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RESEARCH ARTICLE

PULPING QUALITIES OF SIX YEAR OLD CLONES OF *EUCALYPTUS TERETICORNIS*, SM

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ABSTRACT

Cell size and relative fiber dimensions have a major influence on the quality of pulp and paper products and solid wood products. Since many of the wood properties are strongly heritable (Zhang and Jiang, 1998), there is a possibility for improving these traits through tree improvement programmes. *Eucalyptus tereticornis* is commercially planted as a source of paper pulp yet the wood properties show considerable variation among the clones. The present study was mainly intended to understand the wood properties of different clones and their suitability for pulping. The clones were compared for the pulping indices like Felting coefficient, Runkel's ratio, Isenberg coefficient, coefficient of fiber flexibility, inverse of fiber diameter and the amount of solid cell wall materials in the fibers. Clones were categorized based on their suitability for pulping. The clones Et 027, Et 093, Et 147, Et 148, Et 086, Et 082, Et 006 and Et 122 were identified as superior clones for good quality paper production due to their longer and thinner fibers. Clones Et 001, Et 128, Et 003, Et 142 and Et 071 were highly inferior in terms of pulp production due to their shorter and thicker fibers but they are suitable as a source of fuel wood. The clones like Et 111, Et 135, Et 114, Et 032, Et 084, Et 004 and Et 137 were having thinner but shorter fibers while Et 099, Et 105, Et 130, Et 100, Et 007, Et 010, Et 138, Et 132, Et 074 and Et 052 were having longer but thicker fibers. Correlation studies showed a significant positive correlation between height with fiber length and fiber wall thickness and a negative correlation with lumen diameter. Diameter also showed a significant positive correlation with fiber length but an inverse relation with fiber diameter and lumen diameter. The results indicate that during plus tree selection programme due importance must be given to growth traits that would definitely improve other desirable wood traits.

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INTRODUCTION

Eucalyptus tereticornis is an exotic fast growing arborescent species commercially planted as a source of paper pulp. It has been introduced to many countries including India to meet the ever increasing demand for paper pulp. Its wide range of adaptability and astonishing growth characteristics make it an excellent species for pulpwood production. The quality of wood intended for pulping is influenced by many wood traits such as specific gravity, extent of summerwood and other wood fiber characteristics. Fiber characteristics like fiber length, fiber diameter, wall thickness and lumen diameter influence the quality of pulp and paper products. These affect the bulk, burst, tear, fold and tensile strength of paper (Zobel, 1964). Fiber length is a wood quality character of central importance for the pulp industry (Amidon, 1981).It has a marked effect in product quality and the use of wood and it is reported to be a genetically controlled trait (Wheeler *et al.,* 1965; Otegbeye and Kellison, 1980). Wall thickness is of prime importance in wood and is related to specific gravity. Wood with thick cell walls tends to produce paper with poor printing surface and poor mullen (burst) strength (Hall *et al.,* 1973) and also has a major effect on the bending, tear and tensile strengths of paper. It is also a genetically controlled trait (Otegbeye and Kellison, 1980). Fiber diameter and lumen diameter also affect the quality of the end products (Artuz-seigel, 1968) and are heritable traits (Zhang and Jiang, 1998). There are many reports of correlation between wood properties and growth (Wei and Borralho, 1997; King *et al.,* 1998). Therefore, it is important to understand the variability of forest trees for physico-chemical properties and their relationship with growth in order to increase the productivity and for tree improvement strategies. In the present investigation, wood properties of six-year-old clones of *Eucalyptus tereticornis* were studied for their suitability for paper production and correlation studies were carried out to understand the relationship between growth and wood traits.

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MATERIALS AND METHODS

Six year old *Eucalyptus tereticornis* clones (ITC, Bhadrachalam) viz, Et 01, Et 03, Et 04, Et 06, Et 07, Et 10, Et 27, Et 32, Et 52, Et 71, Et 74, Et 82, Et 84, Et 86, Et 93, Et 99, Et 100, Et 105, Et 111, Et 114, Et 122, Et 128, Et 130, Et 132, Et 135, Et 137, Et 138, Et 142, Et 147 and Et 148, planted at Vantimimidi, near Secunderabad, Andhra Pradesh were screened for the growth and wood characteristics. The clones were raised in randomized block design with a spacing of 3mx3m. The soil was red sandy loam with a pH of 5.71. The maximum temperature during summer, ranged from 28^0C to 37^0C and the minimum ranged from 16^0C to 26^0C. The maximum winter temperature ranged from 28^0C to 30^0C and the minimum temperature ranged from 16^0C to 20^0C. The summer rainfall was between 79 to 30mm, the monsoon rainfall between 500 to 700mm and the winter rainfall between 90 to 120mm. The relative humidity was 50% to 60% in summer and 70% to 80% in winter during the study period.

As it was clonal plantation, twenty percent of population from each clone was sampled for studying the growth characteristics. Height was measured using a clinometer, diameter was taken at breast height level (Dbh) using vernier calipers as per standard procedures (IUFRO, 1965). Wood samples were collected at breast height level (1.37m above ground) from five representative trees (having average diameter) of each clone. The wood samples were collected using an increment core and the samples were digested in a mixture of equal volume of chromic acid and nitric acid. It was then heated gently for half an hour for maceration and the separated fibers were mounted on a slide. Hundred unbroken fibers, per sample, were taken for data collection. Wood fiber characteristics such as fiber length, fiber diameter, fiber wall thickness and lumen diameter were measured using Image Analyzer (Q Mac 500). The Pulping qualities of the wood were determined using pulping indices like Felting coefficient (ratio of fiber length to fiber diameter), Runkel's ratio (ratio of double wall thickness to lumen diameter), Isenberg coefficient (ratio of double wall thickness to fiber diameter), Coefficient of fiber flexibility (ratio of lumen diameter to fiber diameter), and inverse of fiber diameter. The amount of solid cell wall materials per unit fiber area was calculated using the formula

Fiber wall area per unit fiber area
$= (\text{fiber diameter})^2 – (\text{lumen diameter})^2/(\text{fiber diameter})^2$

Statistical Analysis

The growth traits and wood traits of the clones of *Eucalyptus tereticornis* were subjected to one-way variance analysis and correlation studies using SPSS 16.0 (SPSS Inc., Chicago, IL, USA).

RESULTS AND DISCUSSION

Significant variation has been observed among the clones of *Eucalyptus tereticornis* for growth and wood traits (table 1). Fiber length, the most important wood property affecting the quality of paper pulp, ranged from 605 µm in Et 122 to a maximum length of 807 µm in Et 003. As suggested by Higgins and Puri (1976), the major constraint that limits the use of eucalypts like hardwoods as a source of pulpwood is their shorter fibers. However, clones like Et 003, Et 010, Et 007, Et 130, Et 138 and Et 148 are promising ones and are suitable for pulping as they contain longer fibers. With improved technologies and breeding strategies, it is possible to overcome this fiber length limitation and make use of these clones as a source of paper pulp. Double wall thickness is another important fiber trait influencing many properties of paper and showed a direct relationship with wood specific gravity. It varied from 5.12 µm in Et 122 to 11.98 µm Et 001. The results showed a higher double wall thickness for Et 001 (11.98 µm), Et 003 (10.07 µm) and Et 071 (10.04 µm). Thinner walls were observed in Et 122 (5.12 µm), Et 082 (5.74 µm), Et 137 (5.86 µm), Et 006 (6.13 µm) and Et 086 (6.19 µm). Wall thickness also has a major effect on the bending, tear and tensile strengths of paper. Fiber diameter varied from 11.72 µm in Et 122 to 18.31 µm in Et 001and the lumen diameter varied from 4.04 µm in Et 130 to 7.53 µm in Et 111 and Et 006.

Felting coefficient ranged from 36.13 to 61.72 (table 2) and a higher value indicate the suitability of fibers for good quality paper production. It influences many of the paper qualities such as ease of sheet formation, sheet smoothness and opacity. Clones like Et 010 (61.72), Et 147 (59.52), Et 130 (59.46), Et 138 (59.29), Et 148 (58.51) are promising clones for good grade paper production compared to Et 111 (36.13), Et 071 (37.57), Et 001 (39.32) and Et 135 (40.75). Runkel's ratio varied from 0.776 to 2.25(table 2) and a lower ratio is highly desirable for quality paper production. Higher ratio was observed in Et 130 (2.250), Et 105(2.220), Et 099 (2.020), Et 001 (1.895), Et 007 (1.867) and Et 100 (1.857) and a lower ratio in Et 122 (0.776), Et 082 (0.810), Et 006 (0.814), Et 086 (0.871) and Et 137 (0.874). Fibers with higher Runkel's ratio indicate thicker fibers that produce more quantity of pulp but the quality of the pulp would be poor due to the stiffness of fibers. Wood with thick cell walls tends to produce paper with a poor printing surface and poor mullen (burst) strength (Hall, *et al.,* 1973). The thick walled fibers do not bend easily and do not collapse upon pulping, which inhibits chemical bonding. The surface of paper made from thick walled fibers does not smoothen and ink tends to spread rather than to produce sharply defined printed letters. Thinner walled fibers collapse upon pulping, bond well chemically to produce a smooth paper surface.

Isenberg coefficient varied from 0.436 to 0.69 (table 2) with a higher value for Et 130 (0.692), Et 111(0.689), Et 105(0.669), Et 100(0.669) and Et 001(0.654) and a lower value for Et 122(0.436), Et 082(0.447), Et 006(0.448), Et 086 (0.465) and Et 137(0.466). It influences the pulping qualities like the degree of flexibility of fibers and the collapse of fibers, both of which control the degree of conformability within the paper sheet and thus the numbers of inter fiber bonds. A lower ratio suggests the suitability for quality paper production. The results showed a lower ratio for Et 122, Et 082, Et 006, Et 086 and Et 137 indicating the suitability of these clones for better quality pulp production compared to Et 130, Et 111, Et 105, Et 100 and Et 001. The coefficient of fiber flexibility ranged from 0.308 to 0.562 (table 2) and the ratio was higher in Et 122 (0.562), Et 082 (0.552), Et 006 (0.551), Et 086 (0.534) and Et 137 (0.533) while lower value was observed in Et 130 (0.308), Et 105 (0.310), Et 099 (0.330), Et 001 (0.345) and Et 007 (0.348).

Table 1. Wood fiber dimensions of six year old Eucalyptus Tereticornis clones

SI.No.	CI.No.	Height	Dbh	FI	Fd	Ld	2W
		(m)	(mm)	(µm)	(µm)	(µm)	(µm)
1	Et 001	14.31	99	720 ± 32.13	18.31± 0.08	6.32± 0.03	11.98± 0.05
2	Et 003	18.15	112	807± 35.11	16.73± 0.07	6.65± 0.02	10.07± 0.04
3	Et 004	13.91	100	627± 23.56	12.89± 0.04	6.42± 0.02	6.47± 0.06
4	Et 006	14.34	112	743± 30.21	13.66± 0.04	7.53± 0.02	6.13± 0.05
5	Et 007	16.21	192	782± 33.23	13.47± 0.04	4.69± 0.03	8.77± 0.06
6	Et 010	14.43	116	802± 38.66	12.99± 0.04	4.6± 0.02	8.39± 0.05
7	Et 027	13.88	112	735± 29.01	13.39± 0.05	5.89± 0.02	7.5± 0.04
8	Et 032	12.82	91	636± 26.79	14.14± 0.06	6.45± 0.03	7.69± 0.05
9	Et 052	15.12	102	717± 28.34	13.12± 0.04	5.36± 0.02	7.76± 0.05
10	Et 071	14.1	124	643± 29.23	17.1± 0.08	7.06± 0.02	10.04± 0.04
11	Et 074	13.34	108	743± 30.02	13.93± 0.04	5.77± 0.02	8.16± 0.04
12	Et 082	12.65	100	663± 25.45	12.82± 0.03	7.08± 0.02	5.74± 0.04
13	Et 084	14.56	103	693± 27.18	15.35± 0.06	7.14± 0.03	8.2± 0.04
14	Et 086	13.1	108	681± 29.82	13.29± 0.04	7.1± 0.03	6.19± 0.04
15	Et 093	16.21	115	757± 32.24	13.63± 0.05	6.95± 0.02	7.67± 0.03
16	Et 099	17.54	105	695± 32.22	13.73± 0.06	4.53± 0.02	9.19± 0.05
17	Et 100	16.31	105	739± 35.75	13.65± 0.04	4.92± 0.02	9.13± 0.05
18	Et 105	17.74	121	723± 27.95	13.27± 0.05	4.11± 0.02	9.15± 0.04
19	Et 111	12.81	95	622± 32.23	17.22± 0.08	7.53± 0.02	9.68± 0.04
20	Et 114	13.5	114	613± 25.13	13.61± 0.03	5.97± 0.03	7.64± 0.04
21	Et 122	14.11	121	605± 23.45	11.72± 0.05	6.59± 0.04	5.12± 0.04
22	Et 128	14.44	114	617± 28.75	12.77± 0.03	4.67± 0.03	8.1± 0.04
23	Et 130	16.21	111	783± 32.88	13.17± 0.03	4.04± 0.02	9.12± 0.05
24	Et 132	13.31	115	641± 29.13	12.14± 0.04	4.63± 0.02	7.5± 0.05
25	Et 135	12.8	101	643± 24.98	15.77± 0.06	7.02± 0.03	8.75± 0.04
26	Et 137	13.89	101	629± 28.67	12.56± 0.03	6.7± 0.03	5.86± 0.05
27	Et 138	14.1	97	773± 31.11	13.02± 0.03	4.84± 0.02	8.18± 0.05
28	Et 142	14.35	104	692± 30.89	14.11± 0.04	5.75± 0.03	8.36± 0.04
29	Et 147	12.75	115	737± 33.33	12.36± 0.03	5.78± 0.03	6.58± 0.05
30	Et 148	13.13	116	763± 30.23	13.04± 0.04	6.46± 0.03	6.58± 0.05
F		7.85*	12.46*	21.63*	9.83*	8.92*	7.45*
SD		1.19	7.13	62.98	1.63	1.08	1.46
LSD		0.73	0.96	13.19	0.39	0.16	0.14

The ratio affects the flexibility of fibers and a higher ratio indicates a better flexibility of fibers. The clones Et 122, Et 082, Et 006, Et 086 and Et 137 were found to have greater fiber flexibility than Et130, Et 105, Et 099, Et 001 and Et 007. The inverse of fiber diameter is usually taken as a measure of wood density, ranged from 0.058 in Et 001 to 0.085 in Et 122 (table 2). Generally high dense wood is indicated by a lower value. The value was higher in Et 122, Et 132, Et 147, Et 137 and Et 128 suggesting a low dense wood than in Et 001, Et 071, Et 111, Et 003 and Et 135. Fiber wall area per unit fiber area, an indication of the amount of solid materials present in the wood, was also calculated in all the clones and it ranged from 0.683 in Et 122 to 0.905 in Et 130 (table 2). The solid material was more in Et 130, Et 105, Et 009, Et 001 and Et 007 indicating a higher quantum of pulp production compared to Et 122, Et 082, Et 006, Et 086 and Et 137. Felting coefficient and Runkel's ratio, the two most important pulping indices were taken together and the average of both ratios were considered for categorizing the clones and the result was summarized in table (3). There were four categories of clones in which the category I consists of Et 111, Et 135, Et 114, Et 032, Et 084, Et 004 and Et 137 showing lower Felting coefficient and lower Runkel's ratio. Lower Runkel's ratio is desirable character for pulping while lower Felting coefficient limits the utilization of these clones for pulp wood production. Genetic improvement is required for longer fibers in order to make use of these clones for pulping. Category II consists of Et 027, Et 093, Et 147, Et 148, Et 086, Et 082, Et 006 and Et 122 which were ideal clones for good quality paper production due to their higher Felting coefficient and lower Runkel's ratio. Category III consists of Et 001, Et 128, Et 003, Et 142 and Et 071 which were highly inferior clones due to their lower Felting coefficient and higher Runkel's ratio. These clones need to be improved further for longer and thinner fibers. Category IV consists of Et 099, Et 105, Et 130, Et 100, Et 007, Et 010, Et 138, Et 132, Et 074 and Et 052which were undesirable for pulping due to higher Runkel's ratio. However, these clones are superior in terms of pulp yield due to their thicker fibers. The results indicate the scope for genetic improvement of these clones so as to optimize their end use.

Correlation studies were carried out to understand the association between growth and wood traits (table 4). Growth in height was accompanied by a significant increase in fiber length (r=0.60) and fiber wall thickness (r=0.40) but a negative correlation existed with lumen diameter (r=-0.4). This indicates that selection for growth in height would definitely improve fiber length which is a desirable quality for pulpwood. However, the corresponding increase in wall thickness and a decrease in lumen diameter may negatively influence pulp quality. Growth in thickness was also accompanied by an increase in fiber length (r=0.53) but a negative correlation existed with fiber diameter (r=-0.42) and lumen diameter (r=-0.53). Fiber length did not show significant correlation with any of these wood traits. However, fiber diameter showed a highly significant positive correlation with wall thickness (r=0.76) and lumen diameter (r=0.46). The correlation studies highlight the significance of considering growth traits in the selection of plus trees and the scope for improving desirable wood traits according to their end use.

Conclusion

Cell size and relative fiber dimensions have a major influence on the quality of pulp and paper products and solid wood products. Since many of the wood properties are strongly heritable (Zhang and Jiang, 1998), there is a possibility for improving these traits through tree improvement programmes. Four categories of clones have been made based on the pulping indices. Category II comprising Et 027, Et 093, Et 147, Et 148, Et 086, Et 082, Et 006 and Et 122 which were ideal clones for good quality paper production due to their higher Felting coefficient and lower Runkel's ratio. Other categories of clones require genetic improvement. Improvement of wood quality necessitates studying associated characters. As height and DBH are positively related to fiber length, selection for faster growth would definitely improve this trait.

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