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Comparative Paper-making Potentials of Three Species from the Verbenaceae and Lamiaceae Family

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Authors' contributions

This work was carried out in collaboration among all authors. Authors GCA and DOA designed the study, wrote the protocol and managed the literature searches. Author EOO performed the statistical analysis, managed the analyses of the study, managed the literature searches and wrote the first draft of the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Fibre dimensions are of great significance due to their strong relationship with the strength properties of wood and paper. The fibre characteristics of three selected plant species (Verbenaceae family - *Duranta erecta* and *Lantana camara,* Lamiaceae family- *Vitex doniana*) were determined and their pulp and paper making potentials were compared with that of *Gmelina arborea*. The mean fibre lengths of the species were found to be short since they were less than 1.6mm. *Gmelina arborea* has the highest slenderness ratio with a mean value of 29.8241±1.0928 and the highest coefficient of flexibility (0.8584±0.0109). The Runkel ratio was highest in *Duranta erecta* recording an average of 0.6507±0.0638. However, the derived fibre values: slenderness ratio, coefficient flexibility and Runkel ratio of the species studied were considered to be good paper making potentials, therefore, making *Duranta erecta, Lantana camara,* and *Vitex doniana* a suitable substitute for *Gmelina arborea* in the papermaking industries.

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1. INTRODUCTION

Paper could be defined as a thin material essentially used for writing and printing upon or packaging [1]. As an end-user product, paper has proven evidence to be critical in driving the most sensitive needs of mankind, remarkably in areas of education, security, communication and sanitation [2]. Generally, paper is cellulose extracted from plant materials whose quality depends on the fineness and brightness of the fibres. Paper is formed by the combination of fibres, usually vegetable fibres made up of cellulose, which are held together by hydrogen bonding. Although the fibres are mostly sourced naturally by origin, a variety of synthetic fibers, such as Polyethylene and Polypropylene may be integrated into the paper as a way of adding desirable physical properties. The most common source of natural fibres for paper making is wood pulp from pulpwood trees [1].

Fibre characteristics are essential when taking into consideration the deployment of any plant for pulp and paper making. Fibres are the major trait used in determining the level of efficiency of wood species in pulping [3]. The strength property of paper is a function of the fibre characteristics used. The characteristics of fibre in wood have been shown to differ widely and consequently exert diverse influence on fibre strength, bulk density and inter-fibre bonding [4]. Woods with long fibres are frequently desirable in the paper industry [5]. Thick wall fibres affect the tensile strength, folding endurance and bursting strength of paper. Wood species with high Runkel ratio usually have stiff fibres that are less flexible and poor bonding ability. Fibre with higher Runkel ratios produces bulkier paper as compared to fibres with lower Runkel ratios. Therefore, any wood species that is of good quality for pulp and paper production must have a Runkel ratio ≤ 1 [6]. Fibre characters such as length, diameter, lumen width, cell wall thickness and their derived values (slenderness ratio, flexibility coefficient, and Runkel ratio) exhibits a significant relationship with the strength of pulp and paper [7].

Several kinds of research had been carried out on *G. arborea*, and have been found suitable for making low grades paper which has found tremendous usage in the newspaper and packaging industries. For this reason, the government of Nigeria in the 1960s established a pulping mill at Oku-Iboku in Akwa-Ibom State which processes *G. arborea* pulp for local consumption. Apart from *G. arborea*, there are other fast-growing plant species whose fibre characteristics are not yet known. According to Oluwadare [8] in light of great demand for paper and paper material in Nigeria, with a high inadequate supply of long fibre for paper production, thorough research of paper potential of other plants is urgently needed. More so, to relieve the pressure and demand on *G. arborea*, there is the need to assess the paper-making potentials of these plant species. The study attempts to bridge the information gap and expand the knowledge of the suitability of other plant species for paper production. Therefore, this study aims at determining the papermaking potential *Duranta erecta, Lantana camara,* and *Vitex doniana* in comparison with *Gmelina arborea*.

2. MATERIALS AND METHODS

All the four species (Verbenaceae family - *Duranta erecta* and *Lantana camara,* Laminaceae family- *Vitex doniana* and *Gmelina arborea*) were supplied by the forestry department of Enugu. They made sure the wood species supplied were of merchantable size and age. The wood species were cut into small blocks with the aid of saw and then oven-dried 80ºC for 48 hours. The small blocks were further reduced to half the sizes of a match stick.

Schultze's method of maceration as adopted by Ajuziogu, et al. [9] was used. In this method, chips of wood about the size of half match-stick were placed differently in long test-tubes bearing the names of the various samples of wood. The test-tubes were secured in test-tubes racks. Two (2) grams of potassium chlorate ($KClO_3$) crystals were added to each of the test-tubes. 10 mls of concentrated Nitric acid (conc. HNO_3) were carefully introduced to the test-tubes. The set-up was allowed to react in a fume cupboard until the clips softened and bleached. Potassium chlorate being a strong oxidizing agent causes an instant reaction with the Nitric acid to effect maceration.

After the reaction, excess solution was decanted from the test-tubes, and the softened bleached chips washed severally in distilled water to prevent further reaction. The test tubes were allowed to stand for 24 hours after which water was decanted from the test tubes. The softened chips were then separately transferred into well-labeled specimen bottles- two bottles (A and B) for each sample. A solution made of phenol and glycerine was poured into the bottles. The phenol protects the fibres from fungal decay, while, the glycerine removes air bubbles from the bottles. The chips in the bottles were stirred with a glass rod. This helps the fibres to tease out and fall apart. The fibres were then stained in crystal blue and safranine for bottles A and B respectively for each of the wood. The stained fibres were mounted on slides.

The fibre dimensions were measured using a Kyowa Tokyo Japan monocular microscope to which an ocular micrometer was fitted in the eyepiece tube. The dimensions measured were the fibre length (L), fibre diameter (D); fibre cell wall thickness (C) and fibre lumen diameter (l). The measurements were taken at x400 magnification in determining the fibre cell wall thickness and lumen diameter, while the fibre length was taken at x100 magnification. The eye-piece micrometer was calibrated using a stage micrometer. Fifteen measurements of the fibre dimensions were taken, and derived fibre values-Runkel ratio (RR), Slenderness ratio (SR) and Coefficient of flexibility (CF), worked out as follows:

- Runkel ratio = $2C/l$
- Coefficient of flexibility = l/D
- Slenderness ratio = L/D

Where C = Cell wall thickness; l = Fibre lumen diameter; D = Fibre diameter; L = Fibre length

The data collected were subjected to a one-way analysis of variance (ANOVA) using IBM Statistical Package for Social Sciences (SPSS version 20, Armonk, NY) to test for significant differences between plant species. Significant means ($p < 0.05$) were then separated using the Duncan's new multiple range test.

3. RESULTS AND DISCUSSION

Fibres above 1.6 mm in length are classified as long fibre [10]. By this classification, the species studied had short fibre length since it less than 1.6 mm. However, *G. arborea* recorded significantly the longest fibre as compared to other species with an average length of 0.8887±0.0281mm (Table 1). The longer the fibre the higher the tear resistance of the paper produced from them [8]. This observation implied that papers produced from fibres of short lengths are likely to have low tear resistance. Oluwadare and Ashimiyu [8] reported that the collapsibility and the inter-fibre bonding qualities of fibres in papermaking are dependent on the fibre lumen diameter. Therefore, the wider fibre lumen diameter of a plant will be better for utilization in papermaking. From Table 1, the mean value of the fibre diameter obtained for the species ranged from 0.0185 in *D. erecta* to 0.0312mm in *V. doniana*. The fibre lumen diameter of the species studied ranged from 0.0143-0.0266 mm with *V. doniana* and *G. arborea* having significant ($P<0.05$) wider lumen. Okereke [11] and Oluwadare and Ashimiyu [8], had earlier reported that fibres with large diameters usually have broad lumen diameter which ensures better collapsibility and bonding during paper production. Therefore, *V. doniana* and *G. arborea* produced better fibres than *D. erecta* and *L. camara.*

The importance of the diverse fibre dimensions in papermaking is base on derived values more than the absolute dimensions. A transformation of these dimensions into ratios provides greater information about the fibres and the kind of pulp and paper to be made from them [1]. The derived values (Runkel ratio, Coefficient of Flexibility and Slenderness ratio) are presented in Table 2. Contemporary anatomical appraisal of pulpwood species considered the relative fibre length (RFL) or the fibre slenderness ratio as an important factor for papermaking, it's an expression of the slenderness of the fibre; the higher the value, the more slender and tear-resistant is the fibre [10]. This could suggest that *D. erecta, L. camara*, and *G. arborea* had better than *V. doniana*. The species studied all had their Runkel ratios less than 1 (<1). The lower the Runkel ratio especially when it is less than 1 the better for papermaking [12,13,14]. Based on this, all the species studied are considered fit for paper-making, however, *V. doniana* will be more preferable for paper making as compared to *G. arborea.* Chittenden and Rotibi [15] pointed out that papers made from fibre with high Runkel ratios are porous and stiff. However, fibres with relatively thin walls collapse more readily in the paper sheet formation. This leads to strong inter-fibre bonding thus increasing the tear resistance of the paper. The Coefficient of Flexibility determines the tensile strength property of the fibre, the higher the value of coefficient, the more flexible and tensile strength is the fibre [8]. The mean Coefficient of Flexibility value of the species studied ranged from 0.7639±0.0163 in *D. erecta* to 0.8584± 0.0109 in *G. arborea*. The standard values for hardwood and softwoods are 0.55-0.70 and 0.75 respectively, whereby fibres having coefficient of

Table 1. Mean fibre characteristics across the four study plant species

Plants	Fibre length (mm)	Fibre diameter (mm)	Fibre lumen diameter (mm)	Cell wall thickness
Duranta erecta	0.4956±0.0225[c]	0.0185±0.0006[c]	0.0143±0.0006[c]	0.0043±0.0003[a].
Lantana camara	0.7039±0.0275[b]	0.027±0.0013[b]	0.0219±0.0014[b]	0.0051±0.0006[a].
Vitex doniana	0.6457±0.0255[b]	0.0312±0.0013[a]	0.0266±0.0013[a]	0.0046±0.0003[a].
Gmelina arborea	0.8887±0.0281[a]	0.0279±0.0017[ab]	0.0262±0.0009[a]	0.0042±0.0003[a].

**Means with different alphabet along each vertical array represent significant differences (P<0.05)*

Table 2. Mean derived fibre characteristics across the four study plant species

Plants	Runkel ratio	Coefficient of flexibility	Slenderness ratio
Duranta erecta	0.6507±0.0638[a]	0.7639±0.0163[b]	26.7688±1.1744[a].
Lantana camara	0.4986±0.0623[b]	0.8041±0.018[b]	27.2155±1.4928[a].
Vitex doniana	0.3675±0.041[bc]	0.8465±0.0126[a]	21.4905±1.1700[b].
Gmelina arborea	0.3398±0.0325[c]	0.8584±0.0109[a]	29.8241±1.0928[a].

**Means with different alphabet along each vertical array represents significant differences (P <0.05)*

flexibility ranging from 0.50 - 0.75 are considered as highly elastic and elastic fibres [14]. This indicates the suitability of *V. doniana* as compared to *G. arborea* for paper-making.

4. CONCLUSION

The results of this present investigation have shown that the wood fibres of *V. doniana* and *G. arborea* among the other two species are the most suitable for papermaking. Working with the principles that the fibres with the lowest Runkel ratio and highest coefficient of flexibility make the strongest papers, the order of quality of the species studied is: *G. arborea* = *V. doniana* > *L. camara* > *D. erecta*. In this regard, *G. arborea* is the best option for paper making followed by *V. doniana.* Since there is no significant difference between *G. arborea* and *V. doniana* in most of the fiber dimensions, and using *G. arborea* as standard since it has been established as a paper-making hardwood species, it may be concluded that *V. doniana* is another better fibrous material with good paper-making potentials apart from the already known *G. arborea*. Also, if fibre length is taken into consideration, *L. camara* shows great potential as a pulping species.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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