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ORIGINAL ARTICLE

A Quantitative Modelling of Pulp and Paper Making Suitability of Nigerian Hardwood Species

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ABSTRACT

An objective method for selecting hardwood species for pulp and paper making (PPM) is being proposed. This technique statistically compares the available anatomical and other relevant data in the reference wood (*i.e. Gmelina arborea* Roxb.) with those of an alternative wood sample. Based on the result of the comparison, it computes the suitability index (SI), a numeric value by which the PPM potential of the alternative hardwood species can be precisely defined. The SI of *G. arborea* wood carries a value of 1.00 while that of any other hardwood ranges between 0 and 1 if the alternative wood sample is less suitable or, above 1 if it is more suitable for pulping. The SI model was used to determine the PPM suitability of 12 Nigerian species of *Ficus* L.in relation to *G. arborea* wood, the widely acknowledged PPM resource in Nigeria. The *Ficus* species investigated in order of their preference for PPM are listed as *F. thonningii* (0.8325), *F. mucuso* (0.7964), *F. ottonifolia* (0.7704), *F. lutea* (0.7545), *F.sur* (0.7504), *F. exasperata* (0.7454), *F. natalensis* (0.7309), *F. ingens* (0.7166), *F. polita* (0.7094), *F. populifolia* (0.7054), *F. ovata* (0.6947) and *F. umbellata* (0.6728). The merits of the technique over the conventional descriptive approach are listed and some of its limitations are highlighted.

Key words: Suitability Index; *Ficus; G. arborea*; pulp and paper; wood structure; algorithmic botany

Introduction

Among many hardwood species found in the Nigerian forests, *Gmelina arborea* Roxb and *Eucalptus* species have been found suitable for pulp and paper making (PPM)(Anon, 1984; 1990). *G. arborea* is particularly acknowledged as the prime source of pulpwood in West Africa and Brazil. This is because of 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, low chemical extractives and so on (Sosanwo,1984; Kpikpi,1992; Evans,1992). Therefore in the search for an alternative wood resources for paper production, paper scientists usually evaluate anatomical and other relevant PPM characteristics in tropical wood samples and define their suitability in relation to the available data on *G. arborea* wood (Sosanwo,1984; Kpikpi and Olatunji,1990; Fuwape,1991; Ogunkunle and Oladele,2008).

In an earlier publication (Ogunkunle *et al.*, 2004), the 7-year old *G. arborea* tree had been statistically shown to exhibit the most desirable wood characteristics for PPM among *G. arborea* trees of different ages from 1 to 16 years. The purpose of this paper is to propose a technique for comparing data on potential PPM wood resources with one another and with those of the widely-accepted standard raw material, *G. arborea*. So far, we have lacked a procedure for such comparisons. Instead, the most frequent way of drawing conclusions from studies of potential pulpwood is by placing the reference data and the test sample data from one or more other wood specimens side by side and simply compared. This practice, which highlights data correspondence with the use of descriptive statements, is subjective as it lacks precision.

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Suppose that three wood samples are being compared with *G.arborea* wood over say, eight quantitative parameter values. If going by four of the parameters the three wood samples are less suitable for PPM and by the other four parameters, they are more suitable than the reference wood, then two pertinent questions may arise: by what degree or to what extent precisely is the suitability of any of the three wood samples defined in relation to the standard ?; and moreover which one of the three wood samples is more suitable for PPM than the others in relation to the standard and by what degree or percentage?. Definitely, the orthodox method of wood comparison and selection for PPM cannot answer these questions satisfactorily.

A more reliable method of comparison should standardize all the available data values in both the reference and the test wood materials, compare the two sets of data objectively and arrive at a single numeric value, the suitability index (SI) for the latter. With this index, the paper making potential of a wood sample can be precisely defined in relation to the acceptable standard (*G. arborea*) and to any other wood sample (Ogunkunle, 2001). Such a technique, being proposed in this paper is an attempt to bring into limelight, the possibility of quantifying the PPM status of hardwoods.

Materials and methods

Standard Plant Material

The wood of the 7-year old *G. arborea* tree was taken as the standard plant material(Ogunkunle *et al*., 2004). Nineteen pulp and paper- based quantitative characteristics (Tables1and 2) were drawn from this sample along with five other *G. arborea* trees of different ages between 1 and 16 years, collected and treated as earlier described in details (Ogunkunle, 2006; Ogunkunle and Oladele, 2008). The reference data were then taken to be the most desirable mean values of each of the 19 wood parameters, of which the 7-year old tree was representative. The % tissues by wood volume (i.e. vessels, fibres, parenchyma, ray, F/V ratio and F/NF ratio), wood specific gravity and % ash content were determined in replicates of four while data on the other eleven parameters were taken in replicates of 30 (Ogunkunle *et al.,* 2004; Tables1 and 2).

Experimental Plant Materials

The experimental plant materials were the wood samples of 12 Nigerian species of *Ficus* (Tables 1 and 2) collected as earlier reported in Ogunkunle and Oladele (2008). From these alternative wood samples, data on the 19 pulp and paper- based wood characteristics were drawn in replicates as in *G. arborea* wood with the aim of determining their PPM suitability in relation to the standard plant material.

The Technique

1. Background information; the fact and the assumptions

By design, the SI of a wood sample was made to range between 0 and 1 if the sample is less suitable than *G. arborea* for PPM, and is above 1 if otherwise. This means that the nearer the SI value of a less suitable wood sample is to 1, the closer is the wood sample to *G. arborea* as a pulp and paper resource. The technique for determining the SI of a wood sample is an algorithm (i.e. a logical step-by-step procedure for solving a computational problem in a definite number of steps), based on a fundamental fact and two basic assumptions. With respect to the fact, wood anatomists and paper scientists have widely acknowledged that there are two categories of quantitative wood variables or parameters in paper making namely, those of category 'A' and those of category 'B' (Dinwoodie, 1965; Okereke,1965; Oladele,1991 and Ogunkunle *et al.*, 2004). The category 'A' variables are those whose inputs are preferred in paper making when their magnitudes are high i.e. the input values contribute positively to the process and product of paper making (Tables 1 and 2). The category 'B'variables on the other hand are preferred when the magnitudes of their input values are low because they eventually contribute negatively to the process and the subsequent product (Tables 1 and 2). The first assumption is that, the wood of *G. arborea* has the most desirable set of anatomical and other characteristics required for paper making (Martin,1984) and secondly, the variation within the 'population' of measured or computed data values of a wood parameter follows the normal distribution pattern (Kelly and Onyeka, 1992).

Arising from the fact and the assumptions, it was established that

a. the mean of the replicated input values of any parameter in *G. arborea* wood, which is representative of that parameter, will produce the maximum output of PPM. This output was assigned a weight or a projected output value of 1 (i.e. 100%);

b. if a parameter is examined in an experimental wood material, its variance and mean may be statistically compared with those of the standard raw material (i.e. *G. arborea*) using the conventional methods (Kelly and Onyeka, 1992);
c. if after the comparison the distribution pattern of an experimental wood parameter is found not to be significantly different from that of the standard, then the two means will carry the same PPM output weight (i.e. 1) for that parameter;
d. if however, the distribution pattern of an experimental wood parameter is significantly different from that of the standard, the PPM output weight of the experimental mean will be determined by a simple ratio between the standard mean and the experimental mean for the parameter, having put into consideration the category of the parameter in question.

2. The Algorithm

The procedure for manipulating pulp and paper-based quantitative wood parameters for the computation of wood suitability indices was represented by a flow chart (Fig1) and presented by Ogunkunle (2001) as follows:

Step 1: For all the parameters in the standard wood (i.e. *G. arborea*), assign a PPM output weight value of 1 to the mean;
Step 2: Select the wood parameters one at a time, conduct the variability test ;(i.e. test of variances) between the replicates of the standard and the alternative wood material and hence, use the appropriate t-test formula to compare the two means;
Step 3: If there is no significant difference between the two means, assign a weight of 1 as well to the mean of the alternative wood for that parameter;
Step 4: But if there exists a significant difference between the two means, check if the parameter is of category 'A' or 'B';
Step 5: If the parameter is of category 'A' (i.e. the higher the better), compute the corresponding PPM output weight value of the experimental wood for that parameter as the direct proportion:

$$\frac{\text{Mean of experimental wood } (\varphi j)}{\text{Mean of standard wood } (\mu i)},$$

Step 6: If however the parameter is of category 'B' (i.e. the lower the better), compute the corresponding PPM output weight value of the experimental wood sample for the parameter as the inverse proportion:

$$\frac{\text{Mean of experimental wood } (\mu i)}{\text{Mean of standard wood } (\varphi j)}$$

Step 7: Compile a list of the means for all the wood parameters used and their weight values (i.e projected PPM outputs), first for the standard wood sample and them for the alternative wood sample;
Step 8: Use the SI model to calculate the PPM suitability index of the experimental wood in relation to that of the standard (i.e. 1) The SI model is a formula adapted from Fisher's ideal index formula (Spiegel, 1992) which employs the weighted aggregate technique to estimate changes in quality or quantity are follows:

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

Where φj = mean values of the parameters in the alternative wood
μi = mean values of the parameters in the standard wood
w_j = projected PPM output values of φj
w_i = projected PPM output values of μi

PPM Suitability Indices of some Nigerian species of Ficus

In line with the proposed algorithm, the mean values of each of the 19 parameters for *G. arborea* (μi) was assigned an output weight value or quality (w_i) of 1. Thereafter, for each species of *Ficus*, one parameter was taken at a time and statistically tested against the corresponding parameter in *G. arborea* using the student t-test with two independent variables technique to obtain a mean φj for the experimental sample.

On the basis of whether there was a significant difference between the two means φ*j* and μ*i* or not and on the basis of the category of the parameter in consideration (Tables 1 and 2), the projected output weight or PPM quality w_j was computed for the *Ficus* species. Thus, the means μ*i* and weights w_i (i.e.1) were obtained in respect of the 19 parameters for *G. arborea* where i = 1,2, 3….s; s being the number of variables used (i.e 19). Similarly, the representative means φ*j* and their corresponding weight values w_j were obtained for each of the the *Ficus* species, j =1,2,3……..t; t being 19, the number of wood variables used. Data on *Ficus* species were used to simulate the suitability index model on the statistical computer package SPSS version 11.0 to obtain the suitability indices for the 12 species studied.

Furthermore, the PPM output weights for each of the 12 species of *Ficus* in the 19 parameters were statistically compared with those of *G. arborea* to determine the nearness of their means using the one sample t-test which adopted 1, the mean output weight for *G. arborea* as the test value. To a certain extent, these results should indicate the level of significance of each of the various wood suitability indices of *Ficus* in relation to 1, the SI of *G. arborea*. Lastly, a one-way classification ANOVA test was conducted on the means of the PPM outputs in the 12 species of *Ficus*. The result of this analysis was thought, should be indicative of affinities among the various species of *Ficus* investigated with respect to their PPM potentials.

Results and discussion

Tables 1 and 2 show the data obtained from both the reference (*G. arborea*) and the alternative (*Ficus*) wood samples. The *Ficus* species studied can be listed in order to their preference for PPM as *F. thonningii, F. mucuso, F. ottonifolia, F. lutea, F.sur, F. exasperata, F. natalensis, F. ingens, F. polita, F. populifolia, F. ovata* and *F. umbellata,* with suitability indices of 0.8325, 0.7964, 0.7704, 0.7545, 0.7504, 0.7454, 0.7309, 0.7166, 0.7094, 0.7054, 0.6947 and 0.6728 respectively. These results show that the Nigerian *Ficus* species investigated are fairly suitable wood resources for PPM. From these results, *F. thonningii F.mucuso* and *F. ottonofolia* can be said to be among the best substitutes for *G.* a*rborea,* each being at least 77 % suitable for papermaking in comparison with *G. arborea*. *F. umbellata* with the least SI of 0.6724 is still potentially good as a substitute for *G. arborea* to the tune of 67.24%.

Table 1: Mean proportion by volume of some tissue types in the wood of *G. arborea* and some Nigerian species of *Ficus**

Species	Mean Percentage by volume					Mean Number of cells/mm^2				
	Vessels (V) B	Fibres (F) A	Parenchy (P) B	Ray (R) B	F/V ratio A	F/NF ratio A	Vessels B	Fibres A	Parenchyma B	Ray B
1. *Gmelina arborea*	9.13^a± 2.14	60.83^a±0.94	3.29^a± 0.66	25.00^a± 1.59	8.26^a±2.45	1.44^a± 0.04	3.10^a± 0.18	512.80^a±26.18	5.80^a± 0.70	10.60^a± 0.31
2. *Ficus lutea*	8.43^a± 1.40	38.50^b± 0.53	20.28^b± 1.45	32.78^a± 1.64	4.69^a± 0.08	0.63^b± 0.04	4.10^b± 0.31	457.20^a± 34.33	166.70^b± 15.41	12.30^a± 0.83
3. *F.natalensis*	8.55^a± 0.80	31.63^b± 1.47	26.38^b± 1.13	28.93^a± 2.43	3.59^a± 0.47	0.49^b± 0.01	4.80^b± 0.59	424.30^b± 26.52	141.10^b± 11.74	22.00^b± 1.31
4. *F.mucuso*	7.96^a± 1.18	38.79^b± 3.20	29.36^b± 2.29	23.89^a± 1.92	5.46^a± 1.38	0.65^b± 0.09	4.00^a± 0.42	408.30^b± 28.31	130.60^b± 12.02	10.00^a± 0.38
5. *F.ovata*	8.22^a± 2.38	37.35^b± 1.06	27.33^b± 2.47	27.10^a± 3.41	6.27^a± 2.18	0.60^b± 0.03	3.50^a± 0.22	352.10^b± 22.75	107.90^b± 14.53	10.10^a± 0.38
6. *F.ingens*	10.98^a± 1.08	36.17^b± 1.07	32.71^b± 0.86	20.14^b± 1.42	3.65^a± 0.80	0.65^b± 0.11	7.90^b± 0.82	355.30^b± 37.42	114.10^b± 10.14	10.50^a± 0.48
7. *F.umbellata*	11.82^a± 1.11	31.87^b± 1.74	24.43^b± 2.20	32.12^a± 1.06	2.79^a± 0.36	0.47^b± 0.03	8.70^b± 3.48	365.90^b± 35.07	187.00^b± 14.96	10.90^a± 0.57
8. *F.ottonifolia*	7.44^a± 1.38	38.08^b± 0.87	27.81^b± 3.16	26.67^a± 2.05	5.69^a± 1.04	0.54^b± 0.08	4.60^b± 0.49	423.20^a± 37.99	105.50^b± 10.54	8.80^a± 0.59
9. *F.polita*	15.54^a± 1.70	35.88^b± 1.27	26.66^b± 1.21	21.91^a± 2.83	2.36^a± 0.14	0.56^b± 0.03	6.40^b± 0.31	462.40^a± 20.25	109.80^b± 11.13	8.70^b± 0.42
10. *F.thonningii*	8.42^a± 1.30	34.55^b± 2.57	29.09^b± 2.72	27.94^a± 3.07	4.67^a± 1.25	0.53^b± 0.06	3.60^a± 0.34	445.40^a± 57.31	143.90^b± 13.80	15.70^b± 0.84
11. *F.ecasperata*	11.92^a± 1.87	31.00^b± 0.79	24.65^b± 1.83	32.03^a± 1.56	2.81^a± 0.46	0.45^b± 0.02	5.30^b± 0.30	261.80^b± 39.08	245.50^b± 21.92	10.40^a± 0.37
12. *F.sur*	18.33^b± 1.69	28.19^b± 1.02	30.91^b± 2.25	22.41^a± 2.59	1.60^b± 0.23	0.39^b± 0.02	12.90^b± 1.02	306.20^b± 25.87	315.10^b± 30.19	10.20^a± 0.20
13. *F.populifolia*	19.05^b± 2.57	30.52^b± 1.76	21.25^b± 2.00	29.17^a± 1.21	1.76^b± 0.41	0.44^b± 0.04	9.90^b± 0.75	409.70^a± 42.36	196.10^b± 26.11	8.40^b± 0.32

* F/V = Fibre-to-Vessel ratio; F/NF = Fibres to non-fibrous tissue ratio = (F/V+P+R); means of *Ficus* species with no significant difference from that of *G.* arborea bear the same superscripts with *G.arborea* (P≥ 0.05) while means with significant difference bear a different superscript (P<0.05). A= Category 'A' parameter; B=Category 'B' parameter

Table 2: Some pulp and paper-based wood fibre and wood constituent characteristics in *G .arborea* and some Nigerian species of *Ficus*.

Species	Mean fibre dimensions (μm)				Mean fibre-derived ratios				
	Length (L) A	Diameter (D) B	Wall thick (c) B	Lumen width (I) B	RFL (L/D) A	Runkel (2C/I) B	Coeff. (I/D) B	S.G.% B	Ash Content B
1. *G. arborea*	1753.09^a± 100.37	23.57^a±1.75	2.82^a± 0.26	17.42^a±1.21	67.01^a±3.74	0.25^a± 0.03	0.79^a± 0.02	0.43^a±0.02	1.94^a± 0.23
2. *F. lutea*	1103.35^b± 67.81	26.62^a± 1.58	4.99^b± 0.48	16.64^a± 1.49	43.75^b± 4.07	0.68^b± 0.09	0.63^b± 0.03	0.56^a± 0.06	2.16^a± 0.12
3. *F.natalensis*	1098.75^b± 59.99	23.38^a± 1.14	3.20^a± 0.29	17.15^a± 1.15	47.95^a± 3.89	0.38^b± 0.04	0.73^b± 0.02	0.45^a± 0.01	1.73^a± 0.18
4. *F.mucuso*	1284.12^b± 64.78	19.97^a± 2.15	2.29^a± 0.20	15.39^a± 1.85	71.99^a± 9.51	0.32^a± 0.03	0.76^a± 0.02	0.45^a± 0.02	1.98^a± 0.08
5. *F.ovata*	1105.92^b± 65.45	20.74^a± 1.17	2.82^a± 0.26	15.36^a± 1.27	55.10^a± 5.25	0.40^b± 0.05	0.73^b± 0.03	0.51^a± 0.02	2.01^a± 0.09
6. *F.ingens*	1159.02^b± 45.36	24.34^a± 1.43	2.82^a± 0.17	19.77^a± 1.38	48.03^a± 4.65	0.29^a± 0.03	0.77^a± 0.02	0.51^a± 0.04	1.97^a± 0.12
7. *F.umbellata*	990.21^b± 56.59	20.48^a± 1.53	2.30^a± 0.26	15.62^a± 1.50	50.51^a± 4.09	0.31^a± 0.04	0.75^a± 0.02	0.49^a± 0.05	1.89^a± 0.09
8. *F.ottonifolia*	1221.63^b± 77.45	23.81^a± 0.88	2.62^a± 0.22	18.56^a± 0.98	51.94^a± 3.75	0.30^a± 0.04	0.78^a± 0.02	0.58^b± 0.02	2.22^a± 0.11
9. *F.polita*	1003.52^b± 70.47	21.12^a± 0.96	2.63^a± 0.24	15.87^a± 0.19	48.28^a± 3.77	0.36^a± 0.05	0.74^a± 0.03	0.51^a± 0.02	2.01^a± 0.06
10 *F.thonningii*	1333.36^b± 53.45	25.09^a± 0.99	3.58^a± 0.32	17.92^a± 0.32	54.11^a± 3.59	0.42^b± 0.05	0.71^b± 0.02	0.46^a± 0.01	1.39^a± 0.09
11 *F.exasperata*	1242.00^b± 97.42	21.25^a± 1.08	2.94^a± 0.38	14.85^a± 1.07	58.76^a± 3.65	0.42^b± 0.07	0.65^b± 0.05	0.48^a± 0.04	1.85^a± 0.12
12 *F.sur*	1197.06^b± 23.92	28.93^b± 1.32	3.97^b± 0.35	20.99^a± 1.25	42.38^b± 2.61	0.39^b± 0.04	0.72^b± 0.02	0.44^a± 0.02	1.99^a± 0.12
13 *F.populifolia*	1008.70^b± 46.38	18.69^b± 1.15	1.94^b± 0.22	14.80^a± 0.80	55.34^a± 3.14	0.26^a± 0.02	0.79^a± 0.02	0.49^a± 0.06	1.93^a±0.03

RFL = Relative fibre length (or fibre slenderness); Coeff = Coefficient of flexibility; Runkel = Runkel ratio;
SG = Specific Gravity. Means of *Ficus* species with no significant difference from that of *G.arborea* bear the same superscripts with *G.arborea* (P ≥0.05) while means with significant difference bear a different superscript (P<0.05)
A=Category 'A' parameter ;B=Category 'B' parameter.

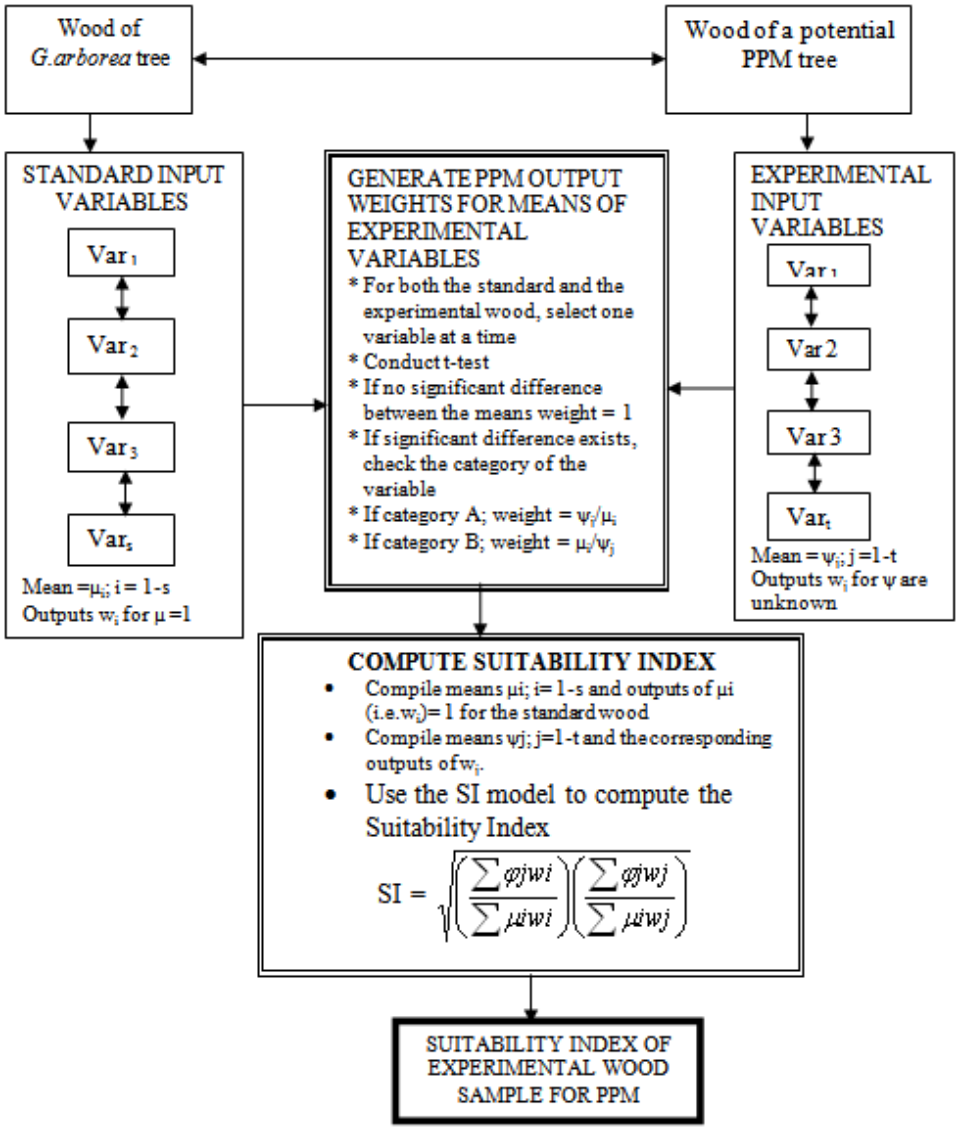

Fig. 1: A Model for Quantifying the PPM Suitability of hardwood species in relation to G. arborea wood; var = variable; PPM = pulp and paper making. Category 'A' variables = those wood parameters which are preferred in PPM when their magnitudes are high; Category 'B' variables = those wood parameters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

The results of the t-tests conducted indicated a significant difference between data from each of the 12 species of *Ficus* and that of *G. arborea* (Table3). These results can not be overemphasized for the fact that the data from *Ficus* species used in the comparisons were the means of the projected PPM outputs for the species rather than the computed suitability indices themselves. The observed differences (i.e $P<0.05$ for all the 12 species of *Ficus*) can possibly be explained by the significantly higher quantity of non-fibrous tissues namely, parenchyma, rays and vessels in the *Ficus* species (Tables 1 and 2), whose contributions alongside the fibrous tissues significantly affected the projected PPM outputs in the negative directions (Figs 2 and 3; Kpikpi and Olatunji, 1990; Kpikpi, 1992).

The one-way classification Analysis of variance conducted on the means of PPM output for the twelve species of *Ficus* did not reflect any significant difference among them (Table 4). This could probably be explained in terms of the expected fairly uniform wood structure and composition in the species of the same genus. It is arguable that the means of projected PPM output values enumerated in Table 3 should suffice as the PPM suitability indices of the *Ficus* species studied, and that there might be no need for the rigours of computing the Si's with Fisher's ideal index formula. However, the justification for these efforts is obvious when we recognize the fact that an arithmetic mean is obtainable from only one, unweighted set of data: in

Table 3: Results of one-sample t-tests on means of PPM projected suitability values in some Nigerian species of *Ficus.**

Species	t	df	Mean	Sig (2-tailed)	Mean difference
F. lutea	-3.598	18	0.7449	0.002	0 -0.2551
F. natalensis	-3.471	18	0.7468	0.003	-0.2532
F. mucuso	-2.409	18	0.8302	0.027	-0.1698
F. ovata	-2.910	18	0.7932	0.009	-0.2068
F. ingens	-2.392	18	0.8077	0.028	-0.1923
F. umbellata	-2.951	18	0.7709	0.009	-0.2290
F. ottonifolia	-2.740	18	0.8045	0.013	-0.1955
F. nolita	-2.617	18	0.8121	0.025	-0.1879
F. thoningii	-2.437	18	0.8121	0.025	-0.1879
F. exasperata	-2.891	18	0.7905	0.010	-0.2095
F. sur	-3.391	18	0.7474	0.003	-0.2526
F. populifolia	-4.803	18	0.6128	0.000	-0.3872

*Test value =1; PPM, puip and making

Table 4: Result of one-way ANOVA on the means of pulp and paper making projected suitability values in twelve Nigerian species of *Ficus.*

	Sum of squares	df	Mean square	f	Sig
Between Groups	0.694	11	0.06307	0.571	0.851
Within Groups	23.954	217	0.110		
Total	24.647	228			

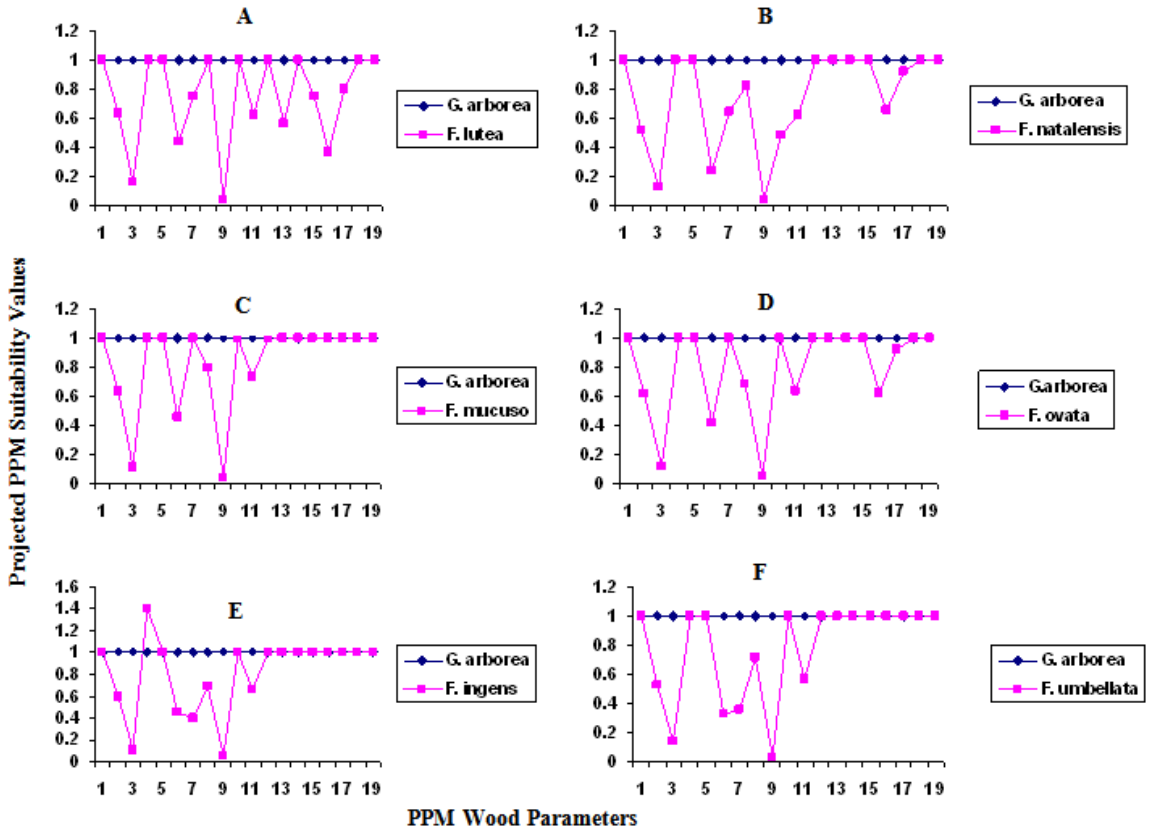

Fig. 2: Variations in the projected pulp and paper-making (PPM) suitability of Ficus lutea (A), F. natalensis (B), F. mucuso(C), F. ovata (D), F. ingens (E), and F. umbellata (F) in relation to G. arborea over 19 wood parameters: 1, % vessel; 2, % fibres; 3, % parenchyma; 4, % ray; 5, fibre/vessel ratio; 6, fibres/non-fibrous tissues ratio; 7, number of vessels /mm2; 8, number of fibres /mm2; 9, number of parenchyma cells /mm2 ; 10, number of rays /mm2 ; 11, fibre length (µm); 12, fibre diameter(µm); 13, fibre wall thickness(µm); 14, fibre lumen width(µm); 15, relative fibre length; 16, Runkel ratio; 17, coefficient of fibre flexibility; 18; wood specific gravity and 19, % ash content.

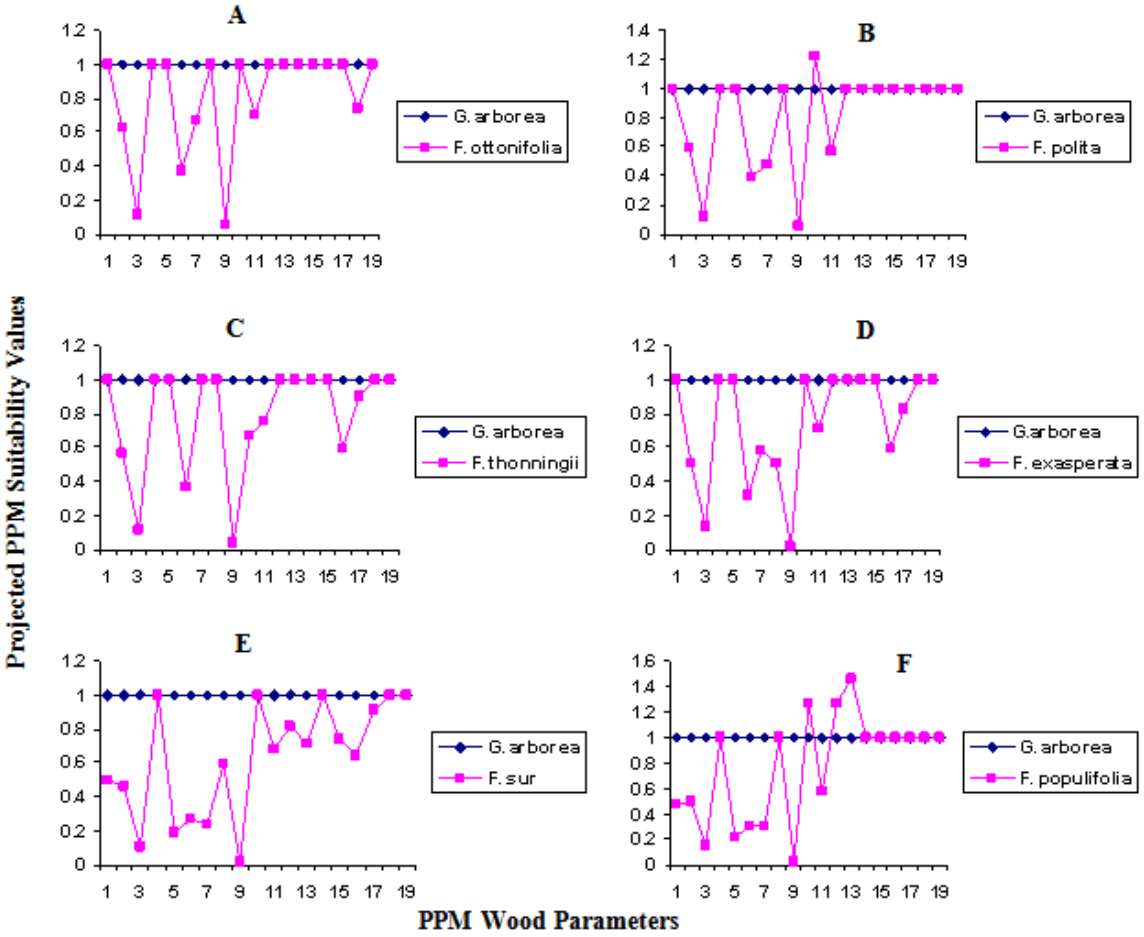

Fig. 3: Variations in the projected pulp and paper-making (PPM) suitability of Ficus. ottonifolia (A), F. polita (B), F. thonningii (C), F. exasperata (D), F. sur (E), and F. populifolia (F) in relation to G. arborea over 19 wood parameters: 1, % vessel; 2, % fibres; 3, % parenchyma; 4, % ray; 5, fibre/vessel ratio; 6, fibres/non-fibrous tissues ratio; 7, number of vessels /mm2; 8, number of fibres /mm2; 9, number of parenchyma cells /mm2 ; 10, number of rays /mm2 ; 11, fibre length (µm); .12, fibre diameter(µm); 13, fibre wall thickness(µm); 14, fibre lumen width(µm); 15, relative fibre length;16, Runkel ratio; 17, coefficient of fibre flexibility; 18; wood specific gravity and 19, % ash content.

this case, wood anatomical data or their projected PPM output values, but never from both. Moreover, Spiegel (1992) has identified three weighted aggregate methods namely, Laspeyre's, Paasche's and Fisher's as being more reliable than arithmetic mean in determining index numbers. Out of these three, Fisher's index is most suitable as it satisfies the tests of an index number (Spiegel, 1992). The strength of these arguments is a justification for this technique, which attempts to establish a framework for quantitative assessment of hardwood species as raw materials for pulp and papermaking.

Although, the SI's of the 12 species of *Ficus* studied are high enough to warrant their recommendation as substitutes for *G. arborea*, these values appear to define mainly, the relationship between the pulp and paper-based fibre characteristics of these species and of *G. arborea* rather than the totality of the relationship between their wood and tree quantity with respect to PPM. This is because the suitability index technique has not been able to assign to, or compute any output weight values for some parameters that are also considered important in an ideal and /or a potential pulp wood species. Some of these parameters include rapidity of tree growth , which has a relevance in economical plantation management; straightness of the boles, which is important in the process of debarking; whiteness of the wood fibres, which has an implication in the cost of bleaching the pulp, and the severity of varying users' demand for a wood resource, which defines the extent of the scarcity of the species for PPM (Dadswell *et al.*, 1959; Semana, 1978; Ogunkunle *et al*, 2004). Furthermore, the technique has not taken care of such factor as wood sclereids or stone cells, or any other wood inclusions, which may show discontinuous variation in the wood structure, but whose presence or absence may have some implications in the pulping process.

Albeit, the procedure developed in this study has made it possible to quantitatively compare potential pulpwood species with one another and evaluate their suitability for PPM with reference to the standard raw material, (i.e *G. arborea* wood). Moreover, the technique can be used to estimate the magnitude of contributions of different wood parameters to PPM. Thus, scientific evaluation of hardwood species in search for alternative pulp and paper resources has been made more objective with the possibility of being computerized in no distant future. To this extent, contemporary botanists, paper scientists and other professionals are enjoined to take interest in this quantitative technique for wood comparisons with a view to developing computer software packages in aid of hardwood selection for PPM. This effort would combine precision with speed, a welcome development in our bid to maximize the use of forest products, ensure tree conservation, reduce competition for pulp and paper making resources and sustain our paper industries.

In conclusion, the foregoing point to the fact that the suitability index technique although, desirable for an objective assessment of PPM wood characteristics, can not be a replacement of the orthodox technique. Rather, it should be a complementary approach such that when the SI of a hardwood species, which defines its PPM quality in relation to that of *G. arborea* is known, a corroborative description of its plantation characteristics, straightness of the bole, extent of its demand as a raw material for other purposes and so on, should be presented. These should altogether give an accurate picture of the suitability of a tree species as a pulp and papermaking resource. As Seligman (1993) has rightly observed, "it is not possible for any biological simulation model to replace subjective assessments and value judgments that enter into many critical decisions".

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