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Pulping quality of *Ceiba pentandra* Kapok under different age gradation

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Abstract
The study was carried out at Forest College and Research Institute, Tamil Nadu, India using four different age gradations *viz.* ten, twenty, thirty and forty year old *Ceiba pentandra* wood samples. About one meter length billets from the felled sample trees were collected from each tree for analysis of pulpwood properties. The billet was debarked, cleaned and labelled for analysis. Four different age gradations of *C. pentandra* were subjected to physical and chemical analysis in order to recommend suitable rotation age for pulp and paper production. The physical properties *viz.* bulk and basic density, all the age gradations were moderate to high in range which indicated their suitability as pulp wood. In the chemical analysis, the lignin content was significant parameter which was also moderate for all the age gradations and hence proved their suitability. Considering this factor the result is investigated that the superiority of fifty year old wood was evident. The highest basic density (438.00 kg /m^3) and bulk density (255.00 kg /m3) and lowest moisture content (10.50 per cent) was observed in forty year old wood samples. The chemical analysis in terms of ash content recorded was highest in ten year old sample (0.95 per cent). Among four, the highest fibre length was observed in forty year old (1219.92 μm) wood sample which is best for pulp and paper making.

Keywords: *Ceiba pentandra*, age gradation, fibre morphology, Physical, chemical, pulpwood

1. Introduction
Ceiba pentandra (Kapok tree) is an ornamental moist evergreen and deciduous tree from the family bombacaceae, native to Mexico, Central America and the Caribbean, northern South America and to West America. The kapok fibers are utilized locally as fiberfill in pillows, quilts, and some soft toys and also manufacturing of pulp and paper (K. Hori *et al.*, 2000) [6] and Walia, *et al.*, 2009) [17].

In India, per capita paper consumption is 13 Kg, as against the global per capita of 57 kg. Paper consumption in India is growing at 6-7 percent annually. The demand and supply gap of timber, fuel wood and fodder is widening. At the same time industries like pulp and paper, match and plywood requires wood based raw materials. The National Forest Policy (1988) suggested that the wood based industries will have to make their own arrangements for the supply of raw materials. Most of the government forest polices and acts stresses on the conservation of existing natural vegetation and not for its exploitation. Hence, the importance of industrial plantations gained momentum across the country, to meet out the industrial raw material needs.

The world wood fiber is the original source of over 98% of the fibrous component of paper. The successful conversion of pulp into a marketable product depends on the original fibre characteristics. The anatomical properties have a positive correlation on the strength characteristics of wood. The analysis of fibre characteristics such as fibre length, fibre diameter, lumen width, cell wall thickness and their derived morphological factors became important in estimating pulp quality of fibre (Kirti and Sekar, 2020) [9].

Under such circumstances *C. pentandra* has been identified as one of the potential pulpwood species. However the age at which the species *C. pentandra* is amenable for pulpwood utility has not been assessed so far and this demands research on pulping characters of *C. pentandra* at various age gradations. Hence the current study, against this backdrop, the current study for wood characterization for pulp and paper properties of *C. pentandra* is conceived and designed under different age gradations.

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2. Material and Method
The investigations were carried out in the laboratory of Department of Agroforestry, Forest College and Research Institute, Mettupalayam, Tamil Nadu, India.

2.1 Collection of sample
The species *C. pentandra* was selected from the Theni district with different age gradation *viz.* ten, twenty, thirteen and fourteen. The sample trees were felled at stump height of 15-20 cm using power chain saw. About one meter length billets from the felled sample trees were collected for analysis. The billet was debarked, cleaned and labelled for analysis.

The wood samples were subjected to analysis of physical and chemical properties which are essential to find out the suitability of the wood sample for pulpwood. The pulping experiments were also carried out to find out its suitability for papermaking at different age gradations.

2.2 Physical properties for pulpwood
Bulk density and basic density was determined using the displacement method (Haygreen and Bowyer, 1982) [4]. Moisture content of wood chips was determined after drying it at $100 + 5$ ℃ for 48 h. The billets collected across the age gradation were chipped in pilot chipper and air-dried for 24 hours. The wood chips were passed through different sieves (50 mm, 10 mm, 5 mm and 2 mm) as per TAPPI methods (TAPPI, 1980) [15] for Chips classification.

2.3 Chemical properties for pulpwood
The billets of individual tree species were chipped in pilot chipper; air-dried and converted into wood meal in a laboratory pulp disintegrator. The wood dust of sample was prepared using Wiley mill and the wood dust passing through 40 mesh but retained over 60 mesh was subjected to analysis for moisture, ash, hot water soluble, one per cent NaOH soluble, AB extractive, Acid insoluble lignin, pentosans, hollo cellulose as per TAPPI methods (TAPPI, 1980) [15].

2.4 Anatomical characteristics of *C. pentandra* under different age gradation
Sample preparation
The logs from *C. pentandra* tree were felled and prepared into chips using pilot chipper. The wood samples each of dimension $2 \times 2 \times 2$ cm^3 were sliced out separately from the tree. From these wood samples thin microscope sections of size 15 to 20 μm were taken using 'Yorco rotater microtome' (lip Shaw type). Temporary slides were made by staining these sections with safranin stain and subjected to measurements and photography using image analysis system (Optika). Measurement of various parameters was done using the Optika software.

2.4.1 Maceration
Maceration is done using Jeffrey's method (Lim and Son, 1997). Jeffrey's solution is prepared by mixing equal volumes of 10 percent potassium dichromate and 10 percent nitric acid. Radial chips of wood shavings were taken from the 1 cm^3 wood blocks. These chips were boiled in the maceration fluid for 15-20 mins so that the individual fibres were separated. Then these test tubes were kept for 5-10 mins so that the fibres settled at the bottom. The solution was discarded and the resultant material was thoroughly washed in distilled water until traces of acid were removed. The samples were stained using safranin and mounted on temporary slides using glycerin as the mountant.

2.4.2 Fibre length
Fibre length (μm) was measured from macerated wood samples by measuring both end of the fibre through Optika image analysis software.

2.4.3 Fibre diameter
Diameter (μm) of the fibre was measured from macerated wood samples by measuring cross sectional area through Optika image analysis software.

2.4.4 Fibre wall thickness
Wall thickness (μm) of the fibre was measured from macerated wood samples by measuring thickness of the fibre wall cross sectional area through Optika image analysis software.

2.4.5 Fibre lumen width
Lumen width (μm) of the fibre was measured from macerated wood samples by measuring width of the lumen at cross sectional area through Optika image analysis software.

2.4.6 Derived values (Indices) from fibre dimensions
Four derived values were also calculated using fibre dimensions:

a. Slenderness ratio
Slenderness ratio was calculated using following formula suggested by Varghese *et al.,* (1995).

$$\text{Slenderness ratio} = \frac{\text{Fibre length}}{\text{Fibre diameter}}$$

b. Flexibility Coefficient
Flexibility coefficient was calculated using following formula Suggested by Wangaard (1962).

$$\text{Flexibility Coefficient} = \frac{\text{Fibre lumen width}}{\text{Fibre diameter}} \times 100$$

c. Runkel ratio
Runkel ratio was calculated using following formula Suggested by Runkel (1949).

$$\text{Runkel ratio} = 2 \times \frac{\text{Fibre wall thickness}}{\text{Fibre lumen width}}$$

d. Rigidity Coefficient
Rigidity Coefficient was calculated using following formula Suggested by Tamolang and Wangaard (1961).

$$\text{Rigidity Coefficient} = \frac{\text{Fibre wall thickness}}{\text{Fibre diameter}}$$

2.5 Statistical analysis
All the data were subjected to analysis of variance (ANOVA) using Completely Randomized Design (CRD).

3. Result and Discussion
3.1 Physical properties of wood chips
The physical properties of wood particularly basic density, bulk density and wood moisture content are highly essential. The influence of moisture content and its effect on dimensional stability are studied as a basic concern when using any forest products. It is not usually desirable to use the material that experiences rapid moisture changes because moisture affects the physical and mechanical properties of

wood materials (Anon, 1992 [2]; Ahamad and Kamke, 2005) [1].

The wood density of pulp wood is possibly one of the most influential factors controlling the strength and several other physical characteristics of the paper sheet. It is relatively simple and inexpensive property to determine, even in unsophisticated environments. In the current study, the physical properties studied had exhibited variation in different age gradation wood samples in *C. pentandra* (Table 1). The highest basic density (438.00 kg /m3) and bulk density (255.00 kg /m3) and lowest moisture content (10.50 per cent) was observed in forty year old wood samples of *C. pentandra*, the lowest basic density (320 kg/m3), bulk density (210.00 kg /m3) and highest moisture content (12.50 per cent) was recorded in ten year old wood sample. This results showed that basic density and bulk density of *C. pentandra* wood increases with age while moisture content decreased with increase in age of the tree.

Pinus taeda wood had higher specific gravity for 22 year old wood sample (0.50) and lower specific gravity for 13 year old wood sample (0.46) (Mcdonough *et al.* 2011) [11]. Similarly the mean density values, based on oven-dry weight and volume were 480, 556 and 650 kg m-3 for 15, 20 and 25-year old *T. grandis* wood (Izekor *et al.*,2010) [5]. The average standard specific gravity was highest in 13 year old trees (0.62) followed by 12 year (0.60) and 8 year old trees (0.57) in *Acacia auriculiformis* (Shukla *et al*. 2007) [13]. Similar results were reported among various Eucalyptus species for basic density which ranged between 425 kg per m3 and 542 kg per m3 (Vennila, 2009) [16].

The wood density properties are of major importance for the production of quality pulp and paper. The amount of wood needed to produce one ton of air dried pulp is calculated from the density and pulp yield (Storebraten, 1990) [14]. Therefore the high density recorded in the forty year old *C. pentandra* wood sample play a significant role in production of air dried pulp. Chips classification results revealed that forty year old wood sample of *C. pentandra* yielded the accepted chips (+7 mm) for cooking which was around 79.20 per cent and dust is only 0.40 per cent. This is the accepted size for pulping due to the optimal chips classification. The heat transfer and chemical penetration during pulping may be uniform in all cases. Hence the optimal chip classification found in five year old wood sample of *C. pentandra* is acceptable for paper industries.

3.2 Chemical properties of wood chips

The proximate chemical analysis unfolds an idea of potentiality of raw material for paper making (Rao *et al.*, 1999) [12]. The chemical analysis in terms of ash content recorded was highest in ten year old sample (0.95 per cent) of *C. pentandra* and lowest in forty year old sample (0.62 per cent) which implies that ash content decreases with the increase in the age of the *C. pentandra* wood. The ash content decreased by 1 per cent and 1.6 per cent in *Acacia nilotica* and *Prosopis julifora*, respectively for 15-year old trees as compared to 5-year old trees. High content of ash will have negative impact on the chemical recovery process and, therefore, could constitute a serious drawback (*Khiari et al.*, 2010) [7]. Similar results were also reported by several workers (Amaducci *et al.*, 2000; Diaz *et al.*, 2007 [3]; Lopez *et al.*, 2008) [10]. Hence the low ash content reported in forty year old wood sample of *c. pentandra* indicated at forty years could be harvested for paper industries as it is congenial for chemical recovery method (Table 2).

All of the soluble material comes under the category of extractives, and these are totally undesirable in pulp and paper making. The water and alcohol-benzene soluble substances affect the pulp yield, paper quality and drainage characteristics of paper machine. In the present study ten year old *C. pentandra* wood sample recorded lowest solubility in alcohol benzene extractive (1.80%), hot water (2.40%) and one per cent NaOH (13.30%) as compared to other age gradations and the forty year old wood sample registered highest solubility in alcohol benzene extractive (3.20%), hot water solubility (3.70%) and one per cent NaOH (15.40%).

One per cent NaOH solubility, which measure low molecular weight carbohydrates, lower in ten year old sample compared to forty year old sample which indicated that *C. pentandra* pulp resistance to degradation due to light, heat and fungal decay is low in first year wood sample and high in five year wood sample (Table 2). The holocellulose results showed that the studied pulp resources were found to be significantly different. Ten year old *C. pentandra* was found to be superior for its holocellulose value (45.00 per cent) followed by twenty, thirty and forty year old sample. This result showed that *C. pentandra* is suitable for pulpwood from ten year onwards. Similar results were observed in *Pinus taeda* at different age gradation (Mcdonough *et al.,* 2011) [11]. Low lignin content was reported in ten year old (22.20 per cent) *C. pentandra* compared to forty year old (26.00 per cent) sample which recorded the highest lignin content. Low lignin content of a ligno-cellulosic material reduces pulping time and chemical change compared to those of other non-wood raw materials (Lopez *et al.,* 2008 [10] and Diaz *et al.*, 2007). Furthermore, higher contents of lignin are predicted to consume more chemicals (Khristova *et al.*, 2005) [8].

This result established that younger age trees of *C. pentandra* are also suitable for paper industry considering lignin content as a parameter (Table 2).

Table 1: Physical characteristics of kapok wood chips at different age gradation

Age in years	Moisture (%) as received	Bulk density (OD basis) (kg /m³)	Basic density (OD basis) (kg /m³)	Chips classification (%)				
				+ 45 mm	+ 8mm (over thick)	+ 7 mm (accepts)	+ 3 mm (pin chips)	- 3mm (dust)
10	12.50	210	320	Nil	5.20	76.50	17.50	0.80
20	12.20	218	385	Nil	5.60	77.70	16.20	0.50
30	11.50	235	415	Nil	6.20	77.90	15.50	0.40
40	10.50	255	438	Nil	4.80	79.20	15.60	0.40
Mean	11.55	229.50	389.50		5.45	77.82	16.20	0.53
S.Ed	0.46	10.95	13.20		0.25	1.09	0.52	0.08
CD (0.05)	0.89	22.56	24.50		0.46	2.14	1.20	0.18

Table 2: Chemical composition of kapok wood sample at different age gradation

Age in years	Ash Content (%)	Acid insoluble lignin (%)	Pentosane (%)	Hollo cellulose (%)	Solubility in (%)		
					Hot water	1% NaOH	Alcohol benzene
10	0.95	22.20	13.50	45.00	2.40	13.30	1.80
20	0.86	22.80	14.20	47.50	2.70	14.70	2.20
30	0.75	24.50	16.00	48.25	3.10	14.80	2.80
40	0.62	26.00	16.80	50.25	3.70	15.40	3.20
Mean	0.79	23.88	15.13	47.75	2.98	14.55	2.50
SEd	0.05	0.32	0.28	0.74	0.08	0.32	0.13
CD (0.05)	0.12	0.78	0.42	1.50	0.18	0.75	0.20

3.3 Anatomical properties of wood chips

Fibre length is one of the most important fibre properties. A long fibre can create strong network compared to short fibre. Fibre length of kapok ranged from 682.00 µm to 1219.92 µm. The variation in fibre length was found to be statistically significant among the different ages of wood sample. The highest fibre length was observed in forty year old (1219.92 µm) wood sample and the lowest value was recorded in ten year old (682.00 µm) wood samples (Table.1).

Fibre diameter varied significantly with age of wood samples. There was no definite trend for variation with respect to age. The highest fibre diameter was observed in thirty year (29.75 µm) and lowest in two year (25.40 µm). Fibre diameter in ten year and twenty year wood were on par with each other. The mean fibre diameter value was 26.89 µm

Fibre lumen width varied between 12.85 µm and 17.30 µm with no definite trend considering the different ages. The lowest lumen width was noticed in thirty year old wood sample. The general mean was 15.04 µm.

The fibre wall thickness varied with ages. The highest fibre wall thickness was observed in 40-year-old wood sample (6.30 µm) and lowest in 10-year-old (4.26 µm) wood sample. The average fibre wall thickness recorded was 5.29 µm. The fibre wall thickness of 10, and 20 year age was on par with each other.

Regarding wood anatomical properties, the observations were made on fibre morphology from their corresponding analysis. Relationships in wood fibers can be a complex mixture of direct and indirect links which determine the pulping properties. There is considerable evidence in the wood profile study of *C. pentandra* which suggest that fibre morphology appears to influenced by age. *C. pentandra* may be recommended for pulp and paper making from the age of five year based on the fibre morphology. However based on elaborate study on physical and chemical properties of four age gradations, it is concluded that the profitable age of harvest for pulp wood is five years (Table 3).

Table 3: Fibre morphology of *C. pentandra* (Kapok)at different ages

Age	Fibre Morphology			
	Fibre length (µm)	Fibre diameter (µm)	Fibre lumen width(µm)	Fibre wall thickness(µm)
10	682.00	25.40	16.54	4.26
20	896.40	25.97	17.30	4.74
30	1076.25	29.75	12.85	5.86
40	1219.92	26.45	13.47	6.30
Mean	968.64	26.89	15.04	5.29
S.Ed	42.40	0.46	0.84	0.27
CD(p=0.05)	94.30	0.94	1.74	0.62

4. Conclusion

The wood anatomical characterization of *C. pentandra* gives an idea about the morphology of fiber length, fiber diameter, fibre lumen width, cell wall thickness, vessel diameter and vessel height and derived values from fiber dimension which indicates that the *C. pentandra* are suitable for making paper. In a holistic perspective, the result of the current study apparently indicates that *C. pentandra* is amenable for pulp and paper industry due to superior pulp yield and quality.

The productivity also indicated that *C. pentandra* is fast growing trees with multifarious utility extend greater scope of its utility for various wood based industries. We recommended five year rotation for *C. pentandra* for pulp and paper industry among the four age gradations studied. However, it is necessary to determine the growth rates and productivity of this species under different ecological conditions and its optimum planting wood density.

It has been verified from the above physical, chemical and anatomical observed values of *C. pentandra* species are in the normal range for hardwoods. Thus, it can be concluded that *C. pentandra* is well suited to produce pulp and paper.

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