

Evaluation of pulp and paper making characteristics of *Polyalthia longifolia* and *Butea monosperma* in Makurdi, Nigeria

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ARTICLE INFO	ABSTRACT
<i>Article history:</i> Received: April 4, 2020 Accepted after corrections September 2, 2020 <i>Keywords:</i> Fibre length, paper, pulp, Runkel ratio, derived indices	Fibre morphology of <i>Polyalthia longifolia</i> and <i>Butea monosperma</i> for pulp and paper production was evaluated. Three sapwood samples from top, middle and base portions were collected from <i>P. longifolia</i> at diameter at breast height (dbh) 0.70 m, 0.74 m and 1.10 m, and <i>B. monosperma</i> at dbh 1.36 m, 1.78 m and 1.80 m, respectively. The samples were macerated in equal volume of glacial acetic acid and hydrogen peroxide. Slides of macerated fibre were inserted unto Reichert visopan microscope; fibre properties were measured and derived indices were calculated. Fibre length, fibre diameter, lumen width and cell wall thickness of <i>P. longifolia</i> and <i>B. monosperma</i> ranged from 0.83-1.00 mm, 14.82-23.12 µm, 8.57 - 16.18 µm, 2.86 - 5.75 µm and 0.834.00 mm, 13.33-22.51µm, 2.45-11.42 µm, 0.44 - 4.62 µm, respectively. Runkel ratio of <i>P. longifolia</i> and <i>B. monosperma</i> ranged from 0.45 – 1.10 and 0.62-5.49, respectively. Though <i>P. longifolia</i> and <i>B. monosperma</i> can both be used for pulp and paper making. However, <i>P. longifolia</i> proved to be better suitable compared to <i>B. monosperma</i> due to its more appreciable fibre length (0.86 mm) and Runkel ratio (0.70). Conclusively, the smaller the dbh, better their suitability of the species for pulp and paper production.

1. Introduction

Pulp and paper industry predominantly utilize wood to supply paper and paper products to more than five billion people globally (Bajpai, 2018). Wood has been largely the conventional raw material used for pulp and paper production even though nonwoods raw material were originally utilized for paper making since the late 1700s (Smook, 1992). Globally, 70 % of worldwide wood fiber roundwood and chips and 30% came from forest residues and manufacturing in 2004 (SCA & WRI, 2007). The global manufacturing of paper and board was reported to be roughly 407 million metric tons in 2015. Global paper utilization in 2020 is expected to reach up to 500 million tons. With regards to some 407.5 million metric tons of paper consumed globally in 2014, the world's paper consumption is approximately equal to the sum of paper produced annually (Bajpai, 2018). Consequently, anticipated global papermaking fibre utilization of 425 million tons in 2010 was reported by Hurter (1998). As a result, several strategies have been proposed towards meeting the increased demand for cellulose fibre.

Polyalthia longifolia commonly called mast tree, masquerade or police tree as it is popularly called in Nigeria is a single-stemmed lofty evergreen tree originally from India, belonging to the family Annonaceae and it is mostly distributed in places like tropical Africa, South and Southeast Asia (Mitra, 1993). It is successfully grown in Nigeria where it is mainly used for its aesthetic value as ornamental tree. The tree has assumed a continually increasing role in landscaping system. This high rate utilization is probably due to its fast growth, straight pole formation, suitable root system, and resistance to wind thrown. *Polyalthia longifolia* is reported to be used for the treatment of skin diseases, fever, diabetes and hypertension (Ogunbinu, et al., 2007). The inner bark of *Polyalthia longifolia* is reported to yield a high-quality bast fibre. The yellowish-white wood is tough, soft, fairly close and even-grained. It can bend effortlessly and has been utilized in the making of barrels (TPD, 2020a). In Asia, the leaves of *Polyalthia longifolia* are used for ornamental decoration during festivals. The wood was also used in the making of masts for sailing ships. That is the reason the tree is also referred to as Mast Tree. Currently, the tree is commonly used for producing small articles like pencils, boxes, matchsticks among others. The oil from the seed has been reported to contain anti-lipoxygenase, anti-oxidant, and antimicrobial that are against various clinical isolates activities among others (Atolani et al., 2019).

Butea monosperma is commonly known as flame of forest, belonging to the family Fabaceae (Patil et al., 2006). This tree grows up to 50 ft high, with clusters of flowers. It loses its leaves as the flowers grow in the month of January to March. *Butea monosperma* is reported to be employed as a cheap board wood for structural

work and for wood pulp which is said to be suitable for newsprint manufacturing (Ambasta, 1994). In south East Asia, this species is used for many purposes. In medicine, it is potent astringent, applied in the treatment of diarrhoea and wounds. The seeds also can be ground into a paste mix with honey are used as anthelmintic, purgative antibacterial and antifungal properties. Other uses of the seeds include mixing the paste with lemon juice used as a rubefacient (TPD, 2020a). The seeds constitute about 18 % oil which is effective in hookworms' treatment. *Butea monosperma* flowers and leaves are aphrodisiac, diuretic and astringent. The flowers are also helpful in the treatment of liver problem. An essential anti-asthmatic property has been reported from *B. monosperma* bark. The agroforestry uses of *B. monosperma* are that the green branches and seedlings are laid in rice farms as salt-filtering substance and green manure. Slime produced by leaf-decomposing bacteria from this species produce can aggregate clay soil particles. As a result, micro-cavities are formed by loosening the compacted of the soil to allow leaching of noxious salts from the soil solution. India farmers regularly use this tree species to stabilize field bunds (TPD, 2020b).

There dearth of information on the suitability of *P. longifolia* and *B. monosperma* trees species for pulp and paper making. Therefore, this study was aimed at evaluating the pulp and paper making characteristics of *P. longifolia* and *B. monosperma* grown in Makurdi, Benue State, Nigeria.

2. Materials and Methods

2.1 Study Area

The study was conducted at the Federal University of Agriculture, Makurdi (FUAM), Benue State. Makurdi town (Figure 1) is located at latitude 7° 38' N - 7° 50' N, and longitude 8° 24' E and 8° 38' E (Abah, 2013). The town experiences two distinct seasons, the rainy season and the dry season. The rainy season lasts from April to October with annual rainfall in the range of 1000 -1200 mm. The temperatures fluctuate between 21- 37 °C in the year. The vegetation is guinea savannah with scattered trees like *Parkia biglobosa*, *Prosopis Africana*, *Daniellia oliveri*, *Vitellaria paradoxa*, *Khaya senegalensis*, *Gmelina arborea*, *Ceiba pentandra*, *Syzygium guineense*, *Melicea excels*, *Anarcadium occidentale*, *Mangifera indica*, *Elaeis guineensis*, *Eucalyptus spp.*, *Tectona grandis*, *Acacia spp.*, *Azadirachta indica*, *Eucalyptus* species, *Terminalia catappa*, *Terminalia molineti*, *Butea monosperma*, *Polyalthia longifolia* among others.

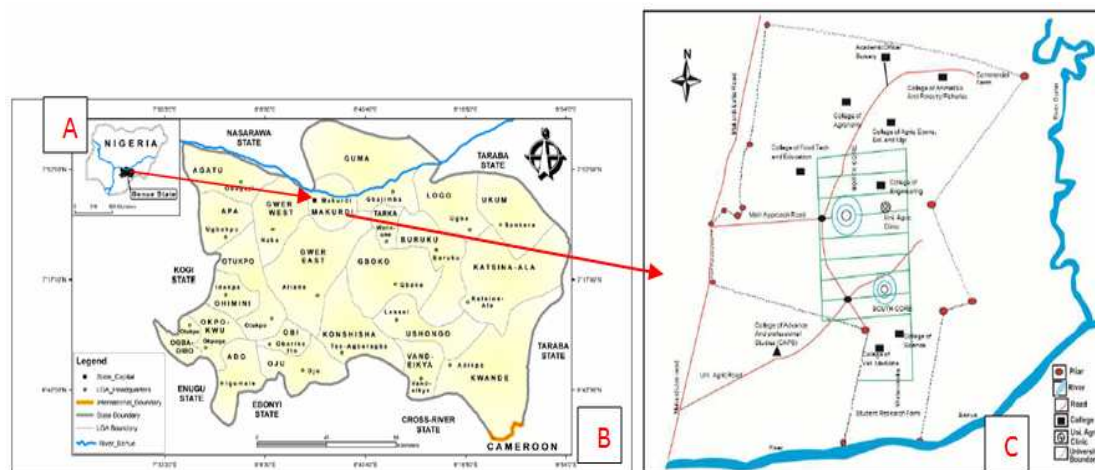


Figure 1. Map of the study area (Source: Abu et al., (2013); Msugh-Ter et al., (2017))
[A] Map of Nigeria, [B] Benue State and [C] Federal University of Agriculture Makurdi

2.2. Sample Collection

Non destructive method was used to collect three sapwood samples from top, middle and base portions from *Polyalthia longifolia* at diameter at breast height (dbh) 0.70 m, 0.74 m and 1.10 m, and *Butea monosperma* at dbh 1.36 m, 1.78 m and 1.80 m, respectively from Federal University of Agriculture, Makurdi. Wood samples were taken by cutting chips of sapwood along the bole of the tree, the base (10%), the middle (30%), and at the top (60%). From each of these three parts, chips of sapwood sample were collected by means of a cutlass without any damage done to the standing trees. The samples were dried at room temperature for two weeks.

2.3. Determination of Fibre Characteristics of *Butea monosperma* and *Polyalthia longifolia*

Fibre characteristics determination was carried out at Forest Research Institute of Nigeria (FRIN) Ibadan. Each representative samples were prepared into slivers of about 1cm × 2 cm × 2 cm. The slivers were macerate in equal volume of ethanoic acid and hydrogen peroxide (1:1) in side an oven at about 100°C for 2 hours. The macerated solution was agitated to separate solution into individual fibres. Slide of macerated fibre was mounted on a Zeiss light microscope (standard 25) under 80x. Twenty fibre were randomly selected and fibre length (L), fibre diameter (D), lumen width (d), with cell wall thickness were measured from each slide according to Jorge (1999) who stated that at least 18 fibres per slide should measured to keep error below 5 % for a 95 % confidence level. The microscopy was performed in accordance with the ASTM D1413-48 of 1983 and ASTM D1413-61 procedure of 2007. From the measured physical characteristics of fibre, derived fibre indices such as Runkel ratio, Elasticity of coefficient (µm), Rigidity of coefficient, F ratio, Luce's solid factor, Solid Factor and Felting rate were calculated as follows:

$$\text{Felting rate (slenderness)} = \text{Fibre length} \div \text{Fibre diameter} \quad (1)$$

$$\text{Elasticity coefficient (\%)} = \text{Lumen} \div \text{Fibre diameter} \times 100 \quad (2)$$

$$\text{Rigidity coefficient (\%)} = \text{Cell wall thickness} \div \text{Fibre diameter} \quad (3)$$

$$\text{Runkel ratio} = (\text{Cell wall thickness} \times 2) \div \text{Lumen diameter} \quad (4)$$

$$\text{F factor (\%)} = \text{Fibre length} \div \text{Cell wall thickness} \times 100 \quad (5)$$

$$\text{Solids factor} = (\text{Fibre Diameter}^2 - \text{Lumen Diameter}^2) \times \text{Fibre length} \quad (6)$$

$$\text{Luce's shape factor} = (\text{Fibre Diameter}^2 - \text{Lumen Diameter}^2) / (\text{Fibre Diameter} + \text{Lumen Diameter}^2) \quad (7)$$

Data collected were subjected to one way Analysis of Variance (ANOVA) to determine the significant effects of different portion on the properties. Follow up tests are carried out using Duncan Multiple Range Test (DMRT) where significant differences exist.

3. Results and discussion

Table 1 shows the means of fibre length, fibre diameter, lumen width and cell wall thickness of *Polyalthia longifolia* at dbh 0.70 m, 0.74 m and 1.10 m at different stem portion of base, middle and top. Form the table, mean fibre length ranges from 0.82 mm-1.00 mm, means fibre diameter from 14.82-23.12 µm, mean lumen width from 8.57-16.18 µm whereas mean cell wall thickness from 2.86-5.75 µm. The result also shows that, means of fibre length, fibre diameter, lumen width and cell wall thickness of *Polyalthia longifolia* are not significantly different among dbh and stem portions at $p < 0.05$. However means of fibre diameter at dbh 0.70 m, 0.74 m and 1.10 m were significantly at $p < 0.05$.

Table 1. Fibre Characteristics of *Polyata logifolia* Wood Species

DBH of Species (m)	Tree Portion	Fibre Length (mm) Mean±Std	Fibre Diameter (µm) Mean±Std	Lumen Width (µm) Mean±Std	Cell wall Thickness (µm) Mean±Std
0.70	A base	0.83±0.15 ^a	18.56±2.99 ^b	10.40±1.30 ^{ab}	4.10±1.10 ^b
	A middle	0.83±0.11 ^{ab}	21.70±2.51 ^c	15.57±3.90 ^d	3.10±1.12 ^a
	A top	0.90±0.11 ^{abc}	23.12±2.77 ^c	16.18±3.01 ^d	3.47±0.80 ^{ab}
0.74	B base	1.00±0.18 ^c	21.62±3.50 ^c	13.26±3.38 ^c	4.18±1.21 ^b
	B middle	1.00±0.10 ^{bc}	22.71±3.19 ^c	11.22±2.64 ^b	5.75±1.26 ^c
	B top	0.86±0.12 ^{ab}	23.12±3.70 ^c	12.01±3.92 ^{cd}	4.25±0.94 ^b
1.10	C base	0.84±0.10 ^{ab}	15.23±3.86 ^a	8.57±2.00 ^a	3.33±1.36 ^{ab}
	C middle	0.82±0.10 ^a	16.18±3.01 ^c	9.11±1.79 ^d	3.54±1.15 ^{ab}
	C top	0.91±0.12 ^{abc}	14.82±3.03 ^a	9.11±1.47 ^{ab}	2.86±1.15 ^a
Total		0.86±0.13	19.66±4.53	12.01±3.92	3.83±1.37

Mean values in the same column with same alphabet are not significantly different from each other ($P < 0.05$).

Table 2 shows the means of Runkel ratio, elasticity coefficient, rigidity coefficient, 16.80 ratio, Luce's shape, solid factor and felting rate ranging from 0.45-1.10; 49.53-69.73 %; 14.33-25.33%; 16.80-39.27; 0.33-0.61; 128.20-241.47 and 38.13-64.73, respectively. The result also shows that the means of Runkel ratio, elasticity coefficient, rigidity coefficient, F ratio, luce's shape, solid factor and felting rate are not significantly different among stem portion at $p < 0.05$.

Table 2. Mean value of Derived fibre indices of *Polyata logifolia* wood species

DBH of Species (m)	Tree Portion	Runkel ratio Mean±Std	Elasticity of coefficient (%) Mean±Std	Rigidity of coefficient (%) Mean±Std	F ratio (%) Mean±Std	Luce's solid factor Mean±Std	Solid factor Mean±Std	Felting rate Mean±Std
0.70	A base	0.78±0.20 ^b	56.80±6.00 ^b	21.67±3.00 ^c	22.47±10.27 ^{abc}	0.51±0.20 ^b	196.60±67.75 ^{ab}	46.67±14.47 ^{ab}
	A middle	0.45±0.26 ^a	71.13±12.40 ^c	14.33±6.18 ^a	32.60±15.84 ^{bcd}	0.33±0.15 ^a	180.73±50.86 ^{ab}	38.73±5.01 ^a
	A top	0.45±0.20 ^a	69.73±8.00 ^c	15.40±4.03 ^{ab}	26.80±7.96 ^{abcd}	0.35±0.10 ^a	241.47±81.87 ^{bc}	38.40±5.25 ^a
0.74	B base	0.68±0.25 ^b	61.00±10.60 ^b	19.40±5.20 ^c	25.53±10.56 ^{abcd}	0.46±0.13 ^b	241.47±81.87 ^c	45.40±7.48 ^{ab}
1.10	B middle	1.10±0.30 ^c	49.53±7.21 ^a	25.33±3.46 ^d	16.80±3.43 ^a	0.61±0.10 ^c	241.47±81.87 ^d	41.53±5.42 ^a
	B top	0.65±0.28 ^{ab}	62.20±10.6 ^{5b}	18.93±5.24 ^{bc}	21.47±5.34 ^{ab}	0.44±0.14 ^b	241.47±81.87 ^c	38.13±7.22 ^a
	C base	0.80±0.27 ^d	57.53±11.33 ^b	21.33±5.64 ^c	36.53±41.74 ^{cd}	0.51±0.14 ^b	144.07±88.43 ^a	58.27±14.30 ^{cd}
	C middle	0.80±0.30 ^d	57.00±9.30 ^b	21.47±4.52 ^c	26.93±12.81 ^{abcd}	0.51±0.12 ^c	147.93±59.19 ^a	52.40±13.20 ^{ab}
	C top	0.64±0.28 ^{ab}	62.73±10.03 ^b	18.67±4.92 ^{bc}	39.27±20.74 ^d	0.44±0.13 ^b	128.20±62.21 ^a	64.73±17.10 ^d
Total		0.70±0.31	60.85±11.33	19.61±5.63	27.60±18.75	0.46±0.14	219.67±116.20	47.14±13.89

Mean values in the same column with same alphabet are not significantly different from each other ($P < 0.05$).

Table 3 shows the means of fibre length, fibre diameter, lumen width and cell wall thickness of *Butea monospama* wood species at different dbh and stem portions. From the Table the means value of fibre length ranged between 0.73mm and 1.00mm, and fibre diameter ranged between 13.33-2.51. There is no significant different among dbh and stem portion at $p < 0.05$.

Table 3. Fibre Characteristics of *Butea monospama* wood species

DBH of Species (m)	Tree Portion	Fibre Length (mm) Mean±Std	Fibre Diameter (μm) Mean±Std	Lumen Width (μm) Mean±Std	Cell wall Thickness (μm) Mean±Std
1.36	D base	0.76±0.13 ^a	18.30±4.73 ^c	11.42±2.56 ^d	3.43±1.54 ^{ab}
	D middle	0.83±0.21 ^a	22.51±4.00 ^d	13.94±4.04 ^f	4.30±1.40 ^d
	D top	0.84±0.21 ^a	21.28±2.61 ^d	12.04±2.47 ^e	4.62±1.30 ^{cd}
1.78	E base	0.73±0.12 ^a	15.30±3.30 ^{ab}	9.66±1.44 ^{cd}	2.82±1.19 ^a
	E middle	0.96±0.24 ^b	13.33±2.85 ^a	2.45±1.70 ^a	0.44±51.12 ^d
	E top	1.00±0.24 ^b	14.42±3.77 ^{ab}	6.05±3.63 ^b	4.18±2.34 ^{bc}
1.80	F base	0.75±0.08 ^a	14.76±3.34 ^{ab}	9.04±1.33 ^c	2.86±1.23 ^a
	F middle	0.80±0.92 ^a	16.32±3.06 ^{bc}	9.66±1.22 ^{cd}	3.33±1.10 ^{ab}
	F top	0.79±0.07 ^a	14.76±3.70 ^{ab}	8.43±1.52 ^c	3.16±1.25 ^{ab}
Total		0.83±0.19	16.77±4.60	9.19±4.00	3.80±1.62

Mean values in the same column with same alphabet are not significantly different from each other ($P < 0.05$).

Table 4 shows the mean values of Runkel ratio, elasticity coefficient, rigidity coefficient, F ratio, Solid factor, Luce's shape, and Felting rate of *Butea monospama* at different dbh and stem portions as spanned from 0.57-5.49; 17.73-64.73 %; 18.10-41.20 %; 104.80-266.60; 17.87-32.18; 0.4 - 0.93 and 38.13-74.87, respectively. The result also showed that the means of Runkel ratio are not significantly different among dbh and stem portions at $p < 0.05$.

Table 4. Mean value of Derived fibre indices of *Butea monospama* wood species

DBH of Species (m)	Tree Portion	Runkel ratio Mean±Std	Elasticity of coefficient (%) Mean±Std	Ridgidity of coefficient (%) Mean±Std	F ratio (%) Mean±Std	Solid factor (SF) Mean±Std	Luce's Solid Factor (LSF) Mean±Std	Felting Rate (Slenderness) (FR/S) Mean±Std
1.36	D base	0.60±0.27 ^a	64.13±11.36 ^b	18.10±5.76 ^a	29.00±17.92 ^{bc}	171.60±112.65 ^a	0.42±0.14 ^a	43.53±11.92 ^a
	D middle	0.67±0.30 ^a	61.50±10.10 ^b	19.40±5.51 ^a	20.73±7.96 ^{ab}	258.33±118.47 ^b	0.45±0.14 ^a	38.13±12.75 ^b
	D top	0.81±0.24 ^a	56.67±10.10 ^b	21.67±5.09 ^a	20.00±8.81 ^{ab}	266.60±130.97 ^b	0.52±0.13 ^a	39.67±10.57 ^a
1.78	E base	0.57±0.24 ^a	64.73±9.20 ^c	17.80±4.38 ^a	32.13±17.24 ^c	104.80±54.40 ^a	0.41±0.12 ^a	50.27±16.44 ^{ab}
	E middle	5.49±2.44 ^c	17.73±8.14 ^a	41.20±4.02 ^c	17.87±4.70 ^a	172.60±98.03 ^a	0.93±0.08 ^c	74.87±21.36 ^c
	E top	3.03±3.38 ^b	43.33±25.33 ^b	28.20±12.60 ^b	30.13±14.14 ^{bc}	174.40±123.21 ^a	0.64±0.28 ^b	73.20±27.49 ^c
1.80	F base	0.62±0.27 ^a	62.87±8.90 ^b	18.73±4.33 ^a	31.87±15.13 ^c	108.47±64.08 ^a	0.44±0.11 ^a	53.67±14.46 ^{ab}
	F middle	0.69±0.20 ^a	60.33±7.40 ^b	19.87±3.64 ^a	27.13±12.09 ^{abc}	142.67±63.64 ^a	0.47±0.10 ^a	50.20±11.56 ^b
	F top	0.73±0.22 ^a	43.33±25.33 ^b	20.87±3.52 ^a	28.53±10.30 ^{bc}	123.47±73.97 ^a	0.50±0.10 ^a	56.33±14.55 ^b
Total		1.47±2.11	54.41±18.60	22.87±9.24	26.38±13.38	169.21±109.79	0.53±0.21	53.32±20.32

Mean values in the same column with same alphabet are not significantly different from each other ($P < 0.05$).

Although the average mean fibre length value of both *Polyatha logifolia* and *Butea monosperma* were short (Table 5), the average mean Runkel ratio of *Polyatha logifolia* and *Butea monosperma* showed that while *Polyatha logifolia* species will be very good for pulp and papermaking, *Butea monosperma* species would produce poor pulp and paper (Table 5).

Table 5. Sustainability of *Polyatha logifolia* and *Butea monosperma* for pulp and paper making based on fibre length and Runkel ratio

Species	Fibre length	Fibre class	Runkel ratio	Ranking
<i>Polyatha logifolia</i>	0.86	short	0.70	good
<i>Butea monosperma</i>	0.83	short	1.47	poor

Table 6 showed the Elasticity coefficient (%) of *Polyatha logifolia* and *Butea monosperma* species. The values obtained in the results revealed that both species are elastic type of fibre.

Table 6. Summary of the Elasticity Coefficient of *Polyatha logifolia* and *Butea monosperma* species

Species	Elasticity coefficient (%)	Types of fibre
<i>Polyatha logifolia</i>	60.85	Elastic
<i>Butea monosperma</i>	54.41	Elastic

Figure 2 shows the comparison of fibre dimension between *Polyatha logifolia* and *Butea monosperm*. The result that there is no much difference between the two species.

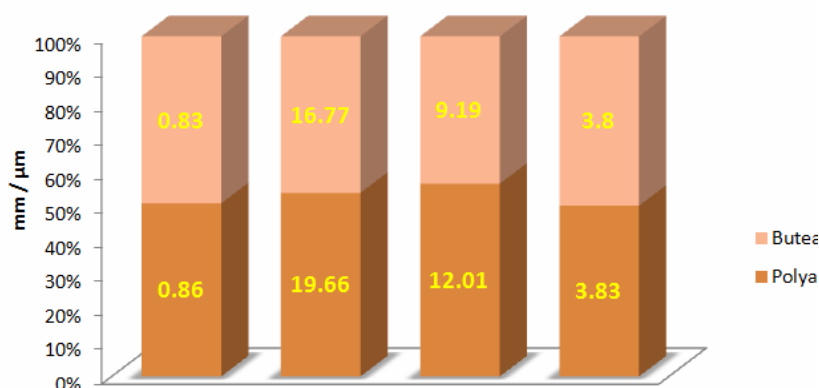


Figure 2. Comparison of fibre dimensions of *Polyatha logifolia* and *Butea monosperma*

3.1. Fibre morphology

a- Fibre length

The average mean fibre length obtained in this study for *P. logifolia* was between 0.82 mm -1.00 mm and 0.73-1.00 mm in *B. monosperm*. This finding is similar to Ajuziogu et al. (2010) study that reported fibre length of 0.89 mm in *Persea Americana*, 1.15 mm in *Dacryodes edulis* and *Anacardium occidentale* and 0.94 mm in *Mangifera indica*. Also, Ekhuemelo and Udo (2016) reported similar average mean of 1.27 for *Moringa oleifera*.

However, the mean values obtained in this study are lower than 1.65mm- 2.33 mm reported by Izeke and Fuwape (2011) for 25 year old teak in eastern Nigeria and 1.57 mm for 42 years old *Hevea brasiliensis* reported by Tembe et al. (2010). Also, the values reported in this study are within the range of 0.93mm and 0.74 mm reported by (Sharma et al., 2013) for *Scorpius dinkis* and *Ageratum conyzoides*. Metcalfe & Chalk (1983) and Anon (1984) defined fibres below 1.60 mm as short, while those higher than 1.60 mm in length were referred to be long fibres. In line with this categorization, *P. logifolia* and *B. monosperm* in this study having mean fibre lengths of less than 1.60 mm were therefore considered as short.

To produce fine papers, both long and short fibres are needed. Short fibre contributes to the properties of pulp blends, especially opacity, printability and stiffness as well as good printability. Paper from *P. longifolia* and *B.*

monosperma species if blended with long fibre materials will give good paper properties. *Polyalthia longifolia* and *B. monosperma* fibre length in this study are lower than the recommended fibre length for good quality pulp and paper. As a result, it will only produce good quality paper when blended with long fibre materials.

b- Fibre diameter

Polyalthia longifolia and *B. monosperma* in this study had fibre diameter of 14.82 -23.12 μm , 18.30-22.51 μm . The values are within the range of 20-40 μm fibre diameter for hardwood fibres reported by Usta & Eroghe (1987). Also, the mean values are comparable with 22.74 μm for *Sida cordifolia* reported by Sharma et al. (2013) and 20.96 μm for bagasse as reported by Hemmasi et al. (2011). Ajuziogu, et al. (2010) reported lower mean fibre diameter of 0.023 ± 0.005 mm in *P. americana* to 0.026 ± 0.005 mm in *M. indica*. Furthermore, the finding is similar mean values of some non-wood materials with paper making potential according to Ogbonnaya et al. (1992) & Pahkale (2001). Fibre diameter is believed to be associated with molecular and physiological variations that occur in the vascular cambium with increase in cell walls during the tree growing process (Plomion et al., 2001; Rogue & Fo, 2007).

c- Lumen width

In this study, the lumen width mean ranged from 8.57-16.18 μm and 2.45-13.94 μm respectively, for *Polyalthia longifolia* and *Butea monosperma*. The means are within the range of 13.0 μm for *Tectonia grandis* reported by Izeke & Fuwape (2011) and 13.0 μm for *Gmelina arborea* and 9.87 μm in *Leucaena leucocephala* according to Ajala (1997). Also, the values are comparable with 5.37-16.40 μm obtained for bast, core and whole stalk of kenaf (Shakhes et al., 2011). However, the mean values are lower than 0.009 ± 0.001 mm in *Anacardium occidentale* and 0.014 ± 0.06 mm in *D. eduli*, reported by Ajuziogu, et al. (2010). Fibre lumen width affects the beating of pulp. The larger the fibre lumen width, the better the beating of pulp due to the penetration of liquids into vascular spaces of the fibres (Panshim & De Zeeuw, 1980). The mean values recorded for fibre lumen width of *Polyalthia longifolia* and *Butea monosperma* in this study implies that the species will be very good during beating up of pulp.

d. Cell wall thickness

Means of cell wall thickness of *Polyalthia longifolia* and *Butea monosperma* observed in this research ranged between 2.86 and 5.75 μm as well as 0.44 and 4.62 μm . These mean values are within the range of 1.94-4.99 μm reported by Ogunkunle (2010) for *Ficus* species, 4.02 μm for *G. arborea* reported by Roger et al., (2007); 3.83 μm for *Gmelina arborea* according to Ogunkunle (2010). Also, it is similar to 4.64 μm in *Crotalaria pallid* as reported by Sharma et al. (2013).

Studies have shown that wood with thick cell walls tends to produce paper with a poor printing surface and poor burst strength. Thick-walled cells do not bend easily and do not collapse upon pulping, which inhibits chemical bonding (Zobel & Van Buijtenen 1989). Thinner-walled cells collapse upon pulping, bond together chemically, and produce a smoother paper surface (Malan, 1991). Fibres with thin cell wall are dense and having good formation hence the suitability of *Polyalthia longifolia* and *Butea monosperma* as a raw material for pulp and paper making base on their cell wall thickness.

3.2. Derived Fibre Morphological Indices

a- Runkel ratio

The result of the Runkel ratios obtained in this study shows that *Polyalthia longifolia* and *Butea monosperma* mean values ranged from 0.45-1.10 and 0.62-5.49 respectively. According to Yusuf (2007) fibre for pulp and paper can be classified into two groups using Runkel ratio. Fibres with Runkel ratio greater than 1 have a very poor paper potential while those with Runkel ratio less than 1 have good paper potential. *Polyalthia longifolia* Runkel ratios less than 1 are within the range of 0.79 for tropical pine species reported by Ajala (1997), 0.99 reported for both *Anthonathama macrophylla* and *Dalium guinensis* hardwood species in Nigerian Rainforest Ecosystem (Ezeibekwe et al., 2009). The values for *Polyalthia longifolia* also falls within the range (0.28 and 0.68) reported for *Gmelina arborea* and *Ficus spp* respectively by Ogunkunle (2010) and 0.59 for *Leucaena leucocephala* according to Oluwadare and Sotannde (2007) and 0.76 for *Dacryodes edulis* as revealed by Ajuziogu et al. (2010).

Dinwoodie (1965) has revealed that, the foundation for establishing the suitability of raw material for pulp and paper making is that the Runkel ratio must be <1. If Runkel ratio for species is <1, such fibre source is suitable for paper production (Volkomer, 1969). On the contrary, Bektas et al. (1999) stated that higher Runkel ratio gives lower paper strength properties especially lower burst, tear and tensile indexes. Fibre with high Runkel ratio value is stiff, less flexible and form bulkier paper of low bounded area than the lower ratio fibre. Therefore, it might be considered that *Polyalthia longifolia* and *Butea monosperma* will produce good paper. Runkel ratio should be less than 1 for good quality of pulp production (Kpikpi, 1992).

b- Elasticity coefficient (%)

Elasticity coefficient of *Polyalthia longifolia* and *Butea monosperma* in this study are within the elastic fibres of 49.53%-71.13%, 17.73%-64.73 %, respectively. Elasticity coefficient is another important criterion for evaluating fibre quality. Elasticity coefficient (flexibility ratio) is classified into four groups of fibres (Bektas et al., 1999): high elastic fibres with elasticity coefficient greater than 75%; elastic fibres having elasticity ratio between 50 and 75%; rigid fibres containing elasticity ratio less than 30-50 % and highly rigid fibres including elastic less than 30%. High flexibility shows that a material may be suitable to produce paper with greater burst and tensile strength. The higher the value of fibre length to width ratio, the greater will be the fibre flexibility and the chance of forming well bonded paper. Similarly, an increase in the rigidity of fibres results in decrease in fibre bonding.

Elasticity coefficient of *Polyalthia longifolia* and *Butea monosperma* in this study is within the value obtained by Brindha et al. (2012) in *Passiflora foetida* where 50-60% was reported. However, flexibility ratio between 50 and 70 implies that the fibers can easily be flat and give good paper with high strength properties (Brindha et al., 2012). Also, elasticity coefficient of *Polyalthia longifolia* and *Butea monosperma* in this study is comparable to 59.5 and 60.43 as reported by Ververis et al. (2004); Sharma et al. (2013) for *Hibiscus cannabinus* and *Urena lobata*, respectively. Elastic fibres can be stretched making it a suitable raw material for paper production in order to achieve high resistance and as such, the suitability of *Polyalthia longifolia* and *Butea monosperma* for paper making.

c- Rigidity coefficient (%)

The rigidity coefficient of *Polyalthia longifolia* and *Butea monosperma* obtained in this study ranged from 14.73 % - 25.33 % and 17.80-41.20%, respectively for the two species. These mean values are similar to 22.95 % reported by Hus et al. (1975) for beech sapwood and 41.61% in *P. americana* to 50.07 % in *A. occidentale* reported by Ajuziogu, et al.(2010). However, Sinha et al. (2019) reported a lower rigidity coefficient in *M. dubia* varied from 0.18 - 0.20 in 1–5 year age as obtained from this study.

Rigidity coefficient is defined as the ratio of double cell wall thickness of fibre to its width. It gives the rigidity of fibres to form paper. The rigidity coefficient is an index for rigidity of fibres to form paper. It indicates the bending resistance of paper (Takeuchi et al. 2016). Fibres with a rigidity coefficient of ≤ 0.5 are normally seen to be good pulpwood because it increases the collapsibility of fibres to make a flexible and strong paper sheet (Tamolang & Wangaard 1961). This implies that paper made from *Polyalthia longifolia* and *Butea monosperma* with high rigidity would have less tensile, tear, burst and double fold resistance making it a suitable raw material for pulp and papermaking. Based on the rigidity coefficient values in this study, *Polyalthia longifolia* and *Butea monosperma* may not be utilized as a promising species for making flexible and strong paper for printing and writing unless the fibres are mixed potential fibre for paper production.

d- Solid factor

From this research, mean values of *Polyalthia longifolia* and *Butea monosperma* of Solid factor varied from (128.20-241.47 and 104.0-266.60, respectively. Ona et al. (2001) reported solids factor of $46 \times 103 \mu\text{m}^3$ and $91.2 \times 103 \mu\text{m}^3$ for 14-year-old *Eucalyptus camaldulensis* and *Eucalyptus globulus*, respectively. They established significant negative relationship between solids factor and sheet density. Takeuchi et al. (2016) reported solids factor of $167 \times 103 \mu\text{m}^3$ for *Macaranga bancana* and $182 \times 103 \mu\text{m}^3$ for *Macaranga pearsonii*. High value of solids factor indicates the lower paper sheet density (Ona et al., 2001). Sinha et al. (2019) in their study on *Melia dubia* wood properties reported Solids factor of *M. dubia* to have significantly increased from 172×103 to $263 \times 103 \mu\text{m}^3$ at five age gradations and it was found to be a maximum at 4–5 years age. Solid factor was found to be related to paper sheet density and could be significantly correlated to breaking length of paper (Ona et al., 2001) that of beech sapwood.

e- Luce's shape factor

Luce's shape factor values obtained from *Polyalthia longifolia* and *Butea monosperma* were between 0.33-0.61 and 0.41-0.93, respectively. The means are within the same range of 0.47 for *Azelia africana* and 0.73 for *Detarium senegalense* as reported by Ojo (2013). Pirralho et al. (2014) has recorded Luce's shape factor between 0.39 and 0.74 in some *Eucalyptus* species. Luce's shape factor of 0.41 in *Leucaena leucocephala* (five year-old) was reported by Oluwafemi & Sotannde (2007). Mercy et al. (2017) also reported 0.26 in *Ricinodendron heudelotii*. Sinha et al. (2019) reported Luce's shape factor ranging from 0.20 - 0.21 for *Melia dubia* at five age gradations. Based on these findings, *longifolia* and *Butea monosperma* could be regarded as suitable for pulp and paper production due to their low beating resistance.

Luce's shape factor shows the beating resistance of pulp Sinha et al. (2019). It was reported to be directly related to paper sheet density and could be significantly correlated to breaking length of paper (Sharma et al., 2013; Ona et al., 2001). Luce's shape factor low value shows the decreased resistance to beating in paper production (Luce, 1970).

f- Felting rate/slenderness

The mean values of felting rate or slenderness ratio of *Polyalthia longifolia* and *Butea monosperma* obtained in this research ranges from 38.13-64.73 and 38.13-74.87 respectively. These values are less than 50.06 for *Gmelina arborea* and 42.38-71.99 reported for different *Ficus* species by Ogunkunle (2010). Sharma et al. (2013) also reported 39.1 for *Gmelina. arborea*. The slenderness ratio of *Manihot utilissima* ranged between 31.02 and 35.16 was within the range of 39.1 for *Gmelina. arborea*. Slenderness ratio values of 58.7 in *M. bancana* and 60.8 in *M. pearsonii* were reported by Takeuchi et al. (2016). Pirralho et al. (2014) reported slenderness ratio between 39.4 and 48.4 for many *Eucalyptus* species. Ohshima et al. (2005) also reported a ratio of 50.5 - 56.5 and 57.7 - 59.9 in fourteen years old *Eucalyptus camaldulensis* and *Eucalyptus globulus*, respectively.

The slenderness ratio is affect the tearing strength and folding endurance of paper and paper products (Yahya et al., 2010). When Slenderness ratio is high, it shows well formed and well-bonded paper (Ashori & Nourbakhsh, 2009). Slenderness ratio of cellulosic material more than 33 is considered to be good for pulp and paper production. It also affects the flexibility and resistance to rupture of the fibres and paper products (Xue et al., 2006). Fibres with a high slenderness ratio are long, thin and have high tearing resistance, whereas short and thick fibres have less slenderness ratio and tearing resistance.

4. Conclusion

The basic information on the fibre characteristics and derived morphology of *Polyalthia longifolia* and *Butea monosperma* for pulp and paper production was investigated. The fibres of the two species are short and elastic. The Runkel ratio values of *Polyalthia longifolia* fibre are within acceptable values for paper production whereas, that of *Butea monosperma* was not. The rigidity of the fibres as observed from the research is low therefore will enhance fibre bonding. Pulp produced from these wood species can be mixed with soft-wood or agricultural residues for pulp and paper making because of the short fibre length of the research samples.

References

1. Abah R. C., 2013. An application of Geographic Information System in mapping flood risk zones in a north central city in Nigeria. *African Journal of Environmental Science and Technology*, 7(6): 365-371.
2. Abu I. N., Madu I. A. & Ajaero C. K., 2015. The Prevalence and Determinants of Under-Five Mortality in Benue State, Nigeria. *SAGE Open* October-December, 1-11.
3. Ajala O.O., 1997. Evaluation of wood and fibre characteristics of Nigerian grown *Pinus caribaea*, Department of Forest Resources Management, University of Ibadan, Ibadan, Nigeria.
4. Ajuziogu G. C., Nzekwe U. and Chukwuma H.I., 2010. Assessment of Suitability of Wood Fibres of Four Nigerian Fruit Trees for Paper-Making. *Bio-Research*, 8(2): 679- 681.
5. Ambasta B.P.,1994. The Useful Plants of India, (Publications and Information Directorate, CSIR, New Delhi, 1-91.
6. Anon, 1984. Chemical Analysis of Nigerian Grown timbers. Annual Report of the Forestry Research Institute of Nigeria. Jan. - Dec., 108-109.
7. Ashori A., Nourbakhsh A., 2009. Studies on Iranian cultivated paulownia: a potential source of fibrous raw material for paper industry. *European Journal of Wood and Wood Products*, (67): 323-327.
8. ASTM (American Society for Testing and Materials), 1983. Standard test method of testing small scale clear specimens of timber. ASTM D143-48.
9. ASTM (American Society for Testing and Materials) 2007: Preparation of decayed wood for microscopical examination. ASTM D1413-61.
10. Atolani O., Areh & Oguntoye O.S., 2019. Chemical composition, antioxidant, anti-lipooxygenase, antimicrobial, anti-parasite and cytotoxic activities of *Polyalthia* seed oil. *Med Chem Res*, (28): 515-527.
11. Bajpai,P., 2018. Challenges and Opportunities for the Pulp and Paper Industry. University of Saskatchewan (Canada).
12. Bektas I., Tutus, A. and Eroglu H., 1999. A study of the suitability of Calabrian pine (*Pinus brutiaten*) for pulp and paper manufacture. *Turkey Journal of Agriculture and Forestry*, (23): 589-599.
13. Brindha D., Vinodhini S., Alarmelumangai K., 2012. Fiber dimension and chemical contents of fiber from *Passiflora foetida*, L. and their suitability in paper production. *Science Research Reporter*, 2(3): 210-219.
14. Dinwoodie J. M., 1965. The relationship between fibre morphology and paper properties of: A Review of Literature. *Tappi*, (48): 440-447.
15. Ekhuemelo D.O. and Udo A. M., 2016. Investigation of Variations in the Fibre Characteristics of *Moringa oleifera* (Lam) Stem for Pulp and Paper Production. *International Journal of Science and Technology*, 5(1): 19- 25.

16. Ezeibekwe I.O., Okeke S.E., Unamba C.I., Ohaeri J.C., 2009. An Investigation into the potentials of *Dactyladenia bacteri*; *Dialum guineense*; and *Anthonotama crophylla* for Paper Pulp Production. *Report and Opinion*, 1(4): 18-25.
17. Hemmasi A.H., Samariha A., Tabei A., Nemati M., Khakifirooz A., 2011. Study of morphological and chemical composition of fibers from Iranian sugarcane bagasse. *American-Eurasian Journal of Agriculture Environment and Sciences*, 11(4): 478-481.
18. Hurter W.R., 1998. Will Non woods Become an Important Fiber Resource for North America? Presented at the 1998 World Wood Summit, Chicago Illinois. http://www.Hurterconsult.com/north_America_nonwoods_.htm
19. Hus S., Tank T. & Gosksal A., 1975. Considering Eucalyptus (*E. Camadulensis* Dnhh) wood which grow in Turkey (in Tarsus-Karabacak). Morphology and opportunity for evaluating semi chemical cellulose in paper industry. Tubitak publication, USA.
20. Izeke D. N. and Fuwape J. A., 2011. Variations in the anatomical characteristics of plantation grown *Tectona grandis* wood in Edo State, Nigeria. *Archives of Applied Science Research*, 3(1): 83-90.
21. Kpikpi W.M., 1992. Wood structure and paper-making potentials of *Ricinodendron heudelotti* and *Albizia zygia* in relation to *Gmelina arborea*. *Niger J Bot*, (5): 41-50.
22. Luce G. E., 1970. Transverse collapse of wood pulp fibres: fibre models. In: Page DH, editor. The physics and chemistry of wood pulp fibres (Special Technical Association publication, no.8). New York (NY): Tappi, 278-281.
23. Malan F., 1991. Variation, association and inheritance of juvenile wood properties of *Eucalyptus grandis* Hill ex Maiden with special reference to the effect of rate of growth. *South African Forestry Journal*, (157): 16-23.
24. Mercy O.B., Adeola F. J., Olajide O.A., Babatunde A. & Sunday F.J., 2017. Evaluation of fibre characteristics of *Ricinodendron heudelotii* (Baill, Pierre Ex Pax) for pulp and paper making. *International Journal of Scientific and Technology Research*, 6(1):634-641.
25. Metcalfe C.R., Chalk L., 1983. Anatomy of the dicotyledons 2, 2. *Nordic Journal of Botany*, 4(5): 668-668.
26. Mitra D., Sharma B.D., Balakrishnan N.P., Rao R.R. & Hajira P.K., 1993. Flora of India (*Ranunculaceae* - *Barclayaceae*). Calcutta: Botanical Survey of India, (1):202-307.
27. Msugh-Ter M. M., Aondowase D. A., & Terese A. E., 2017. Association of Meteorological Factors with Two Principal Malaria Vector Complexes in the University of Agriculture Makurdi Community, Central Nigeria. *American Journal of Entomology*, 1(2): 31-38.
28. Ogbonnaya C., Nwaloze M. and Nwaigbo L. C., 1992. Growth and Wood Properties of *Gmelina arborea* Seedlings grown under five moisture regimes. *Am. J. Bot.*, 79 (2): 128-132.
29. Ogunbinu A. O., Ogunwande I. A., Essien E., Cioni P. L., and Flamini G., 2007. Sesquiterpenes-Rich Essential Oils of *Polalthia longifolia* Thw (Annonaceae) from Nigeria. *Journal of Essential Oil Research*, 19(5), 419 - 421.
30. Ogunkunle A.T.J., 2010. A Quantitative Modeling of Pulp and Paper Making Sustainability of Nigerian Hardwood Species. *Advances in Natural and Applied Sciences*, 4(1): 14-21.
31. Ohshima J, Yokota S, Yoshizawa N, Ona T., 2005. Examination of within-tree variations and heights representing whole-tree values of derived wood properties for quasi-non-destructive breeding of *Eucalyptus camaldulensis* and *Eucalyptus globulus* as quality pulpwood. *Journal of Wood Science*, (51): 102-111.
32. Ojo D. O., 2013. Determination of Pulp and Paper Making Suitability Indices of Some Nigerian Species of Leguminosae: Caesalpinoideae. *Academic Journal of Interdisciplinary Studies*, 2(13): 61-68.
33. Oluwafemi O.A. & Sotannde O.A., 2000. The relationship between fibre characteristics and pulp-sheet properties of *Leucaena leucocephala* (Lam.) De Wit. *Middle-East J Sci Res.*, 2(2): 63-68.
34. Ona T., Sonoda T., Ito K., Shibata M., Tamai Y., Kojima K., Ohshima J., Yokota S., & Yoshizawa N., 2001. Investigation of relationships between cell and pulp properties in Eucalyptus by examination of within-tree property variations. *Wood Science Technology*, (35):229-243.
35. Pahkala L., 2001. Non-wood plants as raw materials for pulp and paper. *Agric. Food science Finland supplement*, 10(1): 1-101.
36. Panshin A., and De Zeeuw C., 1980. Textbook of Wood Technology. 4th edition, McGraw-Hill, New York.
37. Patil M.V. Pawar S. and Patil D.A., 2006. Ethnobotany of *Butea monosperma* (Lam.) Kuntze in North Maharashtra, India. *Natural Product Radiance*, 5(4): 323-25.
38. Pirralho M, Flores D, Sousa VB, Quilho T, Knapic S, Pereira H., 2014. Evaluation on paper making potential of nine Eucalyptus species based on wood anatomical features. *Industrial Crops and Products*, (54): 327-334.
39. Pirralho M., Flores D., Sousa V.B., Quilhó T., Knapic S., & Pereira H., 2014. Evaluation on paper making potential of nine Eucalyptus species based on wood anatomical features. *Industrial Crops and Products*, (54): 327-334.
40. Plomion C, Leprovost G and Stokes A., 2001. Wood formation in trees. *Plant physiology*, (127): 1513-1523.

41. Ramage M. H., Burridge H., Busse-Wicher M., Fereday G., Reynolds T., Shah D. U. and Scherman O., 2017. The wood from the trees: The use of timber in construction. *Renewable and Sustainable Energy Reviews*, 68, 333–359.
42. Roger M. R., Mario T. F. and Edwin C. A., 2007. Fiber morphology in fast growth *Gmelina arborea* plantations. *Madera y Bosques*, 13(2):3-13.
43. Rouge R.M and Fo T.M., 2007. Wood density and fibre dimensions of *Gmelina arborea* in fast growing trees in costa Rica; relation to the growth rate. *Sistemas y Recursos Forestales*, 16(3): 267-276.
44. Sececa Creek Associates (SCA), Wood Resources International (WRI), 2007. Wood paper: Fiber sourcing in the global pulp and paper industry. Paper prepared for American Forest and Paper Association. December, Rev.
45. Sharma M., Sharma C.L. & Kumar Y.B., 2013. Evaluation of fiber characteristics in some weeds of Arunachal Pradesh, India for pulp and paper making. *Research Journal of Agriculture and Forestry Sciences*, 1(3):15-21.
46. Sinha S. K., Chaudhari P. A., Thakur N. S., Jha S. K., Patel D. P., and Dhaka R. K., 2019. *Melia dubia* Cav. wood properties vary with age and influence the pulp and paper quality. *International Wood Products Journal*, 1–10.
47. Smook G.A., 1992. Handbook for pulp and paper technologists, Vancouver, Canada, Angus Wilde Publications. 2nd ed., 210.
48. Takeuchi R., Wahyudi I., Aiso H., Ishiguri F., Istikowati W.T., Ohkubo T., Ohshima J., Iizuka K., Yokota S., 2016. Wood properties related to pulp and paper quality in two *Macaranga* species naturally regenerated in secondary forests, *Central Kalimantan, Indonesia Tropics*, 25 (3):107-115.
49. Tamolang F. N. and Wangaard F. F., 1961. Relationship between hardwood fibre characteristics and pulp sheet properties. *Tappi Journal*, (44): 200 - 216.
50. Tembe E. T., Amonum J.I., & Shomkeg S. A., 2010. Variations in fibre length of rubber wood (*Hevea brasiliensis* (kunth) Muel Arg) grown in south east Nigeria. *Journal of Research in Forestry, Wildlife and Environment*. 2(2): 214-220.
51. Tropical Plants Database (TPD) (2020a). *Polyalthia longifolia* Ke Fern. tropical.theferns.info. Accessed 2020-04-20. <tropical.theferns.info/viewtropical.php?id=Polyalthia+longifolia>
52. Tropical Plants Database (TPD)(2020b). *Butea monosperma* Ken Fern.Tropical.theferns.info. Accessed 2020-04-20. <tropical.theferns.info/viewtropical.php?id=Butea+monosperma>
53. Usta M. & Eroglu H., 1987. Soda-Oxygen Pulping Rye Straw. In: Non-wood plant fibre conference. Washington DC. TAPPI press, progress report. N°. 18, 113-118.
54. Ververis C., Georghiou K., Christodoulakis N., Santas P. and Santas P., 2004. Fibre dimensions, lignin and cellulose content of various plant materials and their suitability for paper production. *Industrial Crops and Products*, (19): 245-254.
55. Volkmer P.J., 1969. Wood Raw Materials for Pulp and Paper in Tropical Countries. *FAO International Review of Forestry and Forest Products. Unasylva* 23(3).
56. Xue Zhang F.C., Sun R.C., Lu Q., 2006. Anatomy, ultrastructure and lignin distribution in cell wall of *Caragana korshinskii*. *Industrial Crops and Products* (24):186-193.
57. Yahya R., Sugiyama J, Silsia D., Grill J., 2010. Some anatomical features of an *Acacia* hybrid, *A. mangium* and *A. auriculiformis* grown in Indonesia with regard to pulp yield and paper strength. *Journal of Tropical Forest Science*, (22): 343-351.
58. Yusuf S. O., 2007. Evaluation of the fiber characteristics of kenaf (*Hibiscus sabdariffa* and *Hibiscus canebianus*, and yellow bush (*Duranta ripens. ripens*). *Nigeria Journal of Forestry*, (20): 23-26.
59. Zobel B. J. and Buijtenen J. P., 1989. Wood variation its causes and control. Springer Series in Wood Science Springer-Verlag, Berlin-Heidelberg. 363.

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