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Screening of indigenous pulpwood for paper production

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Abstract
Thirteen tree species *viz*., *Acrocarpus fraxinifolius, Albizia lebbek, Dalbergia paniculata, Dalbergia sissoo, Erythrinia indica, Grewia tillifolia, Gyrocarpus jacquinii, Melia dubia, Melia composite, Neolamarkia cadamba, Sterculia alata,* Eucalyptus MTP1 (Control 1), TNAU Casuarina MTP 2 (Control 2) were subjected for physical and chemical analysis coupled with pulp yield in order to screen suitable for pulp and paper production. All the thirteen tree species exhibited considerable differences for physical, chemical and pulp yield investigated. Considering physical properties *viz*., bulk and basic density, all tree species were moderate to high in range which indicated for their suitability as pulpwood. Similarly chemical wood analysis of thirteen tree species indicated that the species differed due to chemical properties. In the proximate analysis, the lignin content was significant parameter which was also moderate for all the tree species and hence proved their suitability. The tree species differ significantly for holo-cellulose which constitutes the cellulose and hemi-cellulose which are essential factor for paper production. Considering this factor, among thirteen tree species investigated, the superiority of *Melia dubia* was evident due to maximum holo-cellulose content. The pulp yield and kappa number analysis indicated that the superiority of *Melia dubia* due to higher pulp yield and moderate kappa number.

Keywords: Indigenous species, physical properties, chemical composition and pulp yield

Introduction

The biological diversity of forests and their ecological function are the heritage of man kind. These forests are most important and remarkable natural resources which play a very important role in the economic prosperity and ecological stability of the country. The forests of the country are shrinking under acute socio economic pressure and the foresters are at the cross roads. India's forests till recently are being denuded at an alarming rate of 1.5 million ha per year and has fortunately come down to rapidly with the enactment of the Forest Conservation Act, 1980. Currently, the forest area in the country is around 23.0 per cent and in the state of Tamil Nadu it is around 17.5 per cent which is much low against the mandated requirement of 33.0 per cent. Not only is the forest wealth of the country is poor but its productivity in terms of MAI is also one of the lowest. The MAI of Indian Forest is a meager of 0.5 - 0.7 m^3/ha compared to the global average of 2.1 m^3 /ha. The less forest area coupled with the low productivity of Indian forest has ushered in a total mismatch between the demand and supply of both domestic and industrial wood requirement besides creating environmental disequilibrium and de stability.

The demand for industrial wood raw material is also in the ascendancy but the plantations available in the country are not able to meet the raw material demand. The Forest Policy, 1988 under para 4.9 indicated that the forest based industries should raise the raw material needed for meeting its own requirement.

Paper is one of the significant discoveries that turned the history of the world around. 105 A.D. is often cited as the year in which papermaking was invented by the Chinese, Ts'ai Lun. Paper pervades all sectors of our activity from books to bullets and from morning newspaper to nuclear technology. The importance of paper and paper products in the modern life is so obvious that no other manufactured product possesses such diversity of use. Paper embraces a wide range of products with very different applications; it is a basic medium of communication, dissemination of information and personal hygiene (tissues, napkins), etc.

But the lion's share of consumption is taken up by writing or printing, newsprint and industrial paper (packing and wrapping paper, and paper board). The *per capita* consumption of paper is often regarded as a barometer of socio-economic progress of a country. It measures the living standards and openness of a society and its educational and intellectual attainments.

India due to its burgeoning population is under tremendous pressure to meet the ever-growing multifarious demands for wood and wood products. The demand for pulp and paper is one such thing. Today, there are about 580 mills in India with 20 in the large scale sector and 560 in the medium and small scale sector. During 1990's, the *per capita* consumption of paper was 3.3 kg which has now escalated to 9.4 kg, but still lower compared to the global average of 58 kg (Srivastava, 2005) [25]. Hence, the fortune of paper industry can be closely linked to the buoyancy in the economic development of a country. The current production of raw material for pulp and paper production is 12 million tonnes where as the demand is 14 million tonnes. The shortfall is as high as 45 per cent. The projected demand in 2020 AD is 20 million tonnes which are still more staggering (Srivastava, 2005) [25].

Today, pulp for papermaking is produced mostly from wood fibres (more than 90%) which contain many different chemical substances *viz*., cellulose, hemi cellulose, lignin and extractives. The rest is produced from non-wood fibres like bagasse, straw and bamboos. Forest plantations constitute about 3.8 per cent of the total forest area. Productive forest plantations, primarily established for wood and fibre production, account for 78 per cent of forest plantations, and protective forest plantations, primarily established for conservation of soil and water accounts for 22 per cent.

An availability of adequate raw materials is one of the major constraints for the development of paper industry. The rapidly changing economic, technological and regulatory environment has affected the progress of Indian paper industry due to the poor availability of cellulose raw materials. Amongst the cellulosic raw materials, bagasse, straw and waste paper have inherent drawbacks of limited and scattered availability of suitable technology for conversion into higher-grade pulp. This makes quite imperative to have a sustainable supply of forest based raw materials, which account for 45 per cent of raw materials used (Sarada *et al*., 2000) [23]. The country has just one per cent of world's forest coverage but supports 16 per cent of the world's population (Mall, 1998) [12]. For wood-based industries, industrial plantation is the only answer.

The raw material requirement will shoot up further, as the paper consumption figure is bound to increase with all round development 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 (Salkia *et al*., 1991) [22].

Pulp and paper industry in the country predominately use Eucalyptus and Casuarina as the source of raw materials. But these trees have exhibited the problem of low pulp yield, coupled with poor productivity under marginal lands (Parthiban *et al*., 2004) [18]. Hence, there is a need to identify and screen indigenous pulpwood which has the potential for high pulp recovery coupled with high productivity. However, such studies are very scanty and hence warrant systematic investigation.

Materials and Methods

Thirteen tree species *viz*., *Acrocarpus fraxinifolius, Albizia lebbek, Dalbergia paniculata, Dalbergia sissoo*, *Erythrinssia indica, Grewia tillifolia, Gyrocarpus jacquinii, Melia dubia, Melia composite*, *Neolamarkia cadamba*, *Sterculia alata*, Eucalyptus MTP1 (Control 1), TNAU Casuarina MTP 2 (Control 2) were collected. From each species, a billet of each 1 m length and 50-60 cm girth were collected, debarked and chipped separately and screened. The screened chips were used for pulping experiments. Some chips were converted into dust for proximate chemical analysis. Based on the initial screening study in the laboratory, the wood samples were subjected to analysis of physical and chemical properties. The pulping experiments were also carried out to find out its suitability for papermaking. The physical characteristics such as bulk density, basic density and moisture content of wood chips are estimated. For the chemical properties analysis, the billets of individual tree species were chipped in pilot chipper; airdried and converted into wood meal. 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 (TAPPI, 1980) [27]. The strength properties such as pulping, identification of kappa number, pulp brightness, paper sheet preparation, paper strength measurement, tensile strength, tearing strength, bursting strength measurement were analyzed as per standard method (TAPPI, 1980) [27].

Results and Discussion

Physical properties of wood chips

Wood properties such as density and fibre length are used to evaluate the suitability of a wood for a particular application. Properties like basic density, brightness, and quality of extractives are used by the paper industries as indicators of wood quality for different industrial processes and final paper products. Basic density is related to the yield, paper resistance, optical properties and surface quality. With this view, the physical properties *viz*., bulk density, basic density, chips classification were analyzed along with moisture content and results are presented in Table 1.

The wood sample of thirteen tree species varied due to moisture content which ranged between 7.6 per cent (*Gyrocarpus jacquinii*) and 10.9 per cent (*Sterculia alata*). Compared to Control *viz*., Eucalyptus MTP1 (9.3%) and TNAU Casuarina MTP 2 (9.7%), *Sterculia alata* (10.9%), *Grewia tillifolia* (10.3%), *Erythrinia indica* (9.9%), and *Melia composite* (9.9%) recorded highest moisture content and other tree species *viz*., *Acrocarpus fraxinifolius* (8.9%), *Albizia lebbek* (9.0%), *Dalbergia paniculata* (8.5%), *Dalbergia sissoo* (9.6%), *Neolamarkia cadamba* (8.9%) *Melia dubia* (9.1%) and *Gyrocarpus jacquinii* (7.6%) recorded lower values. 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.

This bulk density ranged between 133 kg m^{-3} (*Gyrocarpus jacquinii*) and 280 kg m^{-3} (*Dalbergia sissoo* and Eucalyptus MTP 1). Compared to Control *viz*., Eucalyptus MTP 1 (280 kg m^{-3}), TNAU Casuarina MTP 2 (230 kg m^{-3}) six species *viz*., *Acrocarpus fraxinifolius* (230 kg m^{-3}), *Albizia lebbek* & *Erythrinia indica* (266 kg m^{-3}), *Dalbergia paniculata* (150 kg m^{-3}), *Grewia tillifolia* (220 kg m^{-3}), *Gyrocarpus jacquinii*

(133 kg m-3), *Melia dubia* (133 kg m-3) *Melia composite* (190 kg m-3), *Neolamarkia cadamba* (160 kg m-3) and *Sterculia alata* (240 kg m-3) recorded lower value and one species *viz*., *Dalbergia sissoo* (280 kg m-3) recorded on bar values.

Basic density was observed highest in *Dalbergia sissoo* (580 kg m-3) and lowest in *Gyrocarpus jacquinii* (326 kg m-3). Compared to TNAU Casuarina MTP 2 (540 kg m-3), one species *viz*., *Dalbergia sissoo* (580 kg m-3) recorded higher values and other trees recorded lower value. The wood density properties are of major importance for the production of quality pulp and paper. The amount of wood needed to produce one tone of air dried pulp is calculated from the density and pulp yield (Storebraten, 1990) [26].

A huge variation in wood and fibre properties of different tree species were also reported (Niskanen, 1998) [14]. Person (1975) [19] found that differences in diameter growth have major impact on basic density. Basic density is again highly correlated with late wood content (Nylinder and Hagglund, 1954 [15]; Ericson, 1966 [5]; Olsen, 1976 [16]; Bergstedt and Olsen, 2000) [2]. Similarly the variability exhibited in most physical properties studied among different tree species in the current study also attests the results of earlier findings.

Chips classification

Chips classification results showed that accept (+7 mm) is highest in *Gyrocarpus jacquinii* (83.2%) and lowest in Eucalyptus MTP1 (77.6%). This is the accepted size for pulping. The heat transfer and chemical penetration during pulping may be uniform in all cases. Pape (1999) [17] found higher basic density in Norway spruce trees stands thinned from above than that thinned from below due to the lower density in dominant trees than in codominant and suppressed trees. Johanson (1993) [10] did not find such a difference in the basic density level between tree classes. This might be probably due to the young material used as indicated by Pape (1999) [17]. However, in the current study the basic density exhibited wider variation which might be due to species or differences between early and late wood formation as reported by Malan and Arbuthnot (1995) [11].

Table 1: Physical characteristics of hardwood chips

Sl. No.	Species	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	*Acrocarpus fraxinifolius*	8.9	230 *	510**	Nil	4.2	80.5	14.9	0.4
2	*Albizia lebbek*	9.0	266**	530**	Nil	3.9	81.2	14.2	0.7
3	*Dalbergia paniculata*	8.5	150	350	Nil	5.4	78.4	15.7	0.5
4	*Dalbergia sissoo*	9.6	280**	580**	Nil	4.8	79.8	14.6	0.8
5	*Erythrinia indica*	9.9	266**	438	Nil	4.8	79.5	15.3	0.4
6	*Grewia tillifolia*	10.3*	220	485	Nil	5.1	78.6	15.7	0.6
7	*Gyrocarpus jacquinii*	7.6	133	326	Nil	4.2	83.2	12.4	0.2
8	*Melia dubia*	9.1	240**	520**	Nil	6.2	79.2	14.2	0.4
9	*Melia composite*	9.9	190	505**	Nil	6.5	82.6	10.1	0.8
10	*Neolamarkia cadamba*	8.5	160	380	Nil	4.1	79.8	15.6	0.5
11	*Sterculia alata*	10.9**	240**	510**	Nil	6.2	77.8	15.4	0.6
12	Eucalyptus MTP1	9.3	280**	525**	Nil	5.8	77.6	16.2	0.4
13	TNAU Casuarina MTP 2	9.7	230*	540**	Nil	6.6	81.5	11.5	0.4
	Mean	9.3	221.8	477.3					
	SEd	0.48	3.80	4.58					
	CD (0.05)	0.99	7.81	9.42					
	CD (0.01)	1.33	10.56	12.73					

Chemical properties of wood chips

The billets of individual tree species were chipped in pilot chipper; air-dried and converted into wood meal in a laboratory Wiley disintegrator. 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, alcohol benzene extractives, acid insoluble lignin, pentosans and holocellulose as per TAPPI methods (TAPPI, 1980) [27].

Table 2: Proximate Chemical Composition of hardwood chips

Sl. No.	Species	Ash content (%)	Acid insoluble lignin (%)	Pentosans (%)	Hollo cellulose (%)	Solubility in (%)		
						Hot water	1% NaOH	Alcohol benzene
1	*Acrocarpus fraxinifolius*	0.65**	25.9**	20.1**	70.7	3.20	13.6	4.4**
2	*Albizia lebbek*	0.54	24.1	18.2	71.5**	2.75	12.5	3.2
3	*Dalbergia paniculata*	0.71*	23.1	18.2	71.6**	1.85	12.2	2.9
4	*Dalbergia sissoo*	0.62*	23.9	17.6	70.4	3.05	15.7**	3.8*
5	*Erythrinia indica*	0.61	24.3	17.2	69.4	2.80	14.2	4.2*
6	*Grewia tillifolia*	0.66**	23.7	17.2	68.9	3.75	16.1**	2.7
7	*Gyrocarpus jacquinii*	0.35	25.8**	17.8	68.7	3.25	15.7**	2.8
8	*Melia dubia*	0.64**	22.5	18.7	72.8**	2.75	13.7	3.8*
9	*Melia composite*	0.53	24.5	18.5	69.5	3.65	16.8**	3.4
10	*Neolamarkia cadamba*	0.74**	25.5**	20.4**	70.5	3.12	11.8	3.6
11	*Sterculia alata*	0.54	23.5	16.7	63.5	3.60*	15.9**	2.8
12	Eucalyptus MTP1	0.65**	23.4	16.2	71.8**	3.15	16.5**	2.4
13	TNAU Casuarina MTP 2	0.60	23.8	17.4	72.4**	3.40	15.5*	3.2
	Mean	0.60	24.15	18.02	70.13	3.11	14.62	3.32

	SEd	0.01	0.28	0.37	0.40	0.24	0.37	0.22
	CD (0.05)	0.02	0.57	0.76	0.83	0.48	0.77	0.46
	CD (0.01)	0.03	0.78	1.03	1.13	0.65	1.04	0.62

The proximate chemical analysis given an idea of potentiality of raw material for paper making (Rao *et al*., 1999) [20]. The results of proximate analysis in this investigation are furnished in Table 2. The chemical analysis in terms of ash content ranged between 0.35 per cent (*Gyrocarpus jacquini*) and 0.74 per cent (*Neolamarkia cadamba*). The chemical investigation carried out in wood pulp of *Morus alba* recorded high ash content of 1.2 per cent (Guha and Madhan, 1962) [9]. Similar observations of high ash content were reported in many species *viz*., *Pinus longifolia (*Guha, 1958) [6]; *Albizia lebbeck* (Manmohan Singh and Mukhergee, 1965) [13]; *Lagerstroemia speciosa* and *Terminalia myriocarpa* (Singh *et al*., 1972) [24]; *Bambusa tulda* (Bhola, 1976) [3]; *Ailanthus excelsa* (Guha and Pant, 1981) [8]; *Populus eupratica* (Chaturvedi, 1997) [4] and *Acacia mangium* (Saepuloh, 1999) [21]. However, all the selected species in the current study exhibited lower ash content which thus lend a scope for utilization as pulp wood.

The alcohol-benzene solubilities of wood constitute the waxes, fats and resinous matter. In the current study, the extractives were in the range between 2.4 per cent (Eucalyptus MTP1) to 4.4 per cent (*Acrocarpus fraxinifolius*) and no much more differences were found among other species. Similar variation in alcohol-benzene extractives were observed among various clones of *Eucalyptus tereticornis* (Rao *et al*., 1999) [20], wherein the extractives ranged between 1.06 and 1.35. The chemical investigation carried out in *Bambusa tulda* (Bhola, 1976) [3]; *Lagerstromia speciosa* and *Terminalia myriocarpa* (Singh *et al*., 1972) [24] also indicated wood variation in the extractives. Among the chemical properties, holocellulose is very important because it is a measure of total carbohydrate content of the wood (Tappi, 2001) [28]. The holocellulose constituting cellulose and hemicellulose is the major portion of fibrous raw material. The holocellulose content in the study ranged between 63.5 (*Sterculia alata*) and 72.8 (*Melia dubia*) and other selected species recorded in between these. The result indicated the superiority of *Melia dubia* as a source of raw material for paper industry.

The content of pentosans ranged between 16.2 per cent (Eucalyptus MTP 1) and 20.4 per cent (*Neolamarkia cadamba*) and acid soluble lignin was found to be in the range of 22.5 per cent (*Melia dubia*,) to 25.9 per cent (*Acrocarpus fraxinifolius*) whereas Eucalyptus MTP 1 and TNAU Casuarina MTP 2 recorded 23.4 and 23.8 per cent respectively. Such variation in the content of pentosans of various species *viz*., *Pinus longifolia* (Guha, 1958) [6]; *Gmelina arborea* (Anon, 1989) [1] and *Acacia mangium* (Saepuloh, 1999) [21] were also evident which corroborate the results of current findings.

Among the chemical properties, holocellulose is very important because it is a measure of total carbohydrate content of the wood. The holocellulose constituting cellulose and hemicellulose is the major portion of fibrous raw material. The holocellulose content in the study ranged between 63.5 per cent (*Sterculia alata*) and 72.8 per cent (*Melia dubia*) and other species recorded in between these. The result indicated the superiority of *Melia dubia* over the other species.

Pulp Yield and Kappa Number

400 gm of OD chips were cooked by kraft process in an electrically under the following constant pulping conditions.

Parameters		**Conditions**
Chemical added as Na_2O (%)	:	15
TAA in White liquor (gpl)	:	85
Cooking Temperature (°C)	:	170
Cooking time (min.)	:	90

At the end of the cooking, the digester were opened and spent pulping liquor was filtered off on double fold nylon cloth. The pulps were washed until the filtrate became colourless. The washed pulps were screened on a flat screen (slot 0.3 mm). The Dryness of the pulps was determined and pulp yield was calculated on the basis of dryness of pulp. Kappa number of each pulp was determined as per TAPPI method: T236-760.

The optimization of chemical requirement for 20 kappa pulp was carried out at standard cooking conditions with different chemical additions. Based on kappa number of the pulp, the chemical requirement was achieved. The pulping experiments were carried out for 20 kappa pulp for each wood species separately. The pulping results like pulp yield and kappa number were analyzed and recorded in Table 3.

Table 3: Pulping results of different hardwood species

Sl. No.	Species	Chemical charge for 20 kappa	Kappa Number	Pulp yield (%)
1	*Acrocarpus fraxinifolius*	16	21.4	42.4
2	*Albizia lebbek*	16	20.1	45.8**
3	*Dalbergia paniculata*	16	20.8	43.6
4	*Dalbergia sissoo*	16	21.6	46.6**
5	*Erythrinia indica*	16	20.4	47.2**
6	*Grewia tillifolia*	16	22.4*	41.7
7	*Gyrocarpus jacquinii*	16	22.6	40.6
8	*Melia dubia*	16	21.0	47.6**
9	*Melia composite*	16	21.8	43.8
10	*Neolamarkia cadamba*	16	20.0	47.4**
11	*Sterculia alata*	16	23.5**	38.5
12	Eucalyptus MTP1	16	20.0	48.6**
13	TNAU Casuarina MTP 2	16	20.7	49.1**
	Mean		21.25	44.83
	SEd		0.49	0.33
	CD (0.05)		1.02	0.69
	CD (0.01)		1.37	0.94

The unbleached pulp yield found to be between 38.5 percent (*Sterculia alata*) and 49.1 percent (TNAU Casuarina MTP 2). Other tree species *viz*., *Acrocarpus fraxinifolius*, *Albizia lebbek*, *Dalbergia paniculata*, *Dalbergia sissoo*, *Erythrinia indica*, *Grewia tillifolia*, *Gyrocarpus jacquinii*, *Melia dubia*, *Melia composite*, *Neolamarkia cadamba* and Eucalyptus MTP1 (Control 1) recorded the pulp yields of 42.4, 45.8, 43.6, 47.2, 41.7, 40.6, 47.6, 43.8, 47.4, 38.5, 48.6 per cent respectively (Table 3). Similarly many coniferous trees *viz*., deodar, kail, silver fir and spruce recorded the unbleached pulp yield of 45 to 60 per cent and bleached pulp yield of 42 to 47 per cent with satisfactory strength properties (Guha and Manmohan, 1960) [7]. Similar results were recorded in the current study by many species investigated, however the species Melia dubia yielded higher value in terms of pulp wood coupled with kappa number

The kappa number is an indicative of lignin content of pulp and gives an idea of bleaching demand in manufacturing process. The minimum kappa number was found in *Neolamarkia cadamba* and Eucalyptus MTP1 (20.0) at 16 per cent chemical charge and maximum in *Sterculia alata* (23.5%) at 16.0 per cent of chemical charge. The *Melia dubia* recorded 20.0 per cent at 16.0 percentage of chemical charge.

Strength Properties of various hard wood species

30 g (dry weight) of pulp was taken and diluted to 1.5 per cent (w/v) with water. This pulp slurry was thoroughly mixed. It was further diluted to 1.0 per cent and kept for 30 min. The measured volume of this was transferred in the sheet form in order to make 60 gsm sheets. These hand sheets were prepared according to TAPPI standard T 205 om-88. By couching, the sheet was removed from the wire with the help of absorbent blotters. These sheets were pressed between the blotters at 0.27 mpa to increase the dryness and to consolidate the sheet and then these sheets were dried at 27 ± 1ºC and 65 per cent ± 2 RH for 24 hrs.

The dried sheets were air dried and 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.

Table 4: The data recorded on yield and strength properties were then grouped (Guha, 1958)[6] as per the followings

Parameter	Very good	Good	Fair	Poor
Pulp yield (%)	> 48.0	> 45.0	> 39.0	<39.5
Breaking length (km)	> 6.0	> 5.0	> 4.8	Under 4.8

The results of the strength properties of unrefined pulp are given in Table 5. Among the species *Acrocarpus fraxinifolius* (24.09 Nm g-1, 3.9 m Nm2 g-1, 2.0 K Pa m2 g-1) have recorded superior strength properties for pulp and paper followed by *Dalbergia sissoo* (22.81 Nm g-1, 3.1 m Nm2 g-1, 1.2 K Pa m2 g-1) and *Melia dubia* (22.47 Nm g-1, 3.3 m Nm2 g-1, 1.6 K Pa m2 g-1). Compare to Control *viz*., Eucalyptus MTP 1(23.78 Nm g-1, 4.1 m Nm2 g-1, 2.2 K Pa m2 g-1,) and TNAU Casuarina MTP2 (24.96 Nm g-1, 4.0 m Nm2 g-1, 2.1 K Pa m2 g-1) exhibited the higher value while all other species showed lower values (Table 5). This might be due to superior fibre characteristic that may be present in the species. This besides, the chemical requirement to achieve 20 kappa in this species is only 16 per cent with normal chemical requirement contributed for improved strength properties

Considering all the parameters into account, the species *Melia dubia* proved superior in terms of pulp yield, kappa number and strength properties and hence this study recommends the suitability of *Melia dubia* as an indigenous pulpwood species.

Table 5: Strength Properties of various hard wood species

Species	Tensile strength	Tensile index (Nm/g)	Breaking length (M)	Tear strength	Tear index (mNm^2/g)	Tear Factor	Bursting strength	Burst index ($kPam^2/g$)	Burst Factor
Acrocarpus fraxinifolius	1450	24.09	2421	235	3.9	39.82	121	2.0	20.50
Albizia lebbek	1270	20.95	2038	180	3.0	30.29	78	1.3	13.12
Dalbergia paniculata	1030	17.13	1754	172	2.9	29.18	63	1.0	10.69
Dalbergia sissoo	1380	22.81	2257	190	3.1	32.04	74	1.2	12.48
Erythrinia indica	1120	18.18	1877	168	2.7	27.81	82	1.3	13.57
Grewia tillifolia	1150	18.98	1877	184	3.0	30.98	68	1.1	11.45
Gyrocarpus jacquinii	1020	16.72	1627	142	2.3	23.74	52	0.9	8.69
Melia dubia	1310	22.47	2195	190	3.3	33.24	92	1.6	16.10
Melia composita	1080	18.60	1833	185	3.2	32.49	102	1.8	17.92
Neolamarkia cadamba	1110	17.76	1797	169	2.7	27.58	88	1.4	14.36
Sterculia alata	1210	20.79	2023	175	3.0	30.68	78	1.3	13.67
Eucalyptus MTP1	1420	23.78	2261	247	4.1	42.20	130	2.2	22.21
TNAU Casuarina MTP 2	1490	24.96	2520	240	4.0	41.01	128	2.1	21.87
Mean	1233	20.55	2037	191	3.2	32.39	89	1.5	15.13
SEd	6.11	0.10		2.83	0.05	0.48	2.26	0.04	0.38
CD (0.05)	12.55	0.20		5.83	0.10	0.99	4.65	0.09	0.78
CD (0.01)	16.97	0.28		7.88	0.14	1.34	6.29	0.12	1.06

Conclusion

In a holistic perspective, the result of the current study apparently indicates that *Melia dubia* is amenable for pulp and paper industry due to superior pulp yield and quality. The indigenous species *Melia dubia* is fast growing trees with multifarious utility extend greater scope of its utility for various wood based industries. However, considering the pulp yield and kappa number coupled with strength properties, the superiority of the indigenous species *viz*., *Melia dubia* and *Neolamarkia cadamba* as a source of pulpwood was evident.

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