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ANATOMICAL AND CHEMICAL PROPERTIES OF WOOD AND THEIR PRACTICAL IMPLICATIONS IN PULP AND PAPER PRODUCTION: A REVIEW

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ABSTRACT
Wood is a highly variable and complex material that has different chemical, physical and anatomical properties that influence its commercial value. This review therefore, explains the wide variability between anatomical and chemical properties of wood and their practical implication in pulp and paper production. In papermaking, fibres are the cell elements that impart strength to the paper sheet. The function of the vessel element is to conduct water and dissolved minerals from the roots to the higher parts of the plant. Generally, lingnocellulose materials from wood and non-wood plant consist of lignin, hemicelluloses, extractive and some inorganic matter. Information on the chemical composition is important in deciding the techno-commercial suitability, pulping method and paper strength of a particular wood material.

Keywoods: Wood, Anatomcal, Chemical, Pulp, Paper

INTRODUCTION
A comprehensive knowledge of the characteristics of any material is essential for its best utilization. This is especially true for wood because of its cellular nature and its complex cell wall structure. One of the greatest architects of our time, Frank Lloyd Wright, put it best in 1928: “We may use wood with intelligence only if we understand wood” (Jozsa and Middleton, 1994). Resource Managers and Foresters, who wish to maximize forest values, need to understand not only the principles of tree growth, but also some of the macroscopic and microscopic features that determine wood (Jozsa and Middleton, 1994).

Wood is a hard, fibrous tissue found in many trees. It has been used for hundreds of thousands of years for fuel, construction and industrial raw materials. It is an organic and natural composite of cellulose fibres embedded in a matrix of lignin which resists compression. Wood is sometimes defined as the only secondary xylem in the stems of trees (Hickey and King, 2001). It is the single most important raw material in pulp and paper production and therefore has to play a major role in industrial and economic growth of a nation.

Among many indices that made wood a valuable raw material valued for pulp and paper production, the anatomical and chemical composition of wood stand out. Though many works have been carried out on the potentials of many wood species for pulp and paper production, no detailed review of the anatomical and chemical properties have been documented to serve as the benchmark for researchers and pulp and paper producers for selecting any wood material for paper production. This paper therefore, attempts to review the major anatomical and chemical properties of wood and their practical implications in pulp and paper making. This is expected to serve as a guide to the pulp paper Producers, Researchers and young Scientist who are in dare need for screening lignocellulosic materials for pulp and paper production.

Anatomical Characteristics of Wood and their Practical Implication in Pulp and Paper Production

Wood anatomy has to do with the arrangement of the cellular structure of the wood and this has a great implication on their end-use. For example, several researchers have revealed that the characteristics of wood pulp and the products made from them are determined by the properties of wood used as raw material and their anatomic, morphological and chemical properties as well. Some of the anatomical properties of importance in the selection of a lignocellulosic material are presented in Table 1, 2 and 3 with their discussions thereafter.

Table 1: Fibre Dimensions of Hard Wood Species suitable for Pulp and Paper making

Fibre Sources	Fibre Length (mm)	Diameter (µm)	Lumen Diameter (µm)	Cell wall Thickness (µm)	Sources
Delonix regia	1.34±0.14	39.42±3.51	26.83±2.75	6.49±0.87	Riki, 2018
Ficus exasperate	1.07±0.28	24.52±15.19	14.05±0.22	5.47±7.23	Anguruwa, 2018
Ricinodedron heudelotti	1.40±0.17	41.40±11.7	32.3±11.0	4.60±1.15	Ogunleye *et al*., 2016
Gerdenia ternifolia	1.18 –1.50	22.80–31.00	5.21 – 7.45	12.80 –16.30	Noah *et al.,* (2015
Ficus mucoso	1.5–1.7	27.4 – 30.1	1.4 – 5.5	19.0– 39.4	Adejoba and Onilude, 2012)
Aningeria robusta	1.66 –1.93	26.42-32.57	5.48-7.50	14.51-18.33	Ajala and Noah, (2019)
Fiji Pinuscaribaea	2.4	0.045-0.047	0.04-0.06	0.036-0.037	FAO (1975)

Table 2: Average Fiber Dimensions of Soft Wood Species suitable for Pulp and Paper making

Fibre Sources	Fibre Length (mm)	Diameter (µm)	Lumen Diameter (µm)	Cell wall Thickness (µm)	Source
Coniferous trees (Softwood e.g *Pinus Caribeae, Picea brewerian,Cedrus alantica, Abies magnifica, Juniperus communic, Metasequoia glyptostroboides etc*)	3.7	32.43	15.30	13.17	As., 2002

Table 3: Fibre Dimensions of some Non-wood plant materials suitable for Pulp and Paper making

Fibre Sources	Fibre Length (mm)	Diameter (µm)	Lumen Diameter (µm)	Cell wall Thickness (µm)	Sources
Oryza sativa (Rice straw)	0.89	14.80	6.40	4.20	Ahmet *et al*., 2004
*Hibiscus cannabinus (*Kenaf - bark)	2.32	21.9	11.9	4.2	Ververis *et al*., 2004
Hibiscus cannabinus (Kenaf- core)	0.74	22.2	13.2	4.3	Ververis *et al*., 2004
Hibiscus cannabinus (Kenaf -whole)	1.29	22.1	12.7	4.3	Ververis *et al*., 2004
Panicum virgatum (Switch grass)	1.15	13.1	5.8	4.6	Ververis *et al*., 2004
Triticum aestivum (Wheat straw)	0.74	13.2	4.0	4.6	Deniz *et al*., 2004
Secale cereale (Rye straw)	1.15	14.7	4.2	1.1	Eroglu, 1998
Gossypium Spp (Cotton stalks)	0.83	19.6	12.8	3.4	Ververis *et al*., 2004
Thaumatococcus daniellii (Miraculus Berry)	2.68	15.61	10.11	2.75	Oluwadare and Sotannde, 2006

Vessel elements and Parenchyma cells

In papermaking, fibres are the cell elements that impart strength to the paper sheet. The function of the vessel element is to conduct water and dissolved minerals from the roots to the higher parts of the plant. As result, the primary cell wall is partly strengthened, or almost entirely covered with a lignified secondary wall. Large vessel elements cause a vessel-picking problem in papermaking when hardwoods are used (Panula-Ontto *et al*., 2007). On the contrary, the function of parenchyma cell in plant is to store water, nutrient and assimilated products. In papermaking, parenchyma cells with spherical and small cells are considered to decrease the raw material quality (Karjalainen *et al*., 2012). Parenchyma has low density and decreases the bulk density of the chip charge to the pulp digester. It also consumes chemicals without participating in paper strength and it makes pulp water drainage more difficult. The proportion of parenchyma cell in fibres used for papermaking is between the range of 20 – 50% (Veveris *et al*., 2004). The image of the vessel element and parenchyma cell is presented in figure 1.

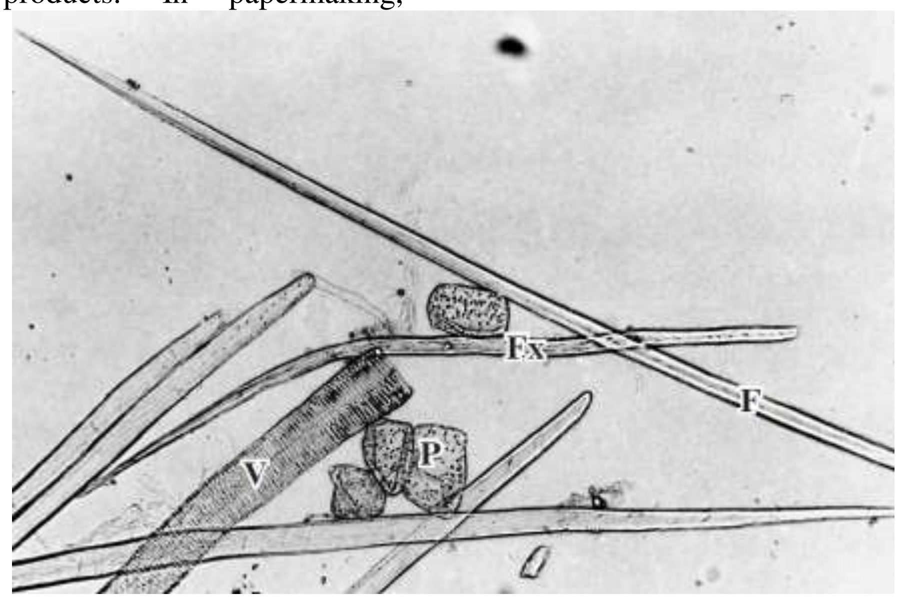

Figure 1: Image of fibre, vessel element and parenchyma cell in a *Cynara cardunculus* plant.
Sources: (Quilhó *et al.,* 2004).

Fibre Length

Fibre length has been described by Dinwoodie (1965) as one of the major factor controlling the strength properties of paper. Others include fibre density and fibre strength. According to him, fibre length is associated with the number of bonding site available on an individual fibre. Montigny and Zoborowski (1982) showed that there is a simple straight line relationship between the fibre length index of pulp and the tearing strength of the paper. This was confirmed by Seth and Page (1988) while working on the dependence of tearing resistance on fibre length, they showed that tearing resistance and to a lesser extend folding endurance are basically dependent upon the fibre length. Fuwape *et al.,* (2010) reported that long fibres have a strong positive correlation with tearing strength only without any clear relationship with other paper properties.

Fibre Diameter

Fibre diameter is the thickness of individual fibres, its measurement is used to determine the end-use of the fibres. Fibre diameters are determined by the dimensions of the cambial fusiform cells from which they are derived and by the process that occurs during cell differentiation (Ridoutt and Sands, 1993; Ridoutt and Sands, 1994; Izekor and Fuwape, 2011). In paper production, the importance of fibre diameter is usually based on its relationship with fibre length. This is otherwise called slenderness ratio or felting rate.

Lumen Width

Lumen is the inside space of a tabular structure. Lumen width is the distance between the diameters of the fibre. Lumen width has an effect on the pulping process. Larger lumen width gives better pulp beating because of the penetration of liquid into empty spaces of the fibres (Emerhi, 2012).

Cell-wall thickness

Cell-wall thickness is one of the significant fibre dimensions that determine the choice of a fibrous raw material for pulp and paper production. The thickness of cell-wall increases with the age of the tree. Atchinson and McGovern (1993), showed that most non-wood fibres are thin-walled which invariably lower the coarseness of their pulp. Research shows that the thin-walled fibres are very important in the manufacture of many grades of papers. Variations in fibre wall thickness from tree to tree and within individual trees are similar to the patterns of variation in density as a result of the close relationship between these two wood properties (Bhat *el al.,* 1990).

Derived fibre morphologies

Some common derived fibre morphologies used in assessing the fibre of lignocellulosic materials for pulp and paper productions are discussed below:

Slenderness Ratio

Slenderness ratio, which is also termed felting power, is inversely proportional to the fibre diameter. It described the value obtained from the ratio of fibre length to fibre diameter. Generally, it is stated that if the slenderness ratio of fibrous material is less than 70, it is stated that it is not valuable for quality pulp and paper production (Veveris *et al*., 2004). This is because a low slenderness ratio means reduced tearing resistance, which is partly due the short thick fibres do not produced good surface contact and fibre-to-fibre bonding (Ogbonnaya *et al*., 1997). This expression for slenderness ratio is stated in equation 1.

$$\text{Slenderness ratio} = \frac{fibre\ length}{fibre\ diameter} \ldots.\text{eqn } 1$$

Flexibility ratio

This measures the ratio of lumen to fibre diameter. It is one of the important factors which determine the suitability of pulp for paper making. It expressed the actual proportion of lumen out of a total circumference of a fibre in percentage. Flexibility according to Stamn (1964), and Amidon (1981), is the key to the development of burst and tensile strength as well as the development of the paper properties that affects printing. The expression for flexibility ratio is stated in equation 2.

Fexibility ratio

$$= \frac{lumen\ width}{fibre\ diameter} \text{ x } \frac{100}{1} \ldots\ldots\ldots\ldots.\text{eqn } 2$$

Based on flexibility ratio, Bektals *et al*. (1999), classified into the following four groups.

High elastic fibres: This represents woods with flexibility ratio greater than 75%. Density of such wood is low, usually less than 0.45g/cm^3 thin-walled and large lumen. Fibres of such wood can collapse easily and flatten to produce good surface area contact, thus, there is a good fibre-fibre bonding.

Elastic fibres: This constitutes woods with fibre flexibility between 50-75%. Density is medium with cell-wall and lumen of equal dimension. The fibre collapsed partially to give relative contact and fibre bonding.

Rigid fibres: This constitutes woods with fibre flexibility between 30-50%. The cell-walls are thicker with medium to high density fibres seldom flatten and have poor surface contact and fibre-to-fibre bonding.

High rigid fibres: Wood with fibre flexibility less than 30%. This is generally applicable to over matured tress. Fibres are very thick-walled with narrow lumina, very poor surface contact and fibre-to-fibre bonding.

Runkel ratio

This measures the amount of wood in respect to the cavity or lumen of the fibre. It is twice the thickness of the cell-wall divided by the width of the lumen as shown in equation 3.

Runkel ratio

$$= \frac{2\ x\ cell\ wall\ thickness}{lumen\ width} \ldots\ldots..\text{eqn } 3$$

Ademiluyi and Okeke (1977), classified fibre value according to the runkel ratio and concluded that as Runkel ratio increases, the paper quality produced decreases with Runkel ratio less than one being the best while those greater than one are of poorer quality. Fibres with Higher Runkel ratio are stiffer, less flexible and form bulkier paper of low bonded areas than fibres with lower Runkel ratio (Veveris *et al*., 2004).

Chemical Components in Wood and Their Practical Implication in Pulp and Paper Production

Chemical composition of candidate plant gives an idea of how feasible the plant is as a raw material for papermaking. The fibrous constituent is the most important part of the plant. Since plant fibres consist of cell walls, the composition and amount of fibres is reflected in the properties of cell walls (McDougall *et al*., 1993). Generally, lingnocellulose materials from wood and non-wood plant consist of cellulose, lignin, hemicelluloses, extractive and some inorganic matter. Information on the chemical composition is important in deciding the techno-commercial suitability, pulping method and paper strength of a particular wood material (Abdul-Khalil *et al,* 2010). Some of the chemical components that are of significance in the selection of a raw material for pulp and papermaking are discussed below:

Lignin

Lignin contents in different woods range between 25-35% in softwoods and 18-25% in hardwoods (Biermann, 1996) while, non-wood fibres contain between 5-23% lignin (Goring, 1971) as presented in Table 4. Lignin is considered as an integral part of the wood and is highly valued in service. It is only in pulping and bleaching that lignin is more or less released in degraded and altered form (Kock, 2006). Because of its importance in pulp and papermaking, several advances have been made towards its removal during pulping processes. Some of these include the use of 75% sulphuric acid (Klasson lignin method), the use of solvents like sodium hydroxide or in conjunction with sodium sulphide (sodium lignin method) and the use of organosolvents (Milled wood lignin method). The ease of delignification of the material during the chemical pulping process can be estimated from lignin content (Mossello *et al.,* 2010). However, it requires high chemical consumption and or reaction time during pulping process in some plants (Abdul-Khalil *et al*., 2010).

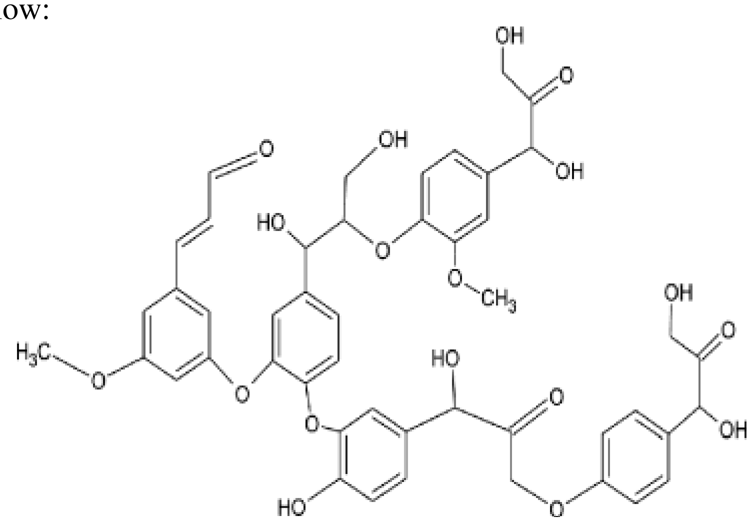

Figure 2: Chemical structure of lignin (Kock, 2006).

Cellulose

This is the chief component of plant fibres used in pulping and the most abundant natural polymer in the world. It is made of 40-45 % of wood dry weight. It is the main component of the fibre wall and the skeletal polysaccharide of cell walls (Marius du Plessis, 2012). Actually, the building block of cellulose is cellobiose since the repeating unites two sugar units. The number of glucose units in cellulose molecule is referred to as the degree of polymerization (DP) that is above 10,000 in native wood but less than 1,000 for highly bleached kraft pulp. Hydrogen bonding between cellulose molecules results in the high strength of cellulose fibre which will lead to increase of fibre strength (Biermann, 1996; Rowell *et al.,* 2000).

Cellulose being the major constituent of papermaking is expected to be in high quality and its quality depends on the raw material and pulping methods. In terms of physical attributes, one of the most important ways in which the individualized fibers in pulp are different in comparison to the wood from which they originated is the great increase in surface area per unit of dry mass, i.e. specific surface area. Studies have shown that the specific surface area of never-dried pulp fibers can be more than 100 square meters per gram (Stone and Scallan 1966). Mechanical pulping processes tend to separate the fiber material into a wide range of sizes, due to partial breakage of many of the individual tracheids and libriform fibers. By contrast, chemical pulping operations tend to leave the fibers relatively intact. Chemical pulping also tends to increase the flexibility and conformability of never-dried fibers (Tam Doo and Kerekes 1982; Paavilainen 1993). One of the most dramatic consequences of such changes is that kraft fibers more readily flatten into a ribbon-like form under compression and shear forces in the wet state. Flexible, ribbonlike fibers tend to form stronger inter-fiber bonding, compared to relatively stiff fibers, in which the open lumen structure may persist during papermaking (Hubbe *et al.,* 2007). Alpha (α) cellulose is the purest form of cellulose. It is insoluble and can be filtered from the solution and washed prior to use in the production of paper or cellulosic polymers. A high percent of alpha cellulose in paper will provides a stable, permanent material.

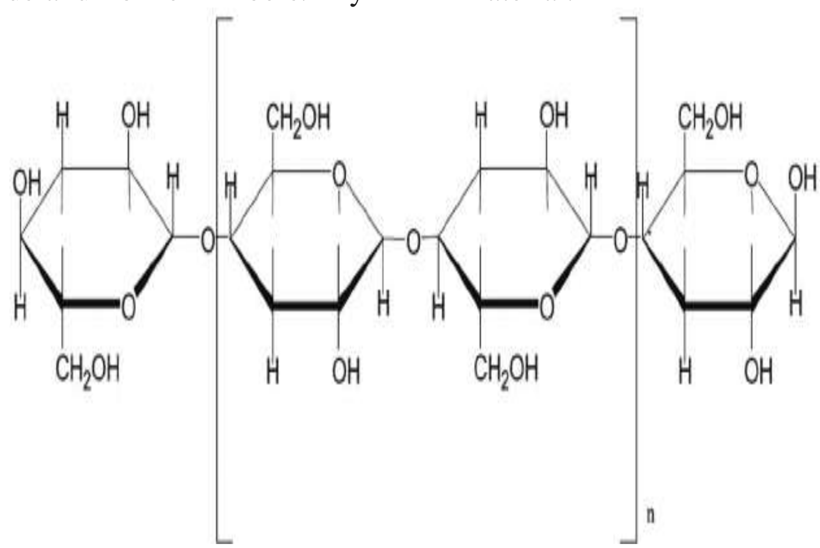

Figure 3: Structural arrangements of cellulose in wood.
Source: (Bowyer and Smith 1998).

Hemicellulose

Hemicelluloses constitutes about 15 - 30 % of dry wood but have shorter chain of polysaccharides (DP of only 50 - 300) compared to cellulose (Biermann, 1996). The main function of hemicelluloses is to increase fibre-to-fibre bonding but at a higher amount, tends to lower the strength properties of paper. Starch is often added to pulp to accelerate the strength of paper with about similar mechanisms of effect as the hemicelluloses (Biermann, 1996).

Hemicellulose is an important component in plant fibre and it contributes to paper properties. During pulping and fibre recycling, it could be removed by either its degradation or release. Although it is less important than the cellulose content in pulp, hemicellulose in pulp brings an important contribution to pulp quality and its prospective loss raises some concerns (Lima *et al.,* 2003; Wan *et al.,* 2010). Firstly, hemicellulose can enhance pulp beatability, because its abundant end groups are more accessible to water molecules compared to cellulose (1). Secondly, hemicellulose in chemical pulp, serving as an inter-fibre binding agent, improves the strength properties of paper products, including tensile, tear, and burst (Lima *et al.,* 2003). In addition, hemicellulose can slow down the deterioration of fibres during manufacturing and the subsequent commercial circulation of paper (Wan *et al.,* 2010). Thus, the hemicellulose loss from pulp has negative effects on the pulp and paper properties (Hu *et al.,* 2013). The average value of hemicellulose that constitute good quality paper is a function of the raw material, quantity and method of pulping.

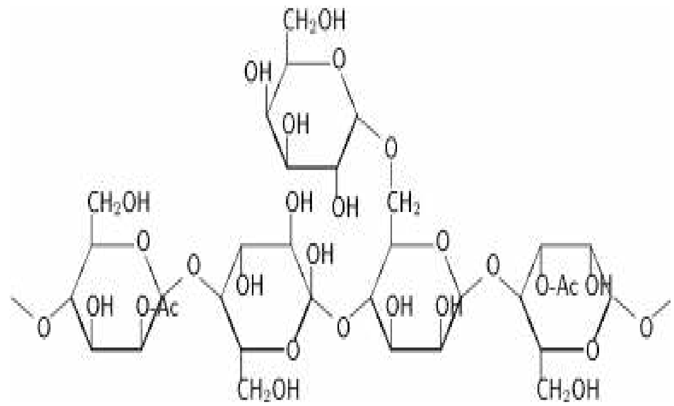

Figure 4: Structural arrangements of Hemicellulose wood. Source: (Bowyer and Smith 1998).

Effects of Hemicellulose Loss on the Strength Properties

The reductions of strength properties with hemicellulose loss are shown in Figure 5. When the hemicellulose loss was 4%, the burst, tear, and tensile indices decreased by 3.5%, 6.7%, and 9.1%, respectively. However, the burst, tear, and tensile indices dropped by 66.7%, 58.0%, and 60.0% respectively, when the hemicellulose loss reached 73%. Similar losses were also observed by Wan *et al.,* (2010). There are three possible explanations for the decrease in the strength properties of pulp with hemicellulose loss. One is that the hemicellulose loss decreases the number of free hydroxyl groups on the fibre surface and then reduces the hydrogen bond strength between fibres (1). Another possible explanation is that the hemicellulose loss decreases the fibril surface area accessible to water molecules and fibre surface charge, which changes fibre swelling and flexibility (Lyytikainen *et al.,* 2011).

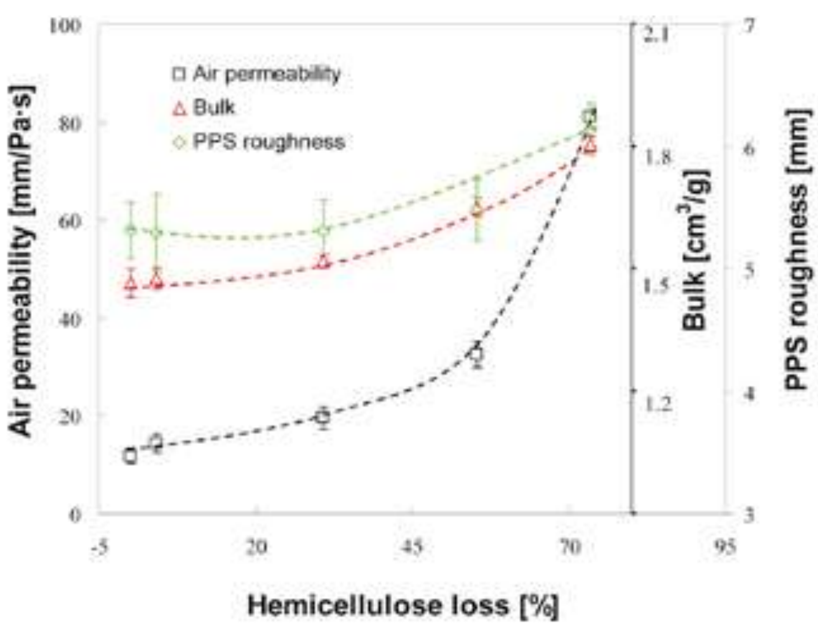

Figure 5: Effects of hemicellulose loss on the strength properties of paper (Hu *et al.,* 2013)

Extractives
Extractives is the extraneous plant component that is generally present in small to moderate amounts and can be isolated by organic solvent or water (Mossello *et al.*, 2010). It contains less than 10 % of the dry weight of wood (Marius du Plessis, 2012). These are generally the heterogenous groups of compounds of lipophilic and hydrophilic including terpenes, fatty acids ester, tannins, volatile oils, polyhydric alcohols and aromatic compounds.
High extractive content lowers pulp yield, impacts on the brightness of unbleached pulp and increases chemical demand of pulping and bleaching chemicals (Little *et al*. 2003). Generally, the presence of extractives in woody materials increases the consumption of pulp reagent and reduces yields. For this reason, material with little or no extractive content is desirable (Rodra-gueza *et al*., 2008).

Inorganic content
The inorganic constituent of lignocellulosic material is usually referred to as ash content which is considered the residue remaining after combustion of organic matter at a temperature of 525±25 ºC (Rowell *et al*., 1997). The ash content consist mainly the metal salts such as silicates, carbonates, oxalates and phosphate of potassium, magnesium, calcium, iron and manganese as well as silicon. Normally, they are deposited in the cell walls, libriform fibres and luminar of parenchyma cells and in the resin canals and ray cells (Sjostrom**,** 1993). High ash content is undesirable during refining and recovery of the cooking liquor (Rodra-gueza *et al*., 2008). For example high silica content can complicate the recovery of chemical during pulping. Nitrogen in the spent liquor can lead to generation of NOx in the chemical recovery furnace while potassium in the fibre can combine with chlorine KCl leading to corrosive effect on metal parts in the furnace and boiler (Salmenoia and Makela, 2000).

Table 4: Percentage Chemical Composition of Non-wood fibres

Plant Species	Lignin	Cellulose	α-Cellulose	Hemi-Cellulose	Ash	Silical	Sources
Palm fruits fibres	18.50	37.01	-	68.52	0.64	-	Sridach *et al*., 2010
Pineapple leaf	10.5	-	73.4	80.5	2.0	-	Abdul-Khalil *et al.,* 2006
Banana stem	18.6	-	63.9	65.2	-	-	Abdul-Khalil *et al.,* 2006
Rice straw (whole)	17.2	48.2	35.6	70.9	16.6	14.9	Ahmet *et al*., 2004
Oil palm frond	20.5	-	49.8	83.5	2.4	-	Abdul-Khalil *et al,* 2006
Kenaf	19.20	-	46.75	71.80	1.40	0.28	Dutt *et al*., 2009
Hemp	18.50	-	46.75	71.80	1.56	0.35	Dutt *et al*., 2009
Wheat straw	15.3	-	38.2	74.5	4.7	-	Deniz *et al*., 2004

CONCLUSION
The anatomical and chemical properties of wood and the products made from them are determined by the properties of wood used as raw material, these are the ultimate factors that determine the overall properties of wood as valuable raw material for pulp and paper production and distinguish it from other non-biological materials. The quality of paper depend solely on the raw material and pulping method used, therefore these properties will serve as a guide to the pulp and paper producers.

REFERENCES
Abdul-Khalil, H.P.S., A.F. Ireana-Yusra, A.H-Bhat and M. Jawaid 2010. Cell wall ultra-structure, anatomy, lignin distribution and chemical composition of Malaysian cultivated Kenaf fiber. In. Crops Pods. (31): Pp 113-121.
Abdul-Khalil, H.P.S., Siti Alwani M. and Mohd Omor A. K. 2006. Chemical Composition, Anatomy, Lignin distribution, and Cell wall structure of Malaysian Plant waste fibers "Cell wall of tropical fibers," *BioResources*, 1 (2) Pp 220-232.
Adejoba, O. R. and Onilude, M. A 2012. Evaluation of Fibre Charateristics of Ficus mucoso: a lesser used species. Proceedings of the 3rd

Biennial National Conference of the Forests and Forest Products Society. Pp162-167.

Ajala, O. O. and Noah, A. S. 2019. Evaluation of Fibre Characteristics of *Aningeria robusta* (A. Chev.) Wood for its Pulping Potentials. *Journal of Forestry Research and Management* 16(1). 90-97.

Ademiluyi, E. O. and Okeke, R. S. 1977. Fibre characteristics of 14 savannah timber specie in relation to pulp making. Paper presented at 6th conference of FAN.

Ahmet, T., Ilhan, D. and Hudaverdi, E. 2004. Rice Straw Pulping with Oxide Added Soda- Oxide-Anthraquinone. *Pakistan Journal of Bilogical Sciences,* 7(8) 1350-1354.

Amidon, T. S. 1981. Effect of the wood properties of hardwood on kraft paper properties Tappi 64(3): 123-126.

Anguruwa, G. T. 2018. Anatomical, Physico-Chemical and Bio-Energy Properties of *Ficus exasperate* Vahl. in Ibadan, Nigeria. PhD Thesis (Unpublished).

As, N., Koc, H., Dogu, D., Atik, C., Aksu, B and Erdinler, S. 2002. The Chemical Mechanical,Physical and Anatomical Properties of Economically Important Wood in Turkey, Istanbul *Technical University Istanbul, Journal of Forestry* : 70-88 pp.

Atchinson, J. E. and McGovern, J. N. (1993). History of paper and the importance of non-wood plant fibre. In F. Hamilton and B. Leopard eds. Pulp and manufacture, 3 Tappi press Atlanta, G.A. 3p.

Bektas, I., Tutus, A. and Eroglu H. 1999. A Study of The Suitability of Calabrian Pine (*Pinus brutia* Ten.) For Pulp and Paper Manufacture. Turkish Journal Agriculture and Forestry 23(3): 589-597.

Bhat, K. and Dhamdodaran, T. 1990. Wood density and fibre length of *Eucalyptus grandis* grown in Kerala, India. *Wood and Fibre Science* 22(1): 54-61.

Biermann, C. J. (1996). Handbook of Pulping and paper making. 2nd., Ed, Acacdemic press, San Dieego, Califonia.

Bowyer, J. L. and Smith, R. L. (1998). The Nature of Wood and Wood Products. CD-ROM, University of Minnesota, Forest Products Management Development Institute, St. Paul, Minnesota, USA. 12.

Deniz, I., Kirci, H. and Ates, S. 2004. Optimization of Wheat Straw (*Tiriticum durum*) Kraft Pulping. *Indian Journal of Crop* Prodution 19(3): 237-243.

Dinwoodie, J. M. 1965. The relationships between fibre morphology and paper properties, A review of literature, Tappi. 48 (8): 440-447.

Dutt, D., Upadhyay, J.S., Singh, B and Tyagi, C. H. 2009. Studies on *Hibiscus cannabinus* and *Hibiscus sabdariffa* as an alternative pulp blend for softwood: An optimization of kraft delignification process. *Industrial Crops and Products* 29 (2009):16–26.

Emerhi, E. A. 2012. Variations in anatomical properties of *Rhizophora racemosa* (Leechm) and *Rhizophora harrisonii* (G. Mey) in a Nigerian mangrove forest ecosystem. *International Journal of Forest, Soil and Erosion*, 2(2): 89-96.

Eroglu, H. 1998. Fiberboard industry, Karadeniz Technical University. Publication No: 304, Trabzon, Pp. 30.

FAO 1975. Pulping and paper Making Properties of Fast –growing Plantation Wood Species. Rome. 466pp

Fuwape J. A., Fabiyi J. S. and Adebayo, B. A. 2010. Introduction to pulp and paper technology in Nigeria. Published by Stebak Books and Publishers.

Goring, D. A. I. 1971. Polymer properties of lignin Derivatives. In Lignins: Occurance, formation, structure and Reactions, Sarkanen, K.V. and C.H Luwig (Eds), Wiley Interscience, New York, pp: 916.

Hickey, M. and King, C. 2001. The Cambridge Illustrated Glossary of Botanical Terms "Cambridge University press" (16), Pp 2000-220.

Hu, G., Shiyu, F. and Liu, H. 2013. Hemicellulose in pulp affects paper properties and printability. 66 (2) 139-141.

Hubbe, M. A., Venditti, R. A. and Rojas, O. J. 2007. "What Happens to Cellulosic Fibers during Papermaking and Recycling?" A Review . *BioResources* 2(4), 739-788

Izekor, D. N. and Fuwape, J. A. 2011. Variation in the anatomical characteristics of plantation grown *Tectona grandis* wood in Edo State, Nigeria. Archives of Applied Science Research 3 (1): 83-90.

Jozsa, L. A., and Middleton G. R. 1994. A Discussion of wood quality attributes and their practical implications.

Karjalainen, M., Ammala, A., Rousu, P., and Niinimaki, J. 2012. Method for Automatic
Analysis of Wheat Straw Pulp cell types. "Wheat Straw cell sizes" *Bioresources*, 7 (1), 827-840.

Kock, G. 2006. Raw material for pulp. In: Handbook of Pulp, Sixta, H. (Ed.). Vol.1. Wiley-
VCH Verlag GmbH and Co., Weinheim, pp: 21-68.

Lima, D.U., Oliveira, B.C. and Buckeridge, M.S. 2003. Seed storage hemicelluloses as wet-end additives in papermaking, *Carbohydrate Polymers*, 52(2003):367-373

Little, K. M., van-Staden, J. and Clarke, G. P. Y. 2003. The relationship between vegetation management and the wood and pulping properties of a *Eucalyptus* hybrid clone. *Annals of Forest Science* 60: 673-680.

Lyytikainen, K., Saukkonen, E., Kajanto, I. and Kayhko, J. (2011). The effect of hemicellulose extraction on fibre charge properties and retention behavior of kraft pulp fibres, *Bioresources*, 6(1): 219-231.

Marius du Plessis 2012. A fibre optimisation index developed from a material investigation of Eucalyptus grandis for kraft pulping process. Pp 174.

McDougall, G. J., Morrison, I. M., Stewart, D., Weyers, J. D. B. and Hilman, J. R. 1993. Plant fibres bptany, chemistry and processing. *Journal of the science of Food and Agriculture* 62:1-20.

Montigny, M and Zoboroski, D. L. 1982. Fibre length and fibre strength in relation to tearing resistance of hard wood pulps Tappi 53 (11): 2153-2154.

Mossello, M., Harun, T., Resalati, H., Ibrahim, R., Md-Tahir, P., Shamsi, S. R. F. and Mohamed A. Z. 2000. Soda-Anthraquinone Pulp from Malaysian Cultivated Kenaf for Linear board Production "Kenaf Na-AQ for board," *Biouresources,* 5(3), Pp 1542-1553.

Noah, A. S., Ogunleye, M. B., Abiola, J. K. and Nnate, F. N. 2015. Fibre Characteristics of Gerdenia ternifolia (Linn C.) Schumach for its Pulping Potential. *American Scientific Journal for Engineering, Technology and Sciences.* Pp322-332.

Oluwadare, A. O. and Sotannde, O. A. 2006. Variation of the fibre Dimentions in the stalks of Miraculous Berry (*Thaumatococcus daniellii* Stalk). *Production Agriculture Technology (PAT),* 2(1): 85-90.

Ogbonnaya, C. I., Roy-Macauley, H., Nwalozie, M. C. and Annerose, D. J. M. 1997. The physical and histochemical properties of Kenaf (*Hibiscus cannabinus L.*) grown under water deficit on a sandy soil. *Industrial crops and products*, 7: 9-18.

Ogunleye, B. M., Fuwape, J. A., Oluyege, A. O., Ajayi, B. and Fabiyi, J. S. 2016. Evaluation Of Fiber Characteristics Of *Ricinodedron Heudelotii* (Baill, Pierre Ex Pax) For Pulp And Paper Making. International *Journal of Science and Technology*, 6(1I): 634-637.

Paavilainen, L. 1993. "Conformability – flexibility and collapsibility – of sulfate pulp fibers," *Paperi Puu* 75(9-10), 896-702.

Panula-Ontta, S., Fuhrmann, A., Kariniemi, M., and Sarkilahti, A. 2007. "Evaluation of Vessel picking tendency in Printing," ICEP Int. Colloquium on Eucalyptus Pulp, March 4-7, Belo Horizonte, Brazil.

Quilho, T., Gominho, J. and Pereira, H. 2004. Anatomical characterisation and variability of the Thistle *cynara cardunculus* in view of pulping potential. *IAWA Journal*, 25 (2): 217–230.

Riki, J. T. B. (2018): Wood Quality Studies of some Hardwood Species in University of Ibadan, Ibadan, Nigeria. M.Sc Dissertation (Unpublished).

Rodra-Gueze, A., Morala, A., Serranoa, L. Labidio, J. and Jimanez, L. 2008. Rice straw pulp obtained by using various methods. *Bioresources Technology*., 99: 2881-2886.

Rowell, R. M., R. A Young and Rowell, J. K. 1997. Paper and composites from Agro-based Resources. Lewis, New York.

Rowell, J. K., Han, J. S. and Rowell, J. S. 2000. Characterization and factors affecting fiber properties Nat. Polymers Agrofibers composites.

Ridoutt and Sands, 1993. Within-tree variation in cambial anatomy and xylem cell differentiation in *Eucalyptus globulus*. Trees 8: 18-22.

Ridoutt and Sands, 1994. Quantification of the Processes of Secondary Xylem Fibre Developmenr in *Eucalyptus Globulus* at two Height Levels. *International Association of Wood Anatomists (IAWA) Journal*, 15 (4), 417-424.

Salmenoja, K., and Makela, K. 2000. "Chlorine-induced superheater corrosion in boilers fired with biomass," In: Proceedings of the fifth European Conference on Industrial Furnaces and Boilers, April 2000, INFUB, Porto, Portugal, 200.

Seth, F.N. and Page, H. 1988. Hardwood fibre length and pulpsheet properties. Tappi 5 (1): 19-25.

Sjostrom, E. 1993. Wood Chemistry, Fundamentals and Applications. 2nd Edn., San Diego, USA.

Stamn, A. J. 1964. Wood and cellulose Science. Reinhod Press Co. New York 54p.

Stone, J. E., and Scallan, A. M. (1968). "A structural model for the cell wall of waterswollen wood pulp fibers based on their accessibility to macromolecules,"*Cellulose Chemical Technology* 2(3), 343-358.

Sridach, W. 2010. "Pulping and Paper properties of Palmyra palm fruits fibers" Songklanakarin. *Journal of Science and Technology,* 32 (2): 201-205.

Tam Doo, P. A., and Kerekes, R. J. 1982. "The flexibility of wet pulp fibers," *Pulp Paper Canada* 83(2), T37-T42.

Ververis, C., Georghiou, K., Christodoulakis, N., Santas, P. and Santas, R. 2004. Fiber dimensions, lignin and cellulose content of various plant materials and their suitability for paper production. *Industrial Crops Products* 19: 245-254.

Wan, J.Q., Wang, Y. and Xiao, Q. 2010. Effects of hemicellulose removal on cellulose fiber structure and recycling characteristics of eucalyptus pulp, *Bioresources Technology* 101: 4577-4583.