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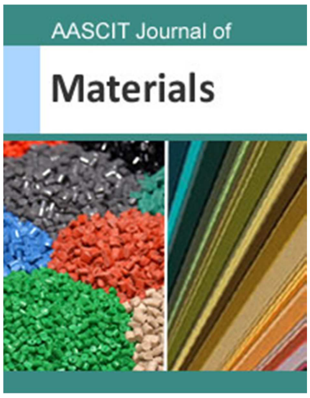

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Biomass Constituents and Physicochemical Properties of Some Tropical Softwoods

Chukwuma Stephen Ezeonu[1, *], Chigozie Margreat Ejikeme[2], Ngozi Cynthia Ezeonu[3], Augustine Eboatu[4]

[1]Department of Biochemistry, Federal University Wukari, Taraba State, Nigeria
[2]Department of Chemical Sciences, Godfrey Okoye University, Thinkers Corner, Enugu, Nigeria
[3]Department of Agricultural Economics and Extension, Federal University Wukari, Taraba State, Nigeria
[4]Department of Pure and Industrial Chemistry, Nnamdi Azikiwe University, Awka, Anambra State, Nigeria

Email address
chuksmaristos@yahoo.com (C. S. Ezeonu)
[*]Corresponding author

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Abstract
Softwoods are readily available in the tropics as found in Nigeria and most African forests; where they are used basically for timber purposes. Their biomass and physical constituents are great qualities needed to assess their values. These parameters (biomass and physicochemical constituents) were determined in some selected softwoods. The results shows that *Combretodendron macrocarpum* showed alkaline properties (8.12) while *Glyphea brevis* has a neutral pH (7.18). The rest of the softwoods were shown to test acidic with pH range of 4.53 – 6.95. The highest moisture content obtained gave value of 38% as found in *Protea ellilottii* closely followed by *Tetrapleura tetraptera* with moisture content of 37%. Highest recorded specific gravity values of 0.54 and 0.44 were obtained in *Sacoglottis gabonensis* and *Cassipourea barteri* respectively. Porosity index recorded for *Amphimas pterocarpoides* (2.44%) and *Afzelia bella* (2.24%) gave optimal values. *Allanblackia floribunda* with range of 95 – 121°C exhibited the highest charring temperature. Optimal lignin content (33%) was shown in *Moringa oleifera.* High hemicelluloses values of 33.5% and 32% were observed in *Dichrostacys cinerea* and *Kaempteria galangal. Cassipourea barteri* (50%) recorded the maximum cellulose content. Optimal crude fibre value of 5.7% was obtained in *Cambretodendron macrocarpum* followed by 5.55% value in *Barteria nigritian. Afzelia bella* with value of 1.72mg/g showed the highest content of carbohydrate in this research while *Afzelia bella* and *Pentaclethra macrophylla* with values of 7.85% and 7.77% respectively recorded the highest protein content.

1. Introduction

Tropical rain forest is the major source of timber supply and energy crops in Nigeria with high plant diversity of over 4,600 plant species [1]. The forest covers 10% of the country's land area with over 560 tree species at a range of about 30 to 70 species per hectare for trees ≥ 5cm diameter at breast height (dbh) [2]. While the timber industry for forest products is well established in Nigeria, the sawmill residues are underutilized [1].

It has been estimated that the volume of waste wood generated nationwide (in approximately 2000 sawmills) is 104,000 m^3 per day [3]. Thus, timber is clearly an untapped resource [1] in Nigeria; especially the wastes (saw dusts). Therefore, timber is a major source of biomass in Nigeria. The components of biomass include cellulose, hemicelluloses, lignin, extractives, lipids, proteins, simple sugars, starches, water, hydrocarbons, ash, and other compounds [4]. Cellulose, hemicellulose and lignin are the major biochemical components of lignocellulosic biomass [5-8]. Lignin can be used in a variety of industrial applications, however, and can also be converted to biodiesel or other liquid fuels [9]. The complex 3-dimensional structure of lignin is decomposed with difficulty by microorganisms and chemicals, and its function is therefore thought to be conferring mechanical strength and protection to plants. Hemicellulose can also be utilized in the production of co-products, such as furfural and acetic acid [9]. Moisture comprises 'free' and 'inherent' moisture; 'free' moisture is essentially surface moisture caused by rain whereas 'inherent' moisture is contained within the pore structure of the wood [10]. The moisture content of biomass is an important parameter in determining the thermal efficiency of plant [10]. The soil pH can affect the pH content of plants as the nutrient supplied in the plant is as a result of the content of the soil pH. According to Williston and LaFayette [11], soils with a pH of 6.0-7.0 typically have high concentrations of available nutrients. This research seeks to establish the biomass content as well as the physical properties inherent in some tropical softwood found in Nigerian. By extension, the knowledge of this will assist in appreciating the timber qualities of these softwood as well as challenge further research on other uses to which these timbers could be utilized other than construction purposes only.

2. Materials and Methods

2.1. Materials

The wood samples were obtained from timber markets in Enugu (Enugu State), Abakaliki (Ebonyi State), Okada (Edo State), and Nnewi (Anambra State) all in Nigeria. The states from where these timbers were collected were ascertained from timber dealers and confirmed by literature [12]. The timber dealers were able to give the local or common names of the timbers while the botanical names were obtained with the aid of Forest Officers and the literature [12].

2.2. Wood Sample Preparation

Fourteen well-grounded fine powdered timber samples were obtained using Angle grinder/polisher (Siemens, Germany). The powdered samples were kept in air- tight polyurethane bags in cool dry cabinets until required.

2.3. Determination of Total Lignin Content

The total lignin content of the wood was obtained by the determination of the soluble and insoluble lignin. The summation of the soluble and insoluble lignin gave the total lignin.

In the insoluble lignin determination, 2.00g of each wood powder were impregnated with 3cm^3 of 72% sulphuric acid and placed in a water bath at a controlled temperature of 30°C for 1h, after which 68cm^3 of deionized water was added to the mixture. The conical flask and its contents (mixture) were heated in an autoclave at 125°C for 1hr. 15min. The conical flask with its content was cooled and the lignin filtered. The insoluble lignin was washed with deionized water until neutral pH and then dried in an oven at a temperature of 80°C until a constant weight [13].

The lignin content was calculated by the following formula:

$$IL = \frac{W\ lignin}{W\ fibre} \times 100$$

Where IL = Insoluble lignin content (%)

W lignin = oven dry weight of insoluble lignin (g)

W fibre = oven dry weight of wood fibres (g)

The filtrate obtained from the insoluble lignin was used to determine the soluble lignin content in sulphuric acid by spectrophotometric method. In this method, 5cm^3 of 3% suphuric acid was added to 5cm^3 of the insoluble lignin filtrate. A UV spectrophotometer was used to measure the absorbance of the solution at a wavelength of 205nm [13]. The soluble lignin content was calculated by the following expression:

$$SL = \frac{CV}{1000\ \times W\ fibre} \times 100$$

Where SL = soluble lignin content (%)

C = concentration of soluble lignin in the filtrate (g/L).

V = total volume of the filtrate (cm^3)

W fibre = oven dry weight of wood fibres (g)

The concentration of soluble lignin in the filtrate (C) is given by

$$C = \frac{A}{110} \times \frac{V\ final}{V\ initial}$$

Where A = absorbance at a wavelength of 205nm.

V final = final volume of the solution (cm^3)

V initial = initial volume of the solution (cm^3)

The total lignin content was obtained by the addition of insoluble and soluble lignin obtained by both methods.

TL = IL + SL

Where TL = total lignin

IL = insoluble lignin

SL = soluble lignin.

2.4. Determination of Hemicellulose

Neutral detergent solution was prepared by weighing

18.61g of disodium ethylenediamine tetraacetate and 6.81g of sodium borate decahydrate into a 1000cm^3 beaker and dissolved in a 200cm^3 distilled water by heating in an electromagnetic stirrer. To this a 150cm^3 solution containing 30g of sodium lauryl sulphate, 10cm^3 of 2-ethoxy ethanol and 100cm^3 solution containing 4.5g of disodium hydrogen phosphate was added. The volume was made up to 1000cm^3 and the pH of the solution kept at 7.

To 1.0g of each wood powder in a refluxing flask, 10cm^3 of cold neutral detergent solution was added followed by 0.5g sodium sulphate. The mixture was heated to boiling and refluxed for 60 min. The solution was filtered through a Whatman filter paper No 42 (125mm) and the residue in the paper washed twice with acetone. The filter paper with the residue was dried in an oven at a temperature of 100°C for 8hrs. The filter paper and its content were cooled in a desiccator and weighed [13]. Hemicellulose is calculated thus:

Hemicellulose = Neutral Detergent Fibre (NDF) – Acid detergent Fibre (ADF)

Where ADF value = Value of Lignin content.

2.5. Determination of Cellulose

One gram of each wood sample was weighed and transferred into a 250cm^3 Erylenmeyer flask. 50cm^3 of 96% ethyl alcohol and 25cm^3 of 65% nitric acid was added. The flask was connected to a condensing apparatus and heated on a heating mantle for 1 hr. After hydrolysis, the flask contents were filtered. Once more, remaining cellulose on the filter paper was transferred into the flask, and the process was repeated twice, the celluloses together with the filter papers were dried at 120°C.

The cellulose content was calculated from the following equation [14-15].

$$Cellulose\ (\%) = \frac{Cellulose\ dry\ weight}{Wood\ Sample\ dry\ weight} \times 100$$

2.6. Determination of Crude Fibre

Five gram of each dry wood sample was weighed into a thimble and transferred into the soxhlet extractor chamber fitted with a condenser and a flat bottomed flask. 150cm^3 of petroleum ether enough to cause reflux was poured into the flask. The sample was extracted of its lipid and interfering pigment for 3hrs at a temperature of 60°C. After extraction, the sample was dried in an oven for 3hrs at a temperature of 80°C.

After drying, 2.00g of each wood sample was boiled with 200cm^3 tetraoxosulphate (VI) acid for 30min on an electric hot plate with bumping chips and filtered through muslin cloth and washed with boiling water until filtrate was no longer acidic. The residue was boiled with 200cm^3 of sodium hydroxide solution on an electric hot plate for 30min and filtered through muslin cloth and washed with 25cm^3 of boiled 1.25% tetraoxosulphate (VI) acid, 350cm^3 of water and 25cm^3 of ethanol. The residue was removed and transferred to an ashing dish (preweighed dish W_1) and dried for 2hrs at a temperature of 130°C. The dish was cooled in a desiccator and weighed (W_2). The ashing dish with the residue was placed in a muffle furnace for 30min at a temperature of 600°C, the dish was cooled in a desiccator and reweighed (W_3) [16]. The crude fibre content was determined as:

$$Crude\ fibre\ (\%) = \frac{Loss\ in\ weight\ on\ ignition\ (W2 - W1) - (W3 - W1)}{Weight\ of\ Sample} \times 100$$

2.7. Determination of Crude Protein

One gram of each wood powder was weighed into a 500cm^3 Kjeldahl flask and 10cm^3 of concentrated sulphuric acid (H_2SO_4) was added gently by swirling under tap water. Anhydrous sodium sulphate (Na_2SO_4) (10g) and 1.00g of copper sulphate ($CuSO_4$) were mixed together and 1.50g of this mixture (Na_2SO_4 and $CuSO_4$) was introduced into the flask, followed by addition of anti-bumping chips into flask. The entire mixture in the Kjeldahl flask was boiled gently in a fume cupboard until charred particles disappear and a clear green solution was obtained. The solution was filtered through a Whatman filter paper No 42 (125mm), the residue washed with distilled water and the digest mixture made up to 50cm^3 volumes with distilled water.

Into a 250cm^3 beaker (receiver beaker) was added 5cm^3 of boric acid followed by one drop of methyl orange indicator. A distillation apparatus fitted with a condenser was set up and 5cm^3 of the digest was placed in a distillation flask, followed by the addition of 15cm^3 of 40% sodium hydroxide slowly with the aid of a syringe. The distillation flask and its content were heated for 10min for distillation to occur. At the end of distillation, the receiver beaker was removed and the distillate titrated with 0.10M hydrochloric acid (HCl) until the end point [17].

The crude protein was determined as:

$$Protein\ (\%) = \frac{1.4x\ \times xDF\ \times 100\ \times 5.55}{Original\ Weight\ of\ Sample\ (mg)}$$

$$Where\ x = Titre\ Value$$

D.F = Dilution factor

1.4 = Amount of nitrogen

100 = Volume of sample

5.55 = Constant Factor

2.8. Determination of Carbohydrate

Anthrone reagent was prepared by dissolving 200mg of anthrone in 100cm^3 of ice-cold 95% tetraoxosulphate (VI) acid. The standard glucose stock was prepared by dissolving 100mg of standard glucose in 100cm^3 of distilled water. The Working standard solution was prepared by dissolving 10cm^3 of the standard glucose stock in 100cm^3 of distilled water, followed by the addition of three drops of toluene.

One gram of each wood powder was weighed into a boiling tube and hydrolyzed by keeping it in a boiling water bath for 3hrs with addition of 5cm^3 of 2.5M hydrochloric acid. Thereafter, it was cooled to room temperature and neutralized with solid sodium carbonate until effervescence ceased. This was made up to 100cm^3 by volume and centrifuged. The supernatant was collected and 1cm^3 of distilled water was added to 1cm^3 of the aliquot (supernatant solution) followed by the addition of 4cm^3 of anthrone reagent. The mixture was heated for 8min for colour development in a boiling water bath, cooled and optical density measured at 630nm.

The carbohydrate standard curve was prepared by pipetting (0-1cm^3) of the working standard solution into six different test tubes where "0" serves as a blank. 1cm^3 of distilled water and 4cm^3 of anthrone reagent added to each tube, mixed and heated in boiling water for 8min. After eight minutes, it was cooled and optical density measured at 630nm [18]. From the graph, the amount of carbohydrate present was calculated as:

$$Carbohydrate\left(\frac{mg}{g}\right)=\frac{mg\ of\ glucose}{Vol.of\ test\ sample}\times 100$$

2.9. Determination of pH

The hydrogen ion concentrations (pH) of the powdered woods were determined as described elsewhere by Amadi *et al*., [17]; using electrical pH meter PHS-25 made by Life Care England.

2.10. Moisture Content Determination

The moisture content was determined by weighing two grams of each wood powder into a pre-heated cooled and weighed crucible. The wood sample in each crucible was dried in an oven for 24 h at a regulated temperature of 100°C, to a constant weight. Each crucible and its content were cooled in desiccators before weighing in accordance to the method by Amadi *et al*. [17].

The moisture content was determined as the percentage moisture.

$$\%\ Moisture=\frac{Weight\ of\ wet\ sample-Weight\ of\ dry\ sample}{Weight\ of\ dry\ sampl}X\ 100$$

2.11. Charring Temperature

The charring temperature was determined by placing 0.50g of the wood powder inside an ignition tube into which a thermometer (0-360°C) was inserted. The combustion tube was then clamped on a heating mantle, which was regulated at constant heating point. As the material was heated to char point, the exact char temperature was recorded.

2.12. Specific Gravity

The specific gravity was determined gravimetrically by measuring the oven-dried wood powder using specific gravity bottle, method of Amadi *et al.,* [17].

2.13. Determination of Porosity Index

Mathematically, Porosity index was calculated thus:

One gram of cold water starch was prepared with 5cm^3 of water. The starch which serves as an adhesive was mixed with 1.03g of the wood powder. The mixture (slurry mixture) was moulded into ring shape and allowed to dry on exposure to air for 15h. The moulded dry wood sample was weighed using an electronic weighing balance, Model B218 and dry weight was determined. The dry wood sample was soaked in 75cm^3 paraffin oil for 24h. The soaked dry wood sample was weighed and the weight noted.

Porosity index = Weight of dry starch wood sample soaked in oil / Weight of dry starch wood sample

2.14. Determination of Colour

The colours of the wood powder were determined using sight observation method. The colours of the wood samples were matched with Chemistry Colour Chart and respective colours were obtained (http://www.rfs.org.uk/learning/what-wood).

3. Result

Table 1 shows the various tropical softwood found in Nigerian; their classification, botanical and indigenous names in addition to locations where they were obtained. Various parameters were examined to ascertain the physical properties of the various softwoods investigated. Thus, the result showed that the pH of the various softwoods had acidic, alkaline or neutral properties. *Combretodendron macrocarpum* gave alkaline value of 8.12 while *Glyphea brevis* (7.18) had a neutral pH. The rest of the softwoods were shown to test acidic with pH range of 4.53 – 6.95. *Allanblackia floribunda* with value of 4.53 was more acidic, while the least acidic was *Amphimas pterocarpoides* (6.95) as shown in table 2. The acidic pH of softwoods obtained in this research was similar to those of pine softwoods, such as *Pinus palustris, Pinus taeda, Pinus echinata and Pinus elliottii* with pH of *4.5* - 7.0 respectively, while *P. rigida* 3.5 - 4.5 was more acidic than the pH from this research [19, 11]. The moisture content is appreciable in that the range in all the softwoods examined was between 13 – 38%. The highest moisture content obtained gave value of 38% as found in *Protea ellilottii* closely followed by *Tetrapleura tetraptera* with moisture content of 37%. Least moisture content values of 13% were observed in each of *Moringa oleifera* and *Anogeissus leiocarpus.* Highest recorded specific gravity values of 0.54 and 0.44 were obtained in *Sacoglottis gabonensis* and *Cassipourea barteri* respectively. The specific gravity value obtained in this research is far less than 1.65 on *Sacoglottis gabonensis* reported by an earlier research [20]. General range of the specific gravity of all the softwoods examined was from

0.13 to 0.54 (Table 2). Least porosity index of 1.15% and 1.19% were obtained in *Moringa oleifera* and *Kaempferia galangal*. All samples examined had porosity index between 1.15 and 2.44% with 2.44% and 2.24% porosity index recorded for *Amphimas pterocarpoides* and *Afzelia bella* as the maximum values in the lot. The charring temperature range recorded in this experiment for all the softwood consists of lower limit of 61°C and upper limit of 121°C. *Allanblackia floribunda* with charring temperature range of 95 – 121°C gave the maximum value in all the samples examined followed by 96-119°C obtained in *Amphimas pterocarpoides*. Least charring temperature range values of 61-92°C, 62-78°C and 63°C were observed in *Tetrapleura tetraptera, Combretodendron macrocarpum* and *Khaya ivorensis.* The different colour of the examined Nigerian softwoods is shown in table 2.

The biomass components investigate showed that the values of lignin in all samples were between 20% and 33% (Figure 1). Least lignin values of 20% were found in each of *Afzelia bella* and *Cordial millenii* while *Moringa oleifera* gave the maximum lignin content value of 33%. Hemicellulose components in the softwood samples examined had values of between 20 and 33.5%. Those with the least hemicelluloses values of 20% include: *Monodara tenuifolia, Moringa oleifera* and *Afzelia bella* while maximum hemicelluloses values of 33.5% and 32% were observed in *Dichrostacys cinerea* and *Kaempteria galangal*. The rest had hemicelluloses values between 20.5 and 30% as shown in figure 1. The Nigerian softwoods in this research gave high cellulose content ranging between 40 and 50% with *Cassipourea barteri* (50%) recorded as the maximum cellulose content. The least cellulose value of 40% was established in each of *Moringa oleifera, Protea ellilottii, Anogeissus leiocarpus, Dichrostacys cinerea* and *Tetrapleura tetraptera*. The maximum crude fibre value of 5.7% was obtained in *Cambretodendron macrocarpum* followed by 5.55% value in *Barteria nigritian*. Minimum crude fibre values of 0.2% and 0.3% were discovered in *Cassipourea barteri* and *Moringa oleifera*. Other softwood crude fibre values were noted to occur between 0.9% and 5% (figure 1). The softwood samples with the least carbohydrate values as obtained in this research are *Allanblackia floribunda* (0.9%), *Cassipourea barteri* (0.92%) and *Moringa oleifera* (0.93%). Majority of these tropical softwoods investigated had carbohydrate values between 1.22 and 1.61%; however *Afzelia bella* with value of 1.72% showed the highest content of carbohydrate in this research. Crude protein values obtained in this research lies between 1.55% and 7.85% with *Afzelia bella* and *Pentaclethra macrophylla* with values of 7.85% and 7.77% as maximum. Minimum crude protein value of 1.55% was seen in *Moringa oleifera, Sterculia oblonga* and *Cordial millenii.*

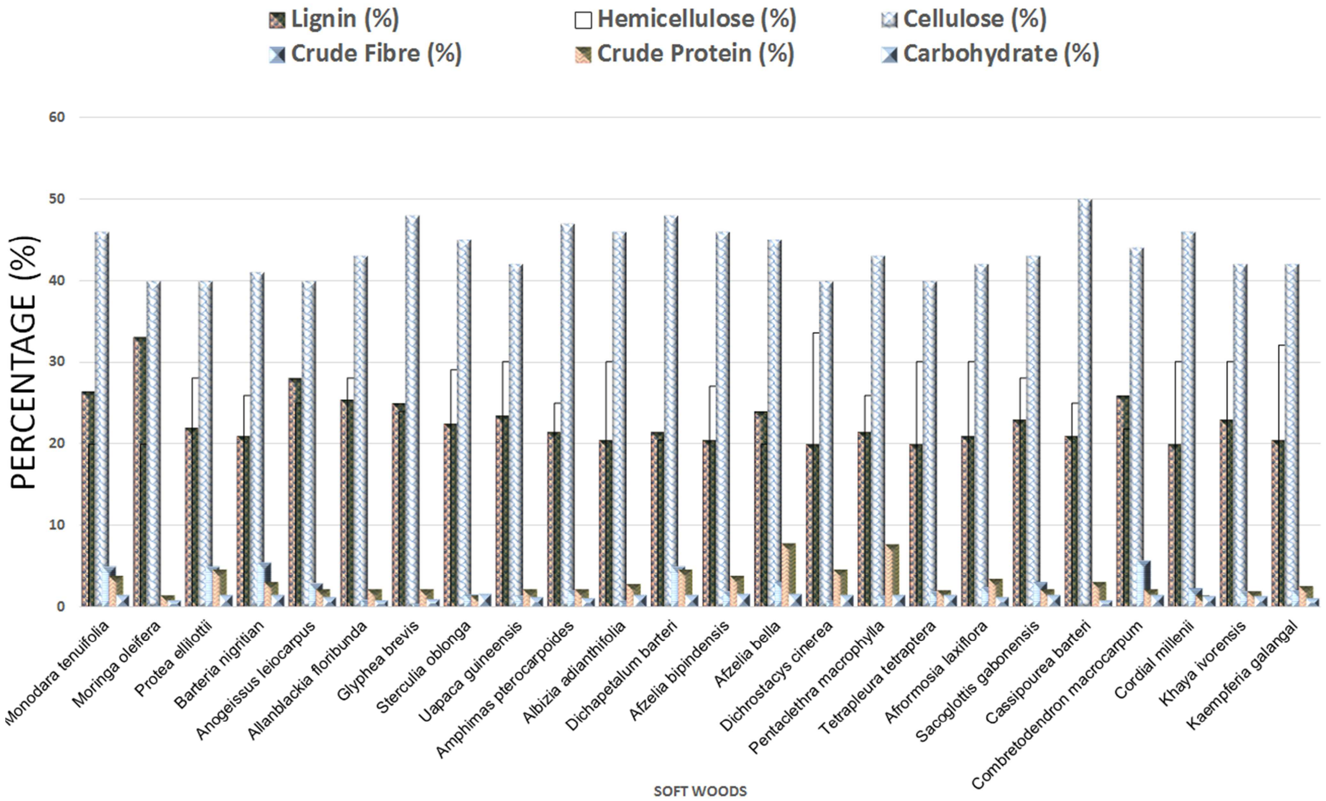

Figure 1. *Biomass constituent values of some tropical softwoods indigenous to Nigeria.*

Table 1. *Table of the Botanical and Local Names as well as Location of Various tropical Nigerian softwoods.*

1	Wood Sample (Botanical Name)	Classification	Botanical families	Igbo	Yoruba	Hausa	Location
1.	*Monodara tenuifolia*	Softwood	Annonaceae	Ehuru ofia	Lakesin	Guyiyadanmiya	Port Harcourt
2.	*Moringa oleifera*	Softwood	Moringaceae	Okwe oyibo	Ewe igbale	Zogalla gandi	Lagos, Ibadan
3.	*Protea ellilottii*	Softwood	Proteaceae	Okwo	Dehinbolorun	Halshena	Nsukka
4.	*Barteria nigritian*	Softwood	-	Ukwoifia	Oko	Idon zakara	Nsukka, Enugu
5.	*Anogeissus leiocarpus*	Softwood	Combretaceae	Atara	Egba	Marike	Onitsha, Awka
6.	*Allanblackia floribunda*	Softwood	Guttiferae	Egba	Orogbo	Guthiferae eku	Calabar, Ikom
7.	*Glyphea brevis*	Softwood	Tiliaceae	Anyasu alo	Eso, shishi	Bolukonu kanana	Calabar
8.	*Sterculia oblonga*	Softwood	Stericuliaceae	Ebenebe	Aworlwo	Kukuki	Ibadan
9.	*Uapaca guineensis*	Softwood	Euphorbiaceae	Obia	Akun	Wawan kurmi	Onitsha
10.	*Amphimas pterocarpoides*	Softwood	Leguminosae	Awo	Ogiya	Wawan kurmii	Umuahia, Iko
11.	*Albizia adianthifolia*	Softwood	Leuminosae-Mimosoideae	Avu	Anyimebona	Gamba	Enugu, Nsukka
12.	*Dichapetalum barteri*	Softwood	Dichapetalaceae	Ngbu ewu	Ira	Kirni	Onitsha, Agulu
13.	*Afzelia bipindensis*	Softwood	Fabaceae	Aja	Olutoko	Rogon daji	Benin
14.	*Afzelia bella*	Softwood	Fabaceae	Uzoaka	-	Epa	Owerri, Orlu
15.	*Dichrostacys cinerea*	Softwood	Fabaceae	Amiogwu	Kara	Dundu	Onitsha
16.	*Pentaclethra macrophylla*	Softwood	Leguminosae	Ugba	Apara	Kiriya	Onitsha
17.	*Tetrapleura tetraptera*	Softwood	Leuminosae-Mimosoideae	Oshosho	Aridan	Dawo	Onitsha, Akpaka
18.	*Afrormosia laxiflora*	Softwood	Leuminosae-papilionoideae	Abua ocha	Shedun	Idon zakara	Sokoto
19.	*Sacoglottis gabonensis*	Softwood	Rhizophoraceae	Nche	Atala	Chediya	Rivers
20.	*Cassipourea barteri*	Softwood	Lecythidaceae	Itobo	Itobo	Odu	Eket
21.	*Combretodendron macrocarpum*	Softwood	Ochnaceae	Anwushi	Anwushi	Akasun	Udi, Owerri
22.	*Cordial millenii*	Softwood	Meliaceae	Okwe	Okwe	-	Owerri, Onitsha
23.	*Khaya ivorensis*	Softwood	Bignoniaceae	Ono	Oganwo	Madachi	Calabar
24.	*Kaempferia galangal*	Softwood	Zingiberaceae	Shanty	-	-	Enugu

Table 2. *Table showing values of some physical properties of some tropical softwoods indigenous to Nigeria.*

S/N	Wood Sample (Botanical Name)	pH Values	Moisture Content (%)	Specific Gravity	Charring Temperature (°C)	Porosity index (%)	Colour
1.	*Monodara tenuifolia*	5.85	27.0	0.43	90 – 101	1.38	Cornsilk
2.	*Moringa oleifera*	6.51	13.0	0.32	92 -115	1.15	Lemonchiffon
3.	*Protea ellilottii*	6.5	38.0	0.29	65 – 90	1.26	Cornsilk
4.	*Barteria nigritian*	6.37	18.0	0.42	99 -117	1.34	Cornsilk
5.	*Anogeissus leiocarpus*	6.26	13.0	0.25	82 -106	1.31	Khaki
6.	*Allanblackia floribunda*	4.53	25.0	0.37	95 – 121	1.23	Cornsilk
7.	*Glyphea brevis*	7.18	27.0	0.39	94 – 101	1.38	Burly wood
8.	*Sterculia oblonga*	6.51	23.0	0.30	92 -114	1.52	Tan
9.	*Uapaca guineensis*	5.3	25.0	0.44	78 – 86	1.55	Khaki
10.	*Amphimas pterocarpoides*	6.95	18.0	0.39	96 – 119	2.44	Tan
11.	*Albizia adianthifolia*	6.65	23.0	0.25	95 – 105	1.85	Khaki
12.	*Dichapetalum barteri*	6.64	24.0	0.16	82 – 96	1.86	Cornsilk
13.	*Afzelia bipindensis*	6.65	14.0	0.42	88 – 110	1.32	Cornsilk
14.	*Afzelia bella*	6.65	23.0	0.16	78 – 92	2.24	Cornsilk
15.	*Dichrostacys cinerea*	6.09	28.0	0.13	75 – 97	1.48	Cornsilk
16.	*Pentaclethra macrophylla*	6.64	16.0	0.40	80 – 109	1.37	Beige
17.	*Tetrapleura tetraptera*	6.55	37.0	0.26	61 – 92	1.31	Lemon Chiffon
18.	*Afrormosia laxiflora*	6.55	34.0	0.20	89 – 101	1.56	Lemon Chiffon
19.	*Sacoglottis gabonensis*	6.37	27.0	0.54	89 – 104	1.41	Tan
20.	*Cassipourea barteri*	6.95	16.0	0.44	97 – 114	1.70	Peru
21.	*Combretodendron macrocarpum*	8.12	26.0	0.36	62 – 78	1.50	Lemon Chiffon
22.	*Cordial millenii*	6.65	30.0	0.36	91 – 103	1.38	Cornsilk
23.	*Khaya ivorensis*	5.31	29.0	0.32	63 – 85	1.39	Cornsilk
24.	*Kaempferia galangal*	6.54	27.0	0.23	93 – 113	1.19	Lemon Chiffon

4. Discussion

Physical properties of woods are used in establishing how they react to manufacturing forces and the durability of product manufactured from these tropical Nigerian indigenous softwoods. Apart from *Combretodendron macrocarpum* which was alkaline and *Glyphea brevis* that tested neutral in this work, the rest of the softwoods had pH values indicative of acidity. Therefore, determination of variation in the acidity of wood during the storage will contribute to the evaluation of wood in industry. In this wise, treatment of wood with preservatives, the adhesive power of glues, production of particle- and fiberboard are directly connected to the pH of wood [21]. Ucar, and Ucar, [22] agreed that the acidity of wood is an important property for various ranges of its utilization in wood working industries. Woods in the acidic range are shown to be durable and more resistant to insect and biological deterioration.

Moisture contents of woods generally are measured in comparison to the fiber saturation point (FSP) which differs according to wood species. It is generally accepted that woods have averages FSP moisture content of about 28%. Based on this fact, the research result shows that apart from *Dichrostacys cinerea, Tetrapleura tetraptera, Afrormosia laxiflora, Protea ellilottii, Cordial millenii and Khaya ivorensis* whose values were equal or above the FSP average value, all other softwoods examined had moisture content below 28% as shown in the result (table 2). Wood strength is maintained without changes above the fiber saturation point. There is increase in wood strength with reduction in moisture content below the fiber saturation point. According to AES [23], the density of wood is related to its hardness, strength and weight. Typically, a dense species of wood is heavier, harder and stronger than other less dense species. Again most of the result in this work is in agreement with moisture content of 5-20% for dried wood used for fuel typically [24-25] as well as 20-25% maximum moisture content of normal Nigerian timber [20]. Most temperate softwood has moisture content ranging from 9.9 – 28.1% [26]. Therefore, tropical softwoods have the requisite strength for any timber uses for which they are needed. Moreover, those with higher FSP as listed above will find great usefulness in the pulp and paper industry. According to Bergman [27], when wood dries, most of its strength properties increase, as well as its electrical and thermal insulating properties. Properly dried lumber can be cut to precise dimensions and machined more easily and efficiently; wood parts can be more securely fitted and fastened together with nails, screws, bolts, and adhesives; warping, splitting, checking, and other harmful effects of uncontrolled drying are largely eliminated; and paint, varnish, and other finishes are more effectively applied and maintained. Wood must be relatively dry before gluing or treating with decay-preventing and fire-retardant chemicals.

In the simplest term, specific gravity gives an idea about the density or weight of particular plant species. Temperate softwoods such as the *Pinacea* family have specific gravity of the range 0.27-0.46, the Fir between 0.31 – 0.46, the spruce between 0.33 – 0.49, cedar between 0.31-0.44 [26]. The following softwoods: *Anogeissus leiocarpus, Albizia adianthifolia, Dichapetalum barteri, Afzelia bella*, *Dichrostacys cinerea, Afrormosia laxiflora and Kaempferia galangal* gave lower specific density in comparison to the values obtained from the temperate softwood trees. The other Nigerian softwoods (table 2) apart from those listed above falls within the range shown in the temperate softwoods. Generally, high density woods are harder than low density woods thus preferred in most construction works. Wood properties that have the greatest effect on the manufacturing and performance characteristics of woods generally are those with greater densities. Low density woods have values in light weight required buildings or furniture tops where priority is not placed on weight. They are equally useful in paper and pulp industries. Biological degradation is bound to affect woods of low density as well.

White and Dietenberger [28], stated that char is the dominant product at internal temperatures less than 300°C whereas volatiles become much more pronounced above 300°C. The self-insulating qualities of wood, particularly in the large wood sections of heavy timber construction, are an important factor in providing a degree of fire resistance. The charring temperatures recorded in this research shows lower limit of 61°C and upper limit of 121°C. These values are in agreement with previous work [29]. Generally the char temperatures of these softwoods is moderate. However, those whose upper char limits exceeded 100°C have less fire resistance than those below these limits. Higher charring temperatures of the wood are an indication of decreased strength of such wood. Tropical softwoods with lower charring temperatures are considered more durable and dependable in door/window construction and house roofing.

According to Ejikeme *et al.* [29], porosity gives a good estimate of wood particle compactness or otherwise and thus shows where they are needed. The percentage porosity index of the tropical Nigerian softwoods are generally low showing that most of them have high compact grain particles suitable for all types of wood uses. This is in agreement with the result of this experiment as the porosity index ranged between 1.19 - 2.44. Porosity in woods shows empty spaces ‘voids’ prevalent in them which are normally occupied by water, mineral salts and air, bearing in mind that the wood was formerly part of a live tree where porosity was required for translocation and conduction in vessels. Colour type is an easy way of identifying different species of wood visually. Colour determination is a quality control measure adopted by commercial timber dealers to ascertain if a given timber from tree species has been well seasoned (dried), it also helps to determine biological degradation as fungal attack may change the colour. Stains in wood shows poor quality timber and therefore the colour for which each timber species are known with must be maintained. Colours were greatly maintained in the softwoods examined in this research.

Lignin content values of 20-33% were obtained in this research on the softwood examined. The result agrees with lignin values 20-29% from Ezeonu *et al.* [30] and 18-25% [31 -34].

The tropical softwoods cellulose content in this research was between 40 – 50%; this is similar to 45-50% stated elsewhere [31 – 34]. The cellulose content also compares favorably with other agro-cellulosic materials like *Aspergillus fumigatus* treated rice husk with value of 45 ± 3.31% and *Aspergillus niger* treated rice husk which gave 40 ± 9.43% cellulose rice husk [30]. This indicates that cellulose is present in appreciable quantities generally in softwood as its content here compares favourable with other plant sources. In the modern papermaking process, softwood pulp is generally used to provide the required strength in the final product, and also used as reinforcing pulp to maintain the high speed of a paper machine [35]. Paper strength also depends on the lignin and cellulose content of raw plant materials; pulp mechanical strength and especially tensile strength is directly proportional to cellulose content [36].

Hemicellulose contents of the softwoods examined in this research was between 20 - 33.5%. The finding by Johansson [37], indicated that hemicelluloses in softwood add up to 25-30% of the dry matter; which is in accord with the findings of this research. Ezeonu *et al.* [38] discovered that fourteen Niger delta indigenous woods investigated had hemicelluloses contents between 20 – 35% which is in agreement to this research results. Glucomannan is the most common hemicellulose found in softwood and has a backbone of glucose and mannose monomers with galactose substituents [38]. Kraft pulping yield increase is mainly due to glucomannan increased retention.

The range values of crude fibre (0.2-5.7%), crude protein (1.55-7.85%) and carbohydrate (0.91 – 1.72) were obtained in the analysis of tropical Nigerian softwoods in this research. Ezeonu *et al*. [38] showed that other Nigerian Niger delta sawmill chips gave crude fibre range value of 0.2- 6.2%, crude protein range value of 1.55 – 4.66% and carbohydrate range value of 0.92 – 1.62% which showed similarities to the values of this research. The fact that carbohydrate *vis a viz* simple sugar is present in these softwoods shows that they can be exploited in production of biofuel such as bio-ethanol. Also research on Nigerian eucalyptus softwood by Ta'awu *et al*.[39] with crude protein content of 5.08 ± 0.80% showed similarity with the current research result, but carbohydrate 3.11 ± 0.34% and crude fibre value not detected in their research [39] differs from that of this research.

Second generation bioethanol pathway has several promising applications in the biorefinery concept [40], from lignin processing for resin and chemicals production, to nanocrystalline cellulose as polymer matrix nanocomposites [42], to bioethanol reforming for power production in molten carbonate fuel cells [43].

5. Conclusion

In this research, these tropical softwoods indigenous to Nigeria have shown to be ideal for all manufacturing processes especially due to their physicochemical properties that are suitable for all types of wood work. The biomass made up of hemicelluloses component will have possibility in the production of industrial lignin based fine chemicals, bioethanol and cellulose, as well as paper and pulp processing. This research has established that both physical and biomass constituents of these soft wood possess such qualities that are required for their commercial usage in wood work and industries.

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