International Journal of Innovative Studies in Sciences and Engineering Technology (IJISSET)

ISSN 2455-4863 (Online) www.ijisset.org Volume: 6 Issue: 1 | 2020

The Paper Making Suitability Indices of Nine Hardwood Species in Ogbomoso, Oyo State, Nigeria

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Abstract: *The pulp and paper making (PPM) wood suitability index (SI) model, a quantitative method for selecting hardwood species for PPM had been developed since about a decade but the suitability indices (SIs) of most Nigerian hardwood are yet to be reported. Using the model, and based on their wood anatomical features, this study determined the PPM suitability of nine Nigerian tree species in relation to Gmelina arborea Roxb., the widely acknowledged PPM resource in the country with SI of 1.00. The tree species evaluated in order of their preference for PPM are Afzelia africana Sm. Ex Pers (1.09), Daniellia oliveri (Rolfe) Hutch. & Dalziel (1.04), Trichilia emetica Vahl (0.98), Azadirachta indica A. Juss (0.86), Annona senegalensis Pers. (0.79), Lannea barteri Engl. (0.66), Bridelia ferruginea Benth. (0.64), Vitex doniana Sweet (0.62), and Anthocleita djalonensis A. Chev. (0.48).The study concluded that three of the evaluated alternative wood resources for PPM namely, A. africana, D. oliveri and T. emetica were about 100% as suitable as G. arborea, while two other species namely, A. indica and A. senegalensis showed substantial compliance (79-86%) with the desirable qualities of the standard wood. However the desirability or otherwise of other important pulpwood properties, which were not built into the SI model, such as growth conditions of the species and their adaptability to plantation techniques, cooking behavior of the wood and ease of pulping, pulp yield and physical properties of the pulp, chemical composition of the wood and physico-mechanical properties of the paper sheets should be taken into consideration in making categorical selection of these tree species as alternative PPM resources..*

Keywords: *Pulp and paper; pulpwood; paper making suitability; suitability index; pulpable hardwoods.*

INTRODUCTION

Paper can be generally defined as a thin material formed by pressing together moist fibres usually derived from grasses, rags, and wood, and drying into flexible sheets. Following extraction by chemical or mechanical means, the disintegrated cellulose fibres from various vegetable sources are beaten and subsequently held together by hydrogen bonding to make a felt (Przybysz, 2016). The cellulose is extracted from different kinds of plant material such as wood, leaf, fruit, straw and bark (CEPI, 2013; Kamoga *et al*., 2013a; Ganie *et al*., 2017) the quality of which depends on finess and brightness of the fibres. Therefore plant anatomy has remained the basic technique for evaluating the quality of all potential plant material for pulp and paper making (PPM), but chemical and biological evaluations of the material are also found helpful (Noah *et al*., 2015).

Historically, non-wood fibre plants and a variety of other fibrous items such as cotton, linen rags, fruits, hemp and reeds were the major sources of materials for paper making (Saijonkari-Pahkala, 2001; Kamoga *et al*, 2013b) but at the turn of the 19th Century, the use of non- wood material for paper pulp reduced substantially due to insufficient supply of some of these materials (Bajpai *et al*., 2004), coupled with the development of the technologies for isolating pulp from wood (Bajpai *et al*., 2004; Kamoga *et al.*, 2013b). Since that time, the most common source of natural fibres for paper making had been wood pulp from trees, to the extent that over 60% of paper is now made directly or indirectly from wood, while other raw materials for the purpose consist of recycled paper (Scott, 2017) and other fibrous materials, mainly from agricultural residues (Saikia *et al.*, 1997; Dutt *et al*., 2004; Kamoga *et al*., 2013a and b). The paper industry is, therefore blessed with a fundamental advantage compared to those industries that depend on finite resources, its basic raw material, wood, being renewable, recyclable and sustainable (CEPI, 2013).

There is a resurgence in the increasing use of non-wood plant materials for paper making , especially from agricultural wastes, food crop residues, grasses, shed tree leaves, and fibrous shells of fruits. This reversal in the trend has been due mainly to short supply of wood resulting from widespread deforestation (Fagbemigun *et al*.2014; Aremu *et al*., 2015) , but also due to increasing awareness of the need to add value to the non-wood fibrous materials that have constituted wastes in our environment, and the necessity to examine raw materials for paper that offer less adverse impact on the environment (Olotuah, 2006; Ekhuemelo and Tor, 2013; Kamoga *et al*., 2013b).

Compared to other non-wood fibres such as rice/wheat straw, reed and bagasse, bamboo has been named as a better fibre raw material for pulp and paper making. Fibres of bamboo are also said to be comparable to those of hardwoods in many respects (Azeez *et al.,* 2016; Chen *et al*. 2019), but some challenges are associated with its use as a paper making raw material, such as difficulty in managing its plantation, logging, storage, transportation and its relatively higher ash and silicon contents (Sharma *et al*. 2011). One good news is that new technologies have been developed such as those for silicon removal and silicon retention, which have made bamboo stems more amenable to pulping (Chen *et al.*, 2019

Softwoods and hardwoods have desirable characteristics of fibres for PPM but over-exploitation of these woods for different purposes has led to a progressive decline in their production from natural forests (Morris, 2010; Sharma *et al*., 2013). As recently observed by Okon (2018), increasing world population has led to increase in the demands for forest products, specifically wood for construction. It can be deduced from Okon's (2018) submission that the Nigeria's tropical rain forest had been degraded by about 75% within a period of eleven years 1991-2002. This reduction, according to Akpan-Ebe (2017) has been essentially due to insatiably high demand for timber, unsustainable agricultural practices and the necessity for public infrastructural development. Although it is believed in certain quarters that the consumption of graphic paper is reducing due to world-wide digitalization, but Bajpai (2018) argues that the reduction is counter-balanced by growth in packaging and hygiene papers. This argument is strengthened by the global paper consumption statistics of 400 mt/year in 2010, 407mt/year in 2015 and projected 500mt/year by 2020 (WWF, 2010; Bajpai, 2018). By extension therefore, it is arguable that wood, which occurs in greater volume than the non-wood raw materials shall remain the major source of cellulose fibres for paper making.

Out of the hardwoods known to the paper making industry, the wood of *Eucalyptus* species is acknowledged world-wide as a raw material for pulping (Pirralho *et al*., 2014). The wood of *Gmelina arborea* Roxb. has, in addition, been found suitable in West Africa and Brazil due to its fair conformity with the qualities of an ideal pulpwood such as rapid growth rate for economical plantation management, longer than average fibre length, Runkel ratio of less than 1, low basic wood density,and low chemical extractives (Ogunkunle, 2010). In Nigeria, the pressure on forest wood resources has been taking its toll on the plantations of *G. arborea* which were originally established for the use of the paper industry, but the wood is now being exploited for other economic purposes such as timber, plywood, fuel wood and as acoustic instrument (Noah *et al*., 2014). This development has brought about the awareness of the necessity to find alternative sources of wood fibres for paper making (Kpikpi and Sackey, 2012; Kiaei *et al.*, 2014; Otoide *et al.*, 2018), more so that the rate of consumption of paper is expanding (Bajpai, 2018). This effort will not only reduce cost of production which might be forced to rise due to scarce raw material, it will also help to avoid competition for a scarce *G. arborea* as the only raw material for pulping.

The important features of a good pulpwood are its wood structure and anatomy, including cell biometry and cell type proportion. These desirable features in *G. arborea* wood along with its pulping properties which are acknowledged to be superior to most of the other hardwoods have led to accepting it as the standard raw material for paper making in the tropics. In search for alternative wood resources for pulping therefore, the practice has been to evaluate wood anatomical and other relevant PPM characteristics in tropical wood samples and define their suitability in relation to available data on the wood of *G. arborea* or other suitable reference material (e.g Kpikpi and Sackey, 2012; Baptista *et al*., 2014).

The PPM wood suitability index (SI) model, a quantitative method for selecting hardwood species for PPM with reference to *G. arborea* had been developed since about a decade (Ogunkunle, 2010) but the suitability indices (SIs) of most Nigerian hardwood are yet to be reported. Therefore, this study adopted the wood SI model to determine the suitability of some Nigerian tree species in relation to *G. arborea*, the widely acknowledged pulpwood in the country with SI of 1.00.

MATERIALS AND METHODS

Experimental and Standard Plant Materials

Wood samples of between 8 and 12 cm diameter were taken from the branches of nine hardwood species within and around the Campus of Ladoke Akintola University of Technology, Ogbomoso, Nigeria (8^0 9' 45.83"N, 4^0 16' 6.21"E to 8^0 10' 12.22"N, 4^0 16' 12,61"E), i.e. *Afzelia africana* Sm. Ex Pers., *Annona senegalensis* Pers., *Anthocleista djalonensis* A. Chev., *Azadirachta indica* Pers., *Bridelia ferruginea* Benth., *Daniellia oliveri* (Rolfe) Hutch. & Dalziel, *Lannea barteri* Engl., *Trichilia emetic* Vahl., and *Vitex doniana* Sweet. Also from the same location, a stem branch of comparable diameter was cut from a *G. arborea* tree, and used as the standard raw material for pulping.

Procedure for Data Collection

Two wood discs, each of about 4cm thick were cut from each stem branch, and from these wood discs, data on 18 pulp and paper-based wood characteristics were drawn in replicates from both the experimental and standard plant materials. In doing these, the circumference of each of the 4cm thick wood discs was first divided into four equal sectors by drawing a cross sign with its origin at the centre. Four blocks of wood, each of about 4 x 2 x 2 cm were then cut out, one from each sector and fixed in Formal-Acetic-Alcohol (FAA) contained in labelled specimen bottles, ready for anatomical work (Uju and Ugwoke, 1997). Another four fresh blocks of the same dimensions were scooped out of each of the wood discs to determine the wood specific gravity (SG) using the oven-dry method as earlier described (Ogunkunle and Oladele, 2008).

Wood blocks fixed in FAA (90ml absolute ethanol: 5ml of 50% formaldehyde: 5ml glacial acetic acid) were prepared for anatomical data collection from their Transverse Sections (TS), Radial Longitudinal Sections (RLS), Tangential Longitudinal Sections (TLS) and tissue maceration as earlier described (Ogunkunle and Oladele, 2008). The parameters measured in micrometers (μm) included the fibre length (L), fibre diameter (D), fibre cell wall thickness (C) and fibre lumen width (I), while the percentage composition by volume of wood tissue in respect of fibres, vessels, axial parenchyma and rays were also determined. The other parameters included density (i.e mean number) of vessels, fibres, axial parenchyma and rays in one mm^2 area of wood tissue. From some of these 12 enumerated quantitative parameters, five derived ratios namely fibre to vessel ratio (F/V), fibrous to non-fibrous tissue ratio (F/NF), relative fibre length (RFL) or fibre slenderness ratio, Runkel ratio and coefficient of fibre flexibility were computed. These 17 wood structural dimensions together with the wood specific gravity (SG) made a total of 18 wood variables recorded for the nine experimental wood samples and *G. arborea,* the standard pulp wood in Nigeria. The sample size for F/V, F/NF, SG, % vessel, fibres, parenchyma and rays was 4, while it was 30 for the other 11 parameters.

Computation of Wood Suitability Indices For the Experimental Plant Materials

With the replicates and mean values of the 18 parameters determined for both the experimental and standard pulp woods, the model for quantifying the PPM suitability of hardwood species in relation to *G. arborea* wood proposed by Ogunkunle (2010) was adopted to compute the SIs for the nine hardwood species studied. In order to do this, the types of the wood variables studied were first noted as Category A (i.e. those wood parameters which are preferred in PPM when their magnitudes are high) for fibre length, Relative fibre length, Coefficient of fibtre flexibility, % fibre content, F/V ratio, F/NF ratio and number of fibres /mm^2, and Category B (i.e. those wood parameters which are preferred in PPM when their magnitudes are low) for the other 12 variables (Figure 1).

In line with the provisions of the SI model, the mean values of each of the 18 variables for *G. arborea* (μi) was assigned an output weight value or quality (wi) of 1. Thereafter, for each of the nine experimental tree species studied, one variable was taken at a time and statistically tested against the corresponding variable in *G. arborea* using the student t-test with two independent variables technique of Version 23 of the computer-based SPSS statistical package to obtain a mean φj for the experimental sample. On the basis of whether there was a significant difference between the two means φj and μi or not, and on the basis of the category of the variable being considered (Tables 1 and 2), the projected output weight or PPM quality wj was computed for the experimental wood samples . If there was no significant difference between the two means, a weight wj of 1 was assigned as well to the experimental wood for that variable. If however there was significant difference between the two means, the weight wj was calculated on the basis of the category of the variable as follows:

ISSN 2455-4863 (Online) www.ijisset.org Volume: 6 Issue: 1 | 2020

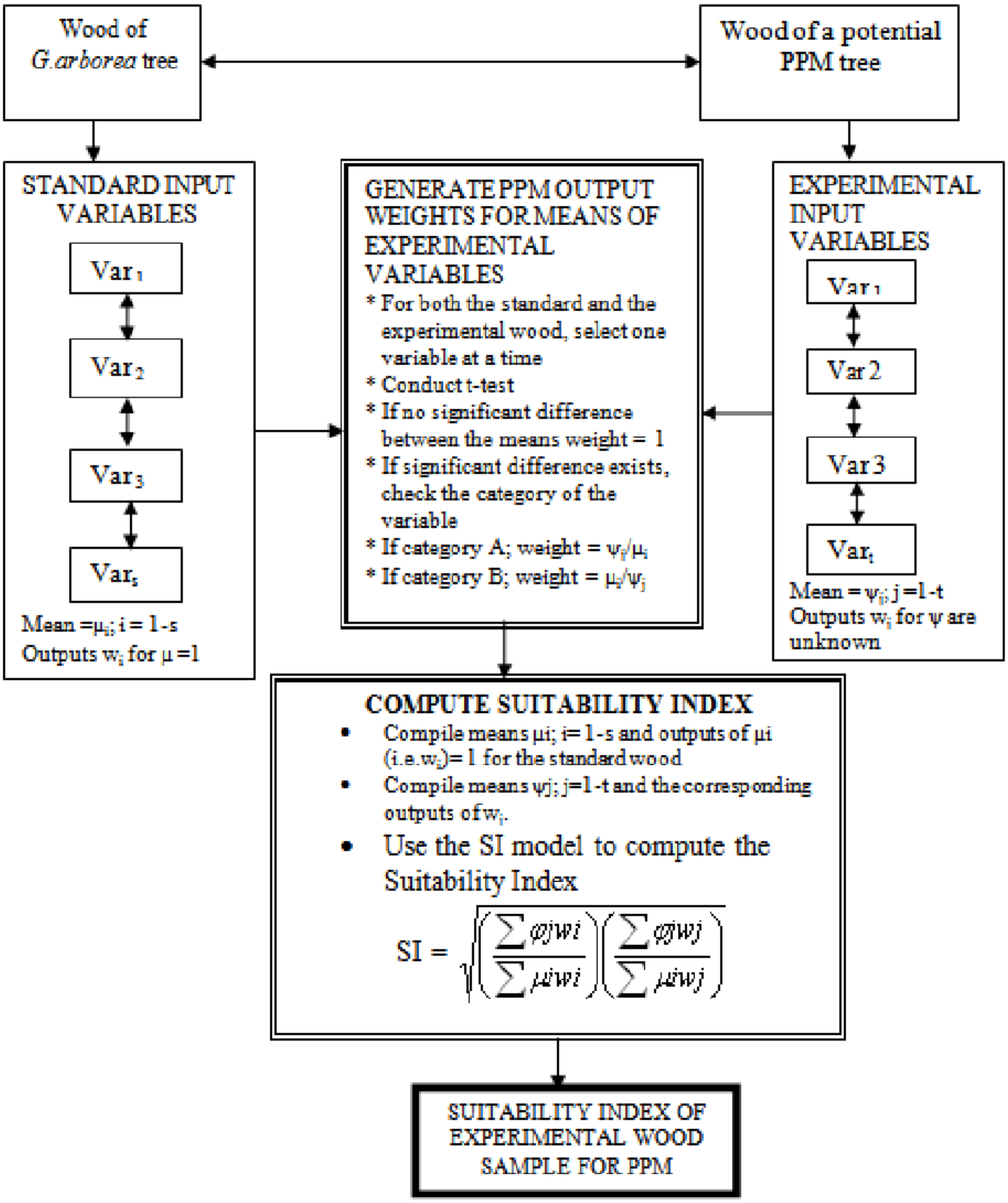

Figure 1: A Model for Quantifying the PPM Suitability of hardwood species in relation to *G. arborea* wood; var = variable; PPM = pulp and paper making. Category 'A' variables = those wood parameters which are preferred in PM when their magnitudes are high; Category 'B' variables = those wood parameters which are preferred in PPM when their magnitudes are low. (Source: Ogunkunle, 2010)

For category 'A' variable,

$$wj = \frac{Mean\ of\ experimental\ wood\ (\varphi j)}{Mean\ of\ standard\ wood\ (\mu i)} \quad (1);$$

and for category 'B' variable,

$$wj = \frac{Mean\ of\ standard\ wood\ (\mu i)}{Mean\ of\ experimental\ wood\ (\varphi j)} \quad (2);$$

Where wj = computed weight values for the variables in the experimental wood.

Thus, the means μi and weights wi (i.e.1) were obtained in respect of the 18 parameters for *G. arborea* on the one hand, where i = 1,2, 3….s; s being the number of variables used (i.e 18). Similarly, the representative means φj and their corresponding weight values wj were obtained for each of the nine experimental species on the other hand, j =1,2,3…………..t; t being 18, the number of wood variables used. Using these two sets of data, the SIs of the experimental wood samples were computed using the following formula according to Ogunkunle (2010):

$$SI = \sqrt{\left(\frac{\sum \varphi jwi}{\sum \mu iwi}\right)\left(\frac{\sum \varphi jwj}{\sum \mu iwj}\right)} \quad (3);$$

Where φj= mean values of the variables in the alternative wood;

μi = mean values of the variables in the standard wood;

wj = projected pulp and paper making output values of φj;

wi = projected pulp and paper making output values of μi.

RESULTS AND DISCUSSION

The data obtained from both the standard (*G. arborea*) and the experimental wood samples are shown in Tables 1 and 2 while the computed pulp and paper making suitability indices of the experimental woods in relation to the standard are as presented in Table 3. The wood fibre morphology and dimensions have been acknowledged as important parameters in identifying potential pulpwoods (Kpikpi and Sackey, 2012;Adi *et al.*, 2014; Pirralho *et al.*, 2014; Soliman *et al.*, 2017 and Ekhuemelo *et al.*, 2018). These features are of great importance because of the strong correlation between them and the strength properties of paper (Ogunjobi *et al.*, 2013). Contrary to the usual practice, the purpose of this study was not to draw conclusions on the PPM suitability of the hardwoods studied by simply comparing the data on the standard and the potential pulpwoods. Such exercise has been described as subjective and its weaknesses have been highlighted by Ogunkunle(2010). In an attempt to simplify raw material selection problem, Ogunkunle (2010) proposed the PPM wood suitability index model. Perhaps, also in recognition of of the weaknesses of the conventional practice, Anupam *et al.* (2013) proposed another multi- criteria decision approach on the basis of cooking experiments, chemical, morphological, and physico-chemical evaluation of pulp and paper making raw materials. These two models are complementary even though they rely on defferent sources of data. In the near future, a further approach is possible in which these two and other data sources shall be harmonized into a single model.

The nine hardwood species studied can be listed in order of their suitability for pulp and paper making in relation to *G. arborea* as *Afzelia africana* (1.09), *Daniellia oliveri* (1.04), *Trichilia emetica* (0.98), *Azadirachta indica* (0.86), *Annona senegalensis* (0.79), *Lannea barteri* (0.66), *Bridelia ferruginea* (0.64), *Vitex doniana* (0.62), and *Anthocleista djalonensis* (0.48). Going by these results, three of the species namely, *A. africana, D. oliveri* and *T. emetica* can be said to be much suitable for pulping as *G. arborea* . They are therefore near perfect in compliance with the pulp and paper qualities of the reference wood. Two other species, namely, *A. indica* and *A. senegalensis* have shown substantial compliance to the tunes of 86% and 79% respectively in relation to *G. arborea*, while the other four species are only averagely suitable (48-66%) for pulping (Table 3).

The aforementioned three categories of paper making raw materials within the nine tree species evaluated in this study appear to be in consonance with some of their wood fibre-derived values. The most notable is the first category of woods with SIs of 0.98 - 1.09, in which the mean relative fibre lengths were either of comparable or significantly higher than that of *G. arborea* (51.03) as observed in , *A.* Africana (50.11) and *D. oliveri* (58.46), or the mean Runkel ratios and coefficient of fibre flexibility were at per with that of *G. arborea* (0.44 and 0.71 respectively) as recorded in *A. africana* (0.49 and 0.69) and *T. emetica* (0.41 and 0.70 respectively). The values of these key fibre-derived ratios in *A. africana, D. oliveri* and *T. emetica* fell in line with those of *G. arborea*. Their outstandingly high SIs of 0.98 -1.09 compared to 1.00 in *G. arborea* were therefore not surprising. In the last category of experimental woods with SIs of 0.48-0.66, the mean F/V and F/NF ratios were observed as either significantly lower than those of G. arborea (i.e 3.03 and 0.58 respectively) as recorded in *L. barteri (1.91 and 0.46respectively),* or the mean Runkel ratio was significantly higher as observed in *Bridelia ferruginea* (0.88), and coefficient of fibre flexibility were significantly lower as observed in *Bridelia ferruginea* (0.57), *Vitex doniana* (0.63), and *Anthocleista djalonensis* (0.64) than those of *G. arborea.* For these reasons, the relatively low SI values recorded in these four species were expected. In confirmation of these submissions, Pirralho *et al.* (2014) have earlier stated that high relative fibre

Table 1: Some pulp and paper-based wood fibre and wood constituent characteristics in *Gmelina arborea* and nine other hardwood species in Nigeria

	Tree species	Mean fibre dimensions (μm)				Mean fibre-derived ratios			
		Length (L)	Diameter (D)	Wall thickness (C)	Lumen width (I)	Relative fibre length (L/D)	Runkel ratio (2C/I)	Coeff of flex (I/D)	Wood specific gravity (%)
		A	B	B	B	A	B	A	B
1	*Gmelina arborea*	1115.14^{a} ±22.04	22.64^{a} ±2.17	3.41^{a} ±0.22	16.98^{a} ±1.12	51.03^{a} ±4.21	0.44^{a} ±0.03	0.71^{a} ±0.02	0.46^{a} ±0.01
2	*Afzelia africana*	1156.28^{a} ±148.15	23.20^{a} ±2.26	3.71^{a} ±0.02	15.62^{a} ±1.19	50.11^{a} ±3.39	0.49^{a} ±0.02	0.69^{a} ±0.07	0.50^{a} ±0.03
3	*Annona senegalensis*	653.31^{b} ±29.91	21.59^{a} ±3.08	3.80^{a} ±0.06	14.00^{a} ±1.49	31.09^{b} ±4.06	0.58^{b} ±0.08	0.62^{a} ±0.22	0.53^{a} ±0.08
4	*Anthocleista djalonensis*	888.23^{b} ±35.64	18.70^{a} ±2.28	3.09^{a} ±1.46	11.84^{a} ±1.84	46.92^{a} ±3.83	0.59^{b} ±0.08	0.64^{a} ±0.21	0.89^{b} ±0.25
5	*Azadirachta indica*	782.33^{b} ±35.09	16.98^{a} ±1.93	3.42^{a} ±1.30	11.26^{a} ±0.83	46.92^{a} ±4.03	0.74^{b} ±0.17	0.65^{a} ±0.07	0.43^{a} ±0.02
6	*Bridelia ferruginea*	876.75^{b} ±37.56	25.50^{b} ±3.06	5.87^{b} ±0.34	14.25^{a} ±4.20	34.44^{b} ±2.08	0.88^{b} ±0.07	0.57^{b} ±0.02	0.91^{b} ±0.55
7	*Daniellia oliveri*	1099.00^{a} ±43.51	18.69^{a} ±1.96	4.08^{a} ±1.04	12.35^{b} ±0.92	58.46^{b} ±5.11	0.71^{b} ±0.24	0.60^{b} ±0.06	0.35^{b} ±0.06
8	*Lannea barteri*	685.39^{b} ±35.18	28.25^{b} ±1,92	3.88^{a} ±0.55	20.48^{b} ±1.29	25.03^{b} ±3.46	0.45^{a} ±0.11	0.72^{a} ±0.04	0.45^{a} ±0.02
9	*Trichilia emetica*	758.48^{b} ±32.52	24.92^{a} ±2.41	3.14^{a} ±0.17	18.09^{a} ±1.16	30.44^{b} ±4.06	0.41^{a} ±0.04	0.70^{a} ±0.02	0.41^{a} ±0.07
10	*Vitex doniana*	651.89^{b} ±29.34	26.62^{b} ±2.24	4.91^{a} ±0.44	16.81^{a} ±1.03	25.06^{b} ±2.39	0.63^{a} ±0.09	0.63^{b} ±0.03	0.39^{a} ±0.02

RFL = Relative fibre length (or fibre slenderness); Coeff of flex= Coefficient of flexibility; Runkel = Runkel ratio; SG = Specific Gravity. Means of the experimental tree species in serial numbers 2 to 10 with no significant difference from that of *G.arborea* (using student t-test) bear the same superscripts with *G.arborea* ($P > 0.05$) while means with significant difference from that of *G. arborea* bear a different superscript ($P < 0.05$) A=Category 'A' variable;B=Category 'B' variable.

Table 2: Mean proportion by volume of tissue types in *Gmelina arborea* and nine other hardwood species in Nigeria

	Tree species	Mean percentage by volume						Mean number of cells /mm^{2}			
		Vessels(V)	Fibres (F)	Parenc (P)	Ray (R)	F/V ratio	F/NF ratio	Vessels	Fibres	Parenc	Ray
		B	A	B	B	A	A	B	A	B	B
1	*Gmelina arborea*	13.86^{a} ±2.64	36.32^{a} ±2.02	17.84^{a} ±2.92	31.98^{a} ±3.23	3.03^{a} ±0.71	0.58^{a} ±0.02	2^{a} ±1.03	812^{a} ±12.02	29^{a} ±3.47	10^{a} ±4.41
2	*Afzelia africana*	10.52^{a} ±1.46	32.85^{a} ±0.99	25.89^{b} ±0.81	30.74a ±1.46	3.37^{a} ±0.06	0.43^{a} ±0.03	36^{b} ±4.03	1151^{b} ±46.00	63^{b} ±3.0*0	3^{b} ±2.10
3	*Annona senegalensis*	21.59^{b} ±3.20	28.58^{a} ±6.10	20.59^{a} ±1.10	29.24a ±1.09	1.35^{b} ±0.89	0.40^{a} ±0.04	20^{b} 2.44	240^{b} ±14.08	137^{b} ±4.43	42^{b} ±2.63
4	*Anthocleista djalonensis*	19.55^{b} ±2.95	35.06a ±4.21	30.04^{b} ±2.84	26.83a ±0.92	0.43^{b} ±0.23	0.25^{b} ±0.01	2^{a} ±1.44	628^{b} ±12.60	53^{b} ±2.84	20^{b} ±2.63
5	*Azadirachta indica*	10.43^{a} ±0.63	31.03a ±5.48	18.67^{a} ±0.68	31.03a ±5.48	3.50b^{a} ±0.25	0.31^{b} ±0.05	10^{b} ±1.47	570^{b} ±9.34	82^{b} ±4.44	23^{b} ±2.00
6	*Bridelia ferruginea*	15.40^{a} ±2.41	32.60^{a} ±4.12	17.79^{a} ±2.91	34.34a ±0.55	0.43^{b} ±0.59	0.35^{a} ±0.02	15^{b} ±2.41	207^{b} ±9.50	73^{b} ±4.21	27^{b} ±2.62
7	*Daniellia oliveri*	8.57^{b} ±0.07	38.20a ±2.68	17.76^{a} ±1.99	35.20a ±0.78	4.60^{b} ±0.65	0.38^{a} ±0.03	4^{a} ±1.07	450^{b} ±23.75	101^{b} ±5.67	26^{b} ±2.66
8	*Lannea barteri*	16.48^{a} ±0.75	31.25^{a} ±0.90	24.54^{b} ±1.30	27.73a ±1.81	1.91^{b} ±0.13	0.46^{b} ±0.01	15^{b} ±2.76	302^{b} ±10.78	50^{b} ±3.49	20^{b} ±2.09
9	*Trichilia emetica*	16.88^{a} ±2.24	30.04^{a} ±1.64	25.04^{b} ±1.49	30.04a ±164	1.91^{b} ±0.31	0.43^{a} ±0.03	25^{b} ±2.44	785^{a} ±30.00	92^{b} ±5.00	25^{b} ±2.00
10	*Vitex doniana*	9.44^{b} ±0.49	34.79^{a} ±0.21	22.80^{b} ±0.93	32.97a ±0.81	3.71^{a} ±0.18	0.53^{a} ±0.01	7^{a} 1.08	249^{a} 17.09	73^{b} ±2.68	11^{a} ±1.49

F/V = Fibre-to-Vessel ratio; F/NF = Fibres to non-fibrous tissue ratio = (F/V+P+R); means of experimental tree species (in serial number 2 to 10) with no significant difference from that of *G. arborea* (using student t-test) bear the same superscripts with *G.arborea* ($P > 0.05$) while means with significant difference from *G. arborea* bear a different superscript ($P < 0.05$). A= Category 'A' variable; B=Category 'B' variable.

Table 3: The pulp and paper making suitability indices of nine Nigerian hardwood species in relation to that of *Gmelina arborea*

	Tree Species	Family	Pulp and Paper Making Suitability Index
1	*Gmelina arborea* Roxb.	Lamiaceae	1.00
2	*Afzelia africana* Sm. Ex Pers	Fabaceae	1.09
3	*Annona senegalensis* Pers.	Annonaceae	0.79
4	*Anthocleista djalonensis* A. Chev.	Logamaceae	0.48
5	*Azadirachta indica* A. Juss	Meliaceae	0.86
6	*Bridelia ferruginea* Benth.	Euphorbiaceae	0.64
7	*Daniellia oliveri* (Rolfe) Hutch. & Dalziel	Fabaceae	1.04
8	*Lannea barteri* Engl.	Anacardiaceae	0.66
9	*Trichilia emetica* Vahl	Meliaceae	0.98
10	*Vitex doniana* Sweet	Verbenaceae	0.62

lenth/ fibre slenderness ratios and fibre flexibility coefficients were indicators for recognizing promising wood raw materials for paper making. So also, low Runkel and high fibre flexibility ratios along with a preponderance of fibres relative to other cells are also acknowledged as desirable in selecting wood for pulping (Kpikpi and Sackey, 2012; Ekhuemelo and Tor, 2013; Ekhuemelo et al., 2018).

In pointing out the suitability of different woody plant species for paper pulp, it should be understood that classification cannot be narrow and precise. In the first place, it cannot be said that paper made from a certain wood will always be stronger than paper made from another wood because wood from various species may respond to treatments differently to the extent that the cooking conditions for example, may substantially weaken the fibres in one than the other. As such, declarations made on paper pulp suitability of a wood without having made an assessed paper sheets from the wood should be done with some caution. Furthermore, it cannot be said in absolute terms, that pulp and paper made from a wood is superior to that from another wood since superiority depends on the users' preference. Hence, in comparing woods for pulping, it is important to consider factors such as ease of pulping, pulp yield, bleaching and beating process, manner of making the paper sheets and the use to which the paper is intended (Noah *et al.*, 2015; Soliman *et al.*, 2017). Additionally, the pulp and paper making potentials of woody species vary somewhat with growth conditions and age (FAO, 1980).

Going by the above submissions, the results of evaluation of the nine alternative hardwoods in this study can be said to be limited by the assumption that the wood pulping process, pulp characteristics, physico-chemical properties and growth/plantation parameters of the nine species are similar to those of *G. arborea*. Hence, the SI value of each tree species being reported is taken as a measure by which the wood is expected to produce paper sheets of comparable physical and mechanical properties as *G. arborea* wood. In practice, this assumption cannot stand, hence, as many as the properties of potential pulpwoods ought to have been incorporated into the PPM wood suitability index model for more dependable results. As this observation is being given effect in the efforts towards revising the PPM suitability index model, it is argued that the model, as it were, can be applied as a tool for preliminary evaluation and selection of potential pulpwoods based on wood structure and anatomy. The line of argument in examining the applicability of the results of this study is that, once a few experimental wood samples are first selected on the basis of their encouraging SI value in relation to the accepted standard pulpwood, further diagnostic and confirmatory studies on the select few should follow with emphasis on their wood chemical and pulp characteristics, physical and mechanical properties of their paper sheets, species adaptability to plantation culture and so on.

Conclusions and Recommendations

Going by their calculated pulp and paper making (PPM) suitability index values, the wood of *Afzelia africana*, *Daniellia oliveri and Trichilia emetica* studied were about 100% suitable in comparison with the wood of *G. arborea.* The wood of *Azadirachta indica* and *Annona senegalensis* also showed substantial compliance (79-86%) with the desirable qualities of this standard pulpwood in Nigeria. It is possible for the paper industry in the country to use the wood of these species enumerated for producing papers of high quality instead of relying entirely on *G. arborea* wood with multifarious other uses. These five hardwood species are therefore recommended as good and suitable fibrous material for the paper industry in the country. The desirability or otherwise of other important pulpwood properties, which were not built into the SI model, such as growth conditions of the species and their adaptability to plantation techniques, cooking behavior of the wood and ease of pulping, pulp yield and physical properties of the pulp, chemical composition of the wood, and physical and mechanical properties of the paper sheets should, however be taken into consideration in making categorical selection of these tree species as alternative PPM resources..

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