Research Journal of Recent Sciences _____ ISSN 2277-2502
Vol. **2(ISC-2012),** 183-188 **(2013)** *Res. J. Recent. Sci.*

Wood Characterization studies on *Melia dubia* cav. for Pulp and Paper Industry at different Age Gradation

Saravanan V., Parthiban K.T., Kumar P. and Marimuthu P.
Department of Tree Breeding, Forest College & Research Institute, Tamil Nadu Agricultural University, Mettupalayam, Tamil Nadu, INDIA

Available online at: www.isca.in
Received 20th October 2012, revised 10th November 2012, accepted 7th March 2013

Abstract

The study was carried out at Forest College and Research Institute, Tamil Nadu, India using five different age gradations viz., one, two, three, four and five year old M. dubia wood samples. The samples were collected from the farm plantations raised at Kollegal, Samraj Nagar District, Karnataka to evaluate the pulpwood properties. Five age gradations of M. dubia were subjected to physical and chemical analysis coupled with strength properties in order to recommend suitable rotation age for pulp and paper production. All the five age gradations exhibited considerable differences for physical, chemical and strength properties. Considering physical properties viz., bulk and basic density, the fifth year was best. Similarly proximate analysis of five age gradations indicated the difference in chemical properties due to age. In the chemical analysis, the lignin content was moderate for all the age gradation and hence proved their suitability. Holocellulose content also differed significantly for five age gradations, holocellulose constitutes the cellulose and hemi-cellulose which is essential property for pulp and paper production. The pulp yield and kappa number analysis indicated the dominance of fifth year wood due to higher pulp yield (50.00 %) and moderate kappa number (22.00). The strength properties of five age gradation revealed the superiority of fifth year in terms of tensile index, burst index and tear index of bleached pulp. Considering all the parameters into account, the fifth year wood proved superior in terms of pulp yield, kappa number and strength properties. Hence this study recommended five year rotation for pulpwood plantation.

Key Words: *M. dubia*; physical, chemical, strength properties, age gradation, rotation age.

Introduction

Melia dubia cav. Synonyms: *Melia composite* Willd., *Melia superba* Roxb. belonging to the family Meliaceae has its trade name as Malabar Neem. Large deciduous and fast growing tree with wide spreading branches on a stout, straight, tall bole. Young shoots with inflorescence covered with mealy stellate hairs. It is indigenous to the Western Ghats of Southern India and is common in moist deciduous forests of Kerala[1]. Outside India, it is found in Sri Lanka, Malaysia, Java, China and Australia. *M. dubia* with its multi-various uses like pulpwood, timber, fuel wood and plywood can fit as a suitable species for agro and farm forestry plantation programme. The wood is also used for packing cases, plywood, ceiling planks, building purposes, agricultural implements, pencils, mach boxes, splints and furniture. It has been screened as an alternate species for pulpwood[2].

In Asia, the per capita consumption of paper during 2008 was 7 kg per annum while it was about 190 kg per year in Western Europe and more than 300 kg in North America. However, total paper and paperboard consumption in Asia already exceeds that in Europe and is projected to grow 3-4 percent per year until 2010 as incomes and population increase. Such a rate of increase would eventually make the region the biggest paper consumer in the world[3]. Indian paper industry is poised to grow at 8 per cent a year and to touch 11.5 million tonnes in 2011-2012 from 9.18 million tonnes in 2009-2010. In India per capita consumption increased to 9.18 kilograms in 2009-10 compared to 8.3 kilograms during 2008-2009[4]. The consumption of paper is directly attached to the growth of the economy. With the emergence of economy use of paper has risen tremendously like in packaging, education and documentation. Hence, there is an increasingly growing demand to grow quality pulpwood through plantation. Depletion of forest areas in the country has badly hit the supply of fibrous raw material to the industry and hence great importance has been given to raise fast growing species for use as raw material for paper and cellulose industries[5]. Under such circumstances *M. dubia* has been identified as one of the potential pulpwood species[2]. However the age at which the species *M. dubia* is amenable for pulpwood utility has not been assessed so far and this demands research on pulping characters of *M. dubia* at various age gradations. Hence the current study. Against this backdrop, the current study for wood characterization for pulp and paper properties of *M. dubia* is conceived and designed under different age gradations.

Material and Methods

The investigations were carried out in the laboratory of Forest College and Research Institute, Mettupalayam; Research and Development Laboratory, Seshasayee Paper and Boards Limited, Erode during 2010-2012. 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.

Sample collection: Five *Melia dubia* trees from each age gradation viz., one, two, three, four and five year old was randomly selected from the farm plantations at Kollegal, Samraj Nagar District, Karnataka at 12˚04'N latitude and 77˚09'E longitude during September, 2010. Five replicates of 1m length samples taken at Breast height (1.37 m) from the trunk of each tree and transported to the laboratory and it was air dried for three months, the wood dust of sample was prepared using Wiley mill to analysis the chemical properties and remaining samples were made into chips with a pilot chipper and used for analysis of physical and strength properties.

Physical Properties: Bulk density and basic density was determined using the displacement method (Haygreen and Bowyer, 1982). Moisture content of wood chips was determined after drying it at 100 $\pm$ 5 ºC for 48 h (Bhatt and Badoni, 1990). 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) for Chips classification.

Chemical properties: 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, hollocellulose as per TAPPI methods[6].

Strength properties: Kraft Pulping: 400 gm of OD chips were cooked by Kraft process in an electrically heated rotary digester of 15 litres capacity under the following constant pulping conditions. Chemical added as Na_2O (18 %), bath ratio (1:2.8), TAA in White liquor (85 gpl), Cooking Temperature (170 °C), Cooking time (90 min.) and H – Factor (1600). At the end of the cooking, digester was opened and spent pulping liquor was filtered off on double fold nylon cloth. The pulps were washed until the filtrate became colorless. The washed pulps were screened on a flat screen (slot 0.3mm). The Dryness of the pulp was determined and pulp yield was calculated on the basis of dryness of pulp.

Kappa number analysis: The Kappa number of each pulp was determined as per TAPPI method: T236-760.

Black liquor analysis: From the black liquor obtained, the following tests; pH, Total solids, Total active alkali (TTA), and Residual active alkali (RAA) were carried out as per TAPPI methods[6].

Strength properties of bleached pulp: The unbleached pulp was bleached by Chlorination-Extraction-Hypo1-Hypo2 (CEHH) sequence. After bleaching, this bleached pulp was subjected to brightness, viscosity and strength properties of paper sheets were determined according to TAPPI standards.
i. Viscosity of the pulp (T 230 om-04), ii. Pulp brightness (T 452 om-98), iii. Paper sheets preparation (T 205 om-88), vi. Paper strength measurement

The dried sheets were air dried and the sheets were again conditioned at 27±1ºC and 65 per cent ±2 RH for four hours before testing. The tensile strength, bursting strength, tensile energy absorption and elongation of paper sheets were measured according to TAPPI standard T 494 om-88.

$$\text{Tensile Index Nm/g} = \frac{\text{Average tense strength N/m}}{\text{Grammage g/m}^2}$$

$$\text{Tear Index mNm}^2\text{/kg} = \frac{\text{Tear Strength in mN}}{\text{Basis weight in g/m}^2}$$

$$\text{Burst index K pam}^2\text{/g} = \frac{\text{Average Bursting Strength (K pa)}}{\text{Grammage (g/m}^2\text{)}}$$

Results and Discussion

Physical properties of wood chips: The physical properties of wood particularly basic density, bulk density and wood moisture are highly essential. The influence of moisture content and its effect on dimensional stability are studied as a basic concern when using wood 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[7,8].

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. In the current study, the physical properties studied had exhibited variation in different age gradation of wood samples in *M. dubia* (table 1). The highest basic density (500.20 kg /m^3) and bulk density (280 kg /m^3) and lowest moisture content (10.00 per cent) were observed in five year old wood sample of *M. dubia* and the lowest basic density (418.30 kg /m^3) and bulk density (220.00 kg /m^3) and highest moisture content (12.00 per cent) was recorded in one year old wood sample. This results showed that basic density and bulk density of *M. dubia* wood increases with age while moisture content decreased with increase in age of the tree. Mcdonough *et al.*[9] reported that *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). similarly Izekor, *et al.*[10] reported 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 *Tectona grandis* wood.

Table-1
Physical characteristics of *Melia dubia* chips at different age gradation

Age in Years	Moisture (%) as received	Bulk density (OD basis) (kg m^{-3})	Basic density (OD basis) (kg m^{-3})	Chips classification (%)				
				+ 45 mm	+ 8mm (over thick)	+ 7 mm (accepts)	+ 3 mm (pin chips)	- 3mm (dust)
1	12.00	220.00	418.30	Nil	5.10	77.60	16.50	0.80
2	11.67	235.00	443.50	Nil	5.40	77.80	16.20	0.60
3	11.05	250.00	468.70	Nil	6.20	79.00	14.40	0.40
4	10.57	268.00	485.60	Nil	6.60	81.00	12.00	0.40
5	10.00	280.00	500.20	Nil	4.60	83.00	12.00	0.40
Mean	11.06	250.60	463.26		5.58	79.68	14.22	0.52
SEd	0.38	9.56	10.74		0.20	1.34	0.50	0.09
CD(0.05)	0.84	21.29	23.92		0.44	2.98	1.12	0.21

Table-2
Chemical composition of *Melia dubia* wood sample at different age gradation

Age in Years	Ash	Solubility in			Acid insoluble lignin	Pentosans (ash corrected)	Hollo cellulose (ash corrected)
		Hot water	1% NaOH	Alcohol benzene			
1	1.00	2.70	11.20	1.10	24.00	13.30	75.50
2	0.87	2.90	11.50	1.19	25.00	13.90	74.33
3	0.75	3.20	12.80	1.24	27.00	14.10	72.25
4	0.63	3.50	13.70	1.52	29.00	15.10	70.07
5	0.50	3.60	14.50	2.02	30.00	16.20	69.00
Mean	0.75	3.18	12.74	1.41	27.00	14.52	72.23
SEd	0.06	0.13	0.39	0.08	0.41	0.20	1.09
CD(0.05)	0.14	0.28	0.88	0.18	0.91	0.45	2.43

Shukla *et al.*[11] reported that 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) as shown in *Acacia auriculiformis*. Similar results were reported among various Eucalyptus species for basic density which ranged between 425 kg m^{-3} and 542 kg m^{-3} [12].

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[13]. Therefore the high density recorded in the five year old *M. dubia* wood sample play a significant role in production of air dried pulp. Chips classification results revealed that five year old wood sample of *M. dubia* yielded the accepted chips (+7 mm) for cooking which was around 83.00 per cent and dust is only 0.40 per cent (Table 1). 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 *M. dubia* is acceptable for paper industries.

Chemical properties: The proximate chemical analysis gives an idea of potentiality of raw material for paper making[14]. The chemical analysis in terms of ash content recorded was highest in one year old sample (1.00 per cent) of *M. dubia* and lowest in five year old sample (0.50 per cent) which implies that ash content decreases with the increase in the age of the *M. dubia* wood. Goel and Behl[15] recorded variation in ash content with relation to the age of the tree. The highest wood ash was observed in all the treatments in *Terminalia arjuna* (5, 10- and 15-year-old trees) as compared with that in other tree species in respective ages.

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 contents of ash will negatively impact the chemical recovery process and, therefore, could constitute a serious drawback[16]. Similar results were also reported by several workers[17,18]. Hence the low ash content reported in five year old wood sample of *M. dubia* indicated that *M. dubia* at five years could be harvested for paper industries as it is congenial for chemical recovery method.

All of the soluble material comes under the category of extractives, and these are totally undesirable in pulp and paper making. The moisture and alcohol-benzene soluble substances affect the pulp yield, paper quality and drainage characteristics of paper machine. In the present study one year old *M. dubia* wood sample recorded lowest in alcohol benzene extractive, hot water solubility and 1 % NaOH as compared to other age gradations and the five year old wood sample registered highest

alcohol benzene extractive, hot water solubility and 1 % NaOH. The lower extractives will create lesser pitch problems and also proved more homogeneity in paper sheet[19]. 1% NaOH solubility, which measure low molecular weight carbohydrates, lower in one year old (11.20 per cent) *M. dubia* sample compared to five year old sample (14.50 %) (table 2). This indicated that *M. dubia* 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.

The holocellulose results were found to be significantly different. One year old *M. dubia* was found to be superior for its holocellulose value (75.5 per cent) followed by two, three, four and five year old sample (table 2). Based on hollocellulose result *M. dubia* is suitable for pulpwood from first year onwards. Similar results were observed in *Pinus taeda* at different age gradation[9] and in *Anthocephalus cadamba* at different heights of the tree[21].

Low lignin content was reported in one year old (24 per cent) *M. dubia* compared to five year old (30 per cent) which recorded the highest lignin content. Low lignin content of a ligno-cellulosic material reduces pulping time and chemical charge compared to those of other non-wood raw materials[20,22]. While higher contents of lignin are predicted to consume more chemicals[23]. This result established that younger age trees of *M. dubia* are also suitable for paper industry considering lignin content as a parameter.

Strength properties: Kraft pulping, Pulp yield and kappa number: The optimization of chemical requirement for any industry is a pre-requisite in order to reduce the pollution hazards. The current investigation on optimization carried out with 20 kappa pulp using different chemical additions in *M. dubia* at different age gradations. The unbleached pulp yield ranged between 39.00 (One year) and 50.00 per cent (Five year). Other age gradations recorded in between. The pulp yield was maximum in five year old *M. dubia* coupled with maximum kappa number. Similar studies were conducted for *Anthocephalus cadamba*[21]. The study indicated that pulp yield of 45.1, 45.8, 46.85 and 49.34 per cent for two, three, four and twelve years old *Anthocephalus cadamba* wood which are similar to the current investigation in *M. dubia*. However the five year old *M. dubia* yielded maximum value in terms of pulp yield coupled with high kappa number while the one year old sample recorded low pulp yield with low kappa number. This result showed that the pulp yield and kappa number increases with increase in the age of the tree. Similar results were reported in *Anthocephalus cadamba* at different age gradations[21] which have lend support to the current study

Strength properties of bleached pulp: The strength properties of any manufactured paper in terms of tear, burst and tensile factors were very important for paper quality[24]. The strength properties *viz.*, tear, tensile and burst factors coupled with the brightness and opacity are the major indicators for pulp quality at 3000 PFI revolutions. In the current study, five year old *M. dubia* wood pulp showed high tensile (97.00 Nm g^{-1}), tear (8.10 mN m^2 g^{-1}) and burst index (4.50 K Pa m^2 g^{-1}) and one year old wood sample recorded slightly low tensile (68.00 Nm g^{-1}), tear (6.80 mN m^2 g^{-1}) and burst index (3.20 K Pa m^2 g^{-1}) (Table 3). According to Guha[25], the tropical hardwood pulp which has breaking length greater than 6.0 km are very good in strength properties and can produce quality paper. So in the current study one year old *M. dubia* recorded lowest breaking length of 6.67 km and five year old pulp recorded highest breaking length of 9.51 km which underscores that the *M. dubia* has very good pulp strength properties from the first year tree.

Thus it can be used for pulpwood production from first year onwards according to the standards of Guha and it was best at five year among the age gradation studied. Similar results were earlier reported in tensile and burst indices of paper obtained from one year old *Leucaena leucocephala*[20] which supports the findings of current result. The pulp and paper property are highly dependent on fibre morphology and sheet forming processes[26].

Table-3
Comparison of different age gradation wood samples of *Melia dubia* for pulp yield and strength properties of bleached pulp

Age of the tree	Chemical charge for 20 kappa	Kappa number	Unbleached pulp yield (%)	Strength properties at 300 ml CSF		
				Tear index (mNm^2 g^{-1})	Tensile index (Nm g^{-1})	Burst index (KPa m^2 g^{-1})
1 Year	18.00	16.00	39.00	7.10	72.00	3.40
2 Year	18.00	18.00	41.00	7.35	80.57	3.75
3 Year	18.00	20.00	45.00	7.50	85.25	4.00
4 Year	18.00	21.00	48.00	8.00	90.50	4.20
5 Year	18.00	22.00	50.00	8.25	95.35	4.50
Mean	18.00	19.40	44.60	7.64	84.73	3.97
SEd		0.41	0.94	0.94	0.82	0.11
CD (p=0.05)		0.91	2.09	2.09	1.82	0.25

Cooking Conditions at 200 gpl Total solids basis:Temperature: 170 ‘C ; Time: 90 min

Properties of bleached *M. dubia* pulp at different PFI revolutions for different age gradation differed significantly. It is evident that strength properties increased with beating levels except for tear strength which increased with beating level at the beginning up to a maximum and then dropped tremendously. Optical properties decreased with increasing beating level while surface properties behaved negatively. Density and porsity increased with beating level while roughness both top side and wire side decreased, but the decrease was very small. These trends shown by strength and opacity properties are as normally expected for most hardwoods. Similar results reported by Gillah and Ishengoma[27] in *Leucaena leucocephala* also extend support to the present findings.

Conclusion

In a holistic perspective, the result of the current study apparently indicates that *M. dubia* is amenable for pulp and paper industry due to superior pulp yield and quality. The productivity also indicated that *M. dubia* is fast growing tree with the growth rate of 41.54 m^3 ha^{-1} yr^{-1} coupled with multifarious utility extend greater scope of its utility for various wood based industries. We recommended five year rotation for *M. dubia* for pulp and paper industry among the five 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.

Acknowledgement

The authors profoundly thank the world bank funded National Agricultural Project (NAIP) on A Value Chain on Industrial Agroforestry in Tamil Nadu wherein the current study formed a part of objective of the scheme. We thank Mr Gautham, promising farmer from Kollegal, Karnataka, India for having permitted the research team for wood sample collection.

References

1. Gamble S.J., A Manual of Indian Timbers: An Account of the Growth, Distribution and Uses of the Trees and Shrubs of India and Ceylon with Description of Their Wood-Structure, International, Reprint, **xxvi,** 868 **(2002)**

2. Parthiban K.T., Bharathi A.K.R., Seenivasan K., Kamala and Rao M.G., Integrating *Melia dubia* in Agroforestry farms as an alternate pulpwood species, *APA News.,* **34,** 3-4 **(2009)**

3. Dogra A.S., Contribution of Trees Outside Forests Toward Wood Production and Environmental Amelioration, *Indian J. Ecol.,* **38 (Special Issue),** 1-5 **(2011)**

4. FAO., Global Forest Resources Assessment. FAO Forestry Paper 163. Food and Agriculture Organization of the United Nations, Rome **(2010)**

5. Salkia C.N., Ali F., Dass N.N., and Baruah J.N., High alpha-cellulose pulp from fast growing plant materials, *I.E.(I) Journal.,* **71,** 72-76 **(1991)**

6. TAPPI. Standard and suggested methods. Technical Association of Pulp and Paper Industry, New York, 200-265 **(1980)**

7. Anon., Advances in pulp and paper research, Indian Council of Forestry Research and Education, Dehra Dun **(1992)**

8. Ahmad M. and Kamke F.A., Analysis of Calcutta bamboo for structural composite materials: Physical and mechanical properties, *Wood Sci Technol.,* **39(4),** 448-459 **(2005)**

9. Mcdonough T.J., Courchene C.E., White D.E., Schimleck L., and Peter G., Effects of loblolly pine tree age and wood properties on linerboard-grade pulp yield and sheet properties: Part 1-Effects on pulp yield, *TAPPI J.,* **9,** 45-53 **(2011)**

10. Izekor D.N., Fuwape J.A., and Oluyege A.O., Effects of density on variations in the mechanical properties of plantation grown *Tectona grandis* wood. Scholars Research Library, *Arch. App. Sci. Res.,* **2(6),** 113-120 **(2010)**

11. Shukla S.R., Rao R.V., Sharma S.K., Kumar P., Sudheendra R. and Shashikala S., Physical and mechanical properties of plantation-grown *Acacia auriculiformis* of three different ages, *Aust For.,* **70(2),** 86-92 **(2007)**

12. Vennila S., Pulpwood traits, genetic and molecular characterization of *Eucalyptus* genetic resources. Ph.D thesis. Tamil Nadu Agricultural University, Coimbatore **(2009)**

13. Storebraten S., Sulfa tfabrikken – virkesforsyningens soppelplass Foredrag i PTF, Masseteknisk gruppe, 9 Oktober, Oslo, Norway. 25 **(1990)**

14. Rao R.V., Kothiyal V., Sreevani P., Shashikala S., Naithani S. and Singh S.V., Yield and strength roperties of pulp of some clones of *Eucalyptus tereticornis, Indian For.,* **125(11),** 1145-1151 **(1999)**

15. Goel V.L. and Behl H.M., Fuelwood quality of promising species for alkaline soil sites in relation to tree age, *Biomass Bioenergy.,* **10(1),** 57-61 **(1996)**

16. Khiari R., Mhenni M.F., Belgacem M.N. and Mauret E., Chemical composition and pulping of date palm rachis and *Posidonia oceanic* - A comparison with other wood and non-wood fiber sources, *Bioresour Technol.,* **101,** 775-780 **(2010)**

17. Lopez F., Garcia J.C., Perez A., Garciam M.M., Feria M.J. and Tapias R., *Leucaena diversifolia* a new raw material for paper production by soda-ethanol pulping Process, *Chem Eng Res Des.,* In press. 9 **(2009)**

18. Ververis C., Georghiou K., Hristodoulakis N., Santas P., and Santas R., Fiber dimensions, lignin and cellulose content of various plant materials and their suitability for paper production, *Ind crop prod.,* **19,** 245-254 **(2004)**

19. Kasiviswanathan K.S., Utilization of bagasse for paper making- An overview, *IPPTA J.,* **10 (3),** 9 – 14 **(1998)**

20. Lopez F., Garcia M.M., Yanez R., Tapias R., Fernandez M. and Diaz M.J., Leucaena species valoration for biomass and paper production in 1 and 2 year harvest, *Bioresour Technol.,* **99,** 4846-4853 **(2008)**

21. Lal M., Dutt D., Tyagi C.H., Upadhyay J.S. and Upadhyay S., Characterization of *Anthocepthalus cadamba* and its delignification by kraft pulping, *TAPPI J.,* **3,** 30-37 **(2010)**

22. Diaz M.J., Garcia M.M., Eugenio M.E., Tapias R., Fernandez M. and Lopez F., Variations in fiber length and some pulp chemical properties of Leucaena varieties, *Ind crop prod.,* **26,** 142-150 **(2007)**

23. Khristova P., Kordsachia O. and Khider T., Alkaline pulping with additives of date palm rachis and leaves from Sudan, *Bioresour Technol.,* **96,** 79-85 **(2005)**

24. Anon., Advances in pulp and paper research in India. Indian Council of Forestry Research and Education, Dehra Dun **(1982)**

25. Guha S.R.D., Summary of investigation on the suitability of indigenous broad leaved woods for production of sulphate pulps for writing and printing papers, *Indian For.,* **95(8),** 579-590 **(1969)**

26. Seth R.S., Jang H.F., Chan B.K. and Wu C.B., Transverse dimensions of wood pulp fibres and their implications for end use. The fundamentals of papermaking materials. 11th Fundamental Research Symposium, Cambridge, Vol. I. Pira International, Surrey, UK. 473-503 **(1997)**

27. Gillah P.R. and Ishengoma R.C., Kraft pulping of *Leucaena leucocephala* grown in Morogoro, Tanzania. *Holz als Rob- und Werkstoff.,* **51,** 353-356 **(1993)**