorific value (Kataki and Konwer, 2001). Another property of fuelwood that equally contributes largely to enhancing its calorific value is high density (Abbot and Lowored, 1999; Kataki and Konwer, 2002; Cardoso et al. 2015; Díez and Pérez, 2017). High calorific value implies high energy content (Demirbas, 2009; Moya and Tenorio, 2013).

In Nigeria, one of the major reasons fuelwoods have been poorly exploited for bioenergy and chemicals production relates to unavailability of adequate data on the energy characteristics and chemical composition of the wood species available in the country, unlike the coniferous wood species (spruce and willows) that are specifically cultivated for bioenergy production purposes in most parts of Europe due to their high energy potential and combustion properties. Building a cache of data on the chemical composition and energy characteristics of wood species in Nigeria is therefore of crucial importance to enable planning of ways to effectively exploit and utilize wood biomass for bioenergy and biofuels production in the country, hence the need for this work.

Significant efforts have been made by researchers in Nigeria to study the thermal properties of wood biomass as possible source of bioenergy. Aina et al. (2006) highlighted the potential of charcoal, obtained from wood residues, as an alternative energy source for cooking purposes. Akintunde and Seriki (2013) evaluated the calorific value of briquette produced from blends of sawdust and paper wastes. Akinola and Fapetu (2015) investigated the energy potential of seven tropical wood species (Triplochiton scleroxylon, Melicia excelsa, Nesogordonia papaverifera, Khaya ivorensis, Cordia platythyrsa, Mansonia altissima, and Terminalia superba) collected from Akure, Ondo State, Nigeria. Results obtained indicated a mean calorific value of 22 MJ/kg and electricity potential of about 6.10 kWh per kg of wood pyrolyzed. Adegoke et al. (2014) evaluated the suitability of three tropical wood species (Gmelina arborea, Terminalia superba and Triplochiton scleroxylon) as fuelwood. Results from the study revealed that the selected wood species are suited for domestic cooking and heating purposes and their bio-oils are of high quality, making them suitable for bioenergy system. Akhator et al. (2017) evaluated the thermal properties and energy contents of five tropical wood species (Lophira alata, Celtis sp, Nesogordonia papaverifera, Cordia millenii, Terminalia superba) collected from Benin City, Edo State, Nigeria. Results from the study revealed that the wood species have high thermal energy potential and thus suitable as fuelwood for bioenergy generation. More recently, Oyebanji *et al*., (2021) studied the physico-chemical properties of five wood species sawdust (Milicia excelsa, Diospyros crassiflora, Entada africana, Baphia nitida and Achyranthes aspera) and reported that the selected woody biomass residues are good sources of biofuels for sustainable development. To the best of our knowledge, there is no report on studies of analyses of chemical composition of wood species in Nigeria. This data is important to determine biofuels potential of wood biomass.

Considering the diverse wood species available in Nigeria, this work therefore intends to investigate the energy and biofuels potential of other tropical wood species not previously studied in the country by evaluating their chemical composition and combustion properties with a view to boosting the data base for wood biomass application and energy policy formulation in Nigeria.

2. Experimental Procedure

2.2 Materials

2.2.1 Study site

The study was conducted in Benin City, Edo State in South West of Nigeria. The study area is Benin metropolis which comprises Egor, Oredo as well as parts of Ikpoba-Okha and Ovia North East Local Government Areas of the State. Samples of the identified wood species were collected from sawmills located within Benin City.

2.2.2 Sampled species

Samples from ten different tropical wood species of class size 45 - 60cm diameter and average age of 110years were collected from the study site. The wood species are listed in Table 1.

Table 1: List of sampled tropical wood species

Sample	Scientific Name	Trade Name (Bini)	Family
1	*Acacia sp.*	Acacia	Fabaceae
2	*Afzelia Africana.*	Apa	Caesalpinaceae
3	*Celtis sp.*	Ohia	Ulmaceae
4	*Brachystegia eurycoma*	Okwen	Caesalpinaceae
5	*Bombax bounopozense*	Bombax	Bombaceceae
6	*Blighia sapida*	Ukpe	Sapindaceae
7	*Piptadeniastrum africanum*	Ikhimi	Mimosaceae
8	*Cleistopholis partens*	Otu	Annonaceae
9	*Triplocyton scleroxylon*	Obeche	Sterculiacea
10	*Albizia sp.*	Albizia	Fabaceae

Residues of these wood species (mostly heartwoods due to their ages and structure) were collected from sawmills in Benin City. The wood species are also cultivated in Ogun, Ekiti and Ondo States all in South West of Nigeria.

2.2 Methods

2.2.1 Analysis of wood species

The collected samples of the wood species were sun-dried for three weeks prior to analyses. Thereafter, the dried samples were subjected to chemical composition, elemental and combustion analyses. The investigations were conducted twice unless otherwise stated.

2.2.2 Determination of moisture content (%MC) and ash content (%Ash)

The moisture content was ascertained in accordance with the ASTM E871 - 82 (2013) procedure and conducted three times. 2 grams of sample were weighed in a ceramic crucible previously of pre-determined weight. The crucible was placed inside an oven at 105°C until a constant weight was recorded. The moisture content was computed using (1).

$$\%\,\mathrm{MC} = \frac{(\mathrm{z}-\mathrm{x})}{\mathrm{z}} \times 100\% \tag{1}$$

Where, z = weight of wet sample, x = weight of dry sample, while (z - x) indicates weight loss.

The ash content was ascertained using the ASTM D1102 - 84 (2013) procedure. 2 grams of dry samples of wood species were placed in a ceramic crucible of known weight and put inside a muffle furnace, and heated at 600°C until a constant weight was recorded. The ash content was computed using (2).

$$\%\,\mathrm{Ash} = \left(\frac{y}{z}\right) \times 100\% \tag{2}$$

Where, z = weight of dry sample and y = weight of ash (measured using a digital weighing scale).

2.2.3 Analysis of Chemical composition of wood species

Sun-dried samples of the wood species were analyzed for their extractives (in solvents and water), holocellulose and Klason lignin contents. The extractive contents were determined using the TAPPI T204cm-97 (2007) procedure. The samples were placed inside a Soxhlet apparatus in an extraction cartridge made with filter paper at a constant weight. The extraction was made with a benzene/ethanol mixture (2:1) for a minimum of 5 h or 16 extraction cycles, and then, the cartridges were drained and dried to a constant weight in a convection oven. Thereafter, the solvent was replaced with ethanol (95% conc.) and the extraction process was repeated. Water was also used for extraction, in accordance with the TAPPI T207 cm-99 (1999) procedure. The remnants from the solvent extraction were heated for an hour in 900mL of distilled water in a round bottom flask. The procedure was repeated twice again and the ensuing suspension was filtered. The obtained solid was oven dried to constant weight. The percentages of extractives at each stage were obtained from the correlation between the dry weight of sample and the weight lost during each extraction. The Klason lignin content was determined in accordance with the TAPPI T222 (2011) modified technique. 1 gram of sample free of extractives was hydrolyzed using 15 mL of 72% (w/w) sulphuric acid (H_2SO_4). The sample was maintained at 15°C using a water bath, while being agitated for 2 h. Thereafter, water was added to the suspension to dilute it to about 4% in concentration and heated for four hours. The resulting solution was filtered and the insoluble fraction was oven dried to constant weight. The lignin contents were ascertained using (3),

$$\%\text{Lignin} = [(\frac{m_r}{m_s}) \times (1 - \frac{Ex_{tot}}{100})] \times 100 \qquad (3)$$

Where, m_r is mass recovered (g), m_s is mass of sample without the extractives (g), and Ex_{tot} is percentage of total extractives (%).

The holocellulose content was obtained using equation 4

$$\%\text{Holocellulose} = 100 - (\%Ex_{tot} - \%\text{Lignin}) \quad (4)$$

2.2.4 Determination of elemental composition and gross calorific value (GCV)

The elemental composition of the wood species was evaluated to ascertain the content of the elements such as carbon, hydrogen, oxygen, nitrogen, and sulfur in the species. For this analysis, a Thermo-Scientific FLASH 2000 Elemental Analyzer was used for the analysis. 2 grams of each sample were placed inside tin capsules and were automatically sampled and analyzed. Obtained results from the analysis were utilized to compute the gross calorific value of each wood specie using the Francis and Lloyd equation (Francis and Lloyd, 1983) shown in (5).

$$GCV=357.8C+1135.6H+54.9N+119.5S-85.4O-974 \quad (5)$$

Where, GCV is gross calorific value (MJ/kg), C, H, N, S, and O are percentages of carbon, hydrogen, nitrogen, sulfur, and oxygen respectively in each sample.

2.2.5 Determination of density and fuel value index (FVI)

Each dry wood specie was compacted into cylindrical shapes of diameter 6cm and length 18cm. The produced specimens were weighed to determine density of each wood specie. The fuel value index (FVI) for each wood specie was computed by combining the obtained calorific values, moisture contents and ash contents of the wood species as shown in equation 6 (Rai *et al.*, 2002).

$$FVI = \frac{GCV \times \rho}{AC \times MC} \qquad (6)$$

Where GCV is gross calorific value (kJ/g), ρ is density (g/cm^3), AC is the ash content (g/g) and MC is moisture content (g/g).

3. Results and Discussion

3.2 Chemical Composition Characterization

Table 2 presents the obtained chemical composition for the sampled wood species. Benzene/ethanol extractives ranged from 4.47% (*Celtis sp*) to 8.56% (*Acacia sp*), ethanol extractives ranged from 1.75% (*Bombax bounopozense*) to 6.21% (*Cleistopholis partens*), and water extractives ranged from 9.21% (*Afzelia africana*) to 14.21% (*Acacia sp*). Results of total extractives from this study were similar to results (values up to 20%) reported by Balodun *et al.* (2014) for tropical wood species. The total extractives ranged from 20.01% for *Brachystegia eurycoma* to 28.08% for *Acacia sp*. Obtained lignin contents ranged from 27.37% for *Bombax bounopozense* to 29.89% for *Acacia sp*. These values were similar to 30% lignin contents reported for tropical species (Nasser and Aref, 2014; Balogun *et al.* 2014). The holocellulose content in the sampled species varied from 42.03% to 52.32%.

Table 2: Chemical Composition of sampled tropical wood Species

Wood Species	**Extractives (%)**			**Total Extractives (%)**	**Klason Lignin* (%)**	**Holo-Cellulose** (%)**
	Benzene/ethanol	**Ethanol**	**Water**			
Acacia sp	8.56±0.1	5.31±0.2	14.21±1.5	28.08±1.28	29.89±0.2	42.03±1.3
Afzelia africana	7.45±0.1	3.89±0.2	9.21±0.2	20.55±0.10	27.57±0.25	51.88±0.1
Celtis sp	4.47±0.12	4.09±0.2	14.35±1.5	22.91±0.16	28.89±0.2	48.20±0.2
Brachystegia eurycoma	7.36±0.1	2.53±0.1	10.12±0.3	20.01±0.28	29.59±0.3	50.40±0.2
Bombax bounopozense	8.29±0.2	1.75±0.1	10.27±0.28	20.31±0.25	27.37±0.2	52.32±0.3
Blighia sapida	8.12±0.15	3.1±0.12	12.12±1.15	23.34±0.2	28.95±0.2	47.71±1.0
Piptadeniastrum africanum	7.57±0.1	2.5±0.2	12.58±2.0	22.65±0.91	28.25±0.22	49.10±0.2
Cleistopholis Partens	8.35±0.2	6.21±0.3	10.22±1.5	24.78±0.25	27.67±0.3	47.55±0.2
Triplocyton scleroxylon	7.98±0.2	4.42±0.28	9.85±0.3	22.25±0.5	29.05±0.25	48.70±0.3
Albizia sp	8.35±0.3	5.45±0.3	13.85±2.0	27.65±1.5	29.85±0.2	42.50±0.2

Mean±standard deviation. *Average was computed using the average value of total extractives.

** Holocellulose was calculated using the average value of total extractives and lignin content.

High extractives and lignin contents are indication of high energy content for wood biomass (Demirbas, 2009; Moya and Tenorio, 2013), which implies that these wood species are viable sources of bioenergy. Biofuels potential of woody biomass depends on their holocellulose content (Tag *et al.* 2016; Ezhumalai and Kumar, 2017). From Table 2, it can be observed that *Bombax bounopozense* has the highest content of holocellulose (52.32%), and closely followed by *Afzelia Africana* (51.88%) and *Brachystegia eurycoma* (50.40%). For biofuels considerations, these species should be specially grown and deployed either single mode or mixed with each other.

3.2 Elemental Composition, Gross Calorific Values (GCV) and Fuel Index Values (FVI)

Table 3 presents results of the elemental composition analysis, computed gross calorific values and the computed FVI values for the wood species sampled. It was observed that carbon and oxygen were the predominant elements in the species studied, having percentages of 41.07% to 49.05% and 45.13% to 53.16% respectively. Results revealed that the hydrogen content was approximately 5%, and the percentages of sulfur and nitrogen were lower than 0.03 and 0.32 respectively. The gross calorific values obtained for the sampled wood species ranged from 16.30 to 18.90 MJ/kg, and within the range of values reported in literature for wood residues (Garcia *et al.* 2014). For example, 18.40 MJ/kg was reported for black poplar tree and 16.30 MJ/kg for orange tree. The obtained calorific values were equally within the range of results reported by Huhtinen (2009) (18.50 – 21.00 MJ/kg) and Akhator *et al.* (2017) (19.45 – 20.15 MJ/kg).

Although energy content mainly determines the selection of wood species for use as fuelwood, parameters, such as low humidity, flammability and ability to produce ember, also need to be considered when making such selection. These parameters are indicated by certain characteristics of woody biomass, including moisture content, density, and ash content. The fuel value index (FVI) takes into account these characteristics, hence, should also be considered when selecting wood species for use as fuelwood. Table 3 reveals that the species *Acacia sp*, *Bombax bounopozense, Triplocyton scleroxylon and Albizia sp* had densities greater than 1g/cm^3, while *Celtis sp* and *Blighia sapida* had lowest densities of 0.685g/cm^3 and 0.582 g/cm^3 respectively. The high density values from this study, in comparison with values reported in literature for tropical wood (densities < 1), especially by Carsan et al. (2002) occurred because density value obtained in literature were computed using the dry weight and the volume of green wood. Whereas, in this study, density values were computed using the dry weight and the volume of wood species at the obtained moisture levels (8.62% to 10.53%).

The ash values in the sampled wood species varied from 4.73% for *Celtis sp* to 7.33% for *Acacia sp*. These values were similar to the values reported by Demirbas, (2009) for some other tropical woods. Obtained moisture values ranged from 8.62% to 10.53%. Low moisture levels are advantageous as it improves thermochemical conversion processes (Huhtinen, 2009) and inproves the energy obtainable from wood biomass as less energy will be needed to evaporate moisture during thermochemical processes (Akinola and Fapetu, 2015).

Table 3: Elemental composition and combustion properties of sampled wood species

Wood Species	Elements (%wt.)					GCV (MJ/kg)	Density (g/cm3)	Moisture Content (%)	Ash (%)	FVI
	C	H	O	N	S					
Acacia sp	49.05±0.1	5.46±0.3	45.13±0.2	0.32±0.2	0.03±0.1	18.944±0.6	1.125±0.3	9.68±0.2	5.38±0.21	4092.19±0.2
Afzelia africana	48.26±0.1	5.27±0.3	46.15±0.2	0.29±0.2	0.03±0.1	18.356±0.2	0.792±0.3	10.00±0.2	6.28±0.25	2315.00±0.2
Celtis sp	45.06±0.1	5.04±0.3	49.62±0.2	0.25±0.2	0.03±0.1	16.652±0.1	0.658±0.2	9.84±0.2	4.73±0.2	2354.11±0.2
Brachystegia eurycoma	47.72±0.1	5.74±0.3	46.35±0.2	0.18±0.2	0.02±0.1	18.673±0.12	0.735±0.3	9.52±0.2	5.35±0.2	2694.64±0.2
Bombax bounopozense	45.38±0.1	5.53±0.3	48.94±0.1	0.14±0.2	0.01±0.1	17.372±0.1	1.007±0.3	10.17±0.2	5.78±0.25	2976.02±0.2
Blighia sapida	46.66±0.2	5.16±0.3	47.88±0.2	0.28±0.2	0.03±0.2	17.511±0.2	0.582±0.3	9.84±0.2	7.24±0.3	1430.51±0.2
Piptadeniastrum africanum	42.67±0.1	5.60±0.3	51.48±0.2	0.24±0.2	0.02±0.1	16.272±0.1	0.843±0.3	10.17±0.2	4.87±0.21	2769.59±0.3
Cleistopholis partens	49.11±0.1	5.33±0.3	45.34±0.2	0.2±0.2	0.02±0.1	18.792±0.3	0.751±0.3	10.53±0.2	5.85±0.2	2290.98±0.2
Triplocyton scleroxylon	46.28±0.1	5.46±0.3	48.07±0.2	0.17±0.2	0.02±0.1	17.692±0.1	1.032±0.2	9.09±0.2	6.78±0.24	2962.52±0.2
Albizia sp	41.07±0.1	5.53±0.3	53.16±0.2	0.22±0.2	0.02±0.1	15.475±0.1	1.056±0.3	8.62±0.1	7.33±0.2	2586.38±0.2

Mean±standard deviation.

The obtained FVI values were between 1431 and 4092. These differences in the FVI values were as a result of the variations in densities, ash content and moisture levels of the wood species. High density increases the FVI, whereas high ash and moisture levels decreases the FVI. High density wood biomass are more preferable because they maintain embers for longer duration. It was observed that *Acacia sp* with a high density of 1.125 g/cm^3 and low ash content of 5.38% had the highest FVI value (4092), while *Blighia sapida* with a density value of 0.582 g/cm^3 and ash content of 7.24% had the lowest FVI value (1431). This clearly indicates that *Acacia sp* is more suitable for bioenergy production than the other species analyzed. To ensure optimal harnessing of woody biomass for bioenergy production, wood species with higher energy potential as indicated by their FVI (in this case, *Acacia sp*) should be specially grown and deployed either single mode or mixed with other species with average energy potential.

4. Conclusion

The bioenergy potential of ten tropical wood species from Nigeria were evaluated using their chemical compositions and thermal properties. Results obtained showed that sampled wood species have high percentages of extractives (20% to 28%), and high holocellulose content (43% to 52%). It was also observed that the sampled wood species had high lignin contents (27% to 30%); this was adduced to the old wood species analysed. The calorific values of sampled wood species, computed from their elemental analysis, were between 15.50 and 18.90 MJ/kg, which were similar to values reported for wood biomass suitable as fuelwood. Factors such as chemical composition, calorific value, and density influence the various wood to bioenergy conversion processes (combustion, pyrolysis, and gasification). Thus, *acacia sp* having the highest FVI value (4092) occasioned by its high gross calorific value, density and low ash value was found to be more suitable of the sampled wood species for bioenergy generation while *Blighia sapida* was found to be the least suitable.

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