RESEARCH PROJECT ON

"RESEARCH ON WOOD QUALITY AND PHYSICAL PROPERTIES OF PULPWOOD FIBRES AS THE BASIS FOR DEVELOPMENT ON EUCALYPTUS AND SUBABUL PLANTATIONS"

SUBMITTED
TO

RSC-DCPPAI COMMITTEE

BY

PAPRI

PULP AND PAPER RESEARCH INSTITUTE
JAYKAYPUR – 765 017 (ORISSA)

ENDORSEMENT FROM THE HEAD OF THE INSTITUTION

"RESEARCH ON WOOD QUALITY AND PHYSICAL PROPERTIES OF PULPWOOD FIBRES AS THE BASIS FOR DEVELOPMENT ON EUCALYPTUS AND SUBABUL PLANTATIONS"

1. Certified that the institute welcomes the participation of Dr. Surendra Pratap Singh Scientist-B, PAPRI as the Principal Investigator (Project Leader)

2. Certified that the equipment and other facilities as enumerated in the proposal as per the terms and conditions of the grant extended to the investigators throughout the duration of the project.

Dated:

Place: Jaykaypur, Orissa

(Vinay Dwivedi)
Vice Chairman (Committee of Management)
Pulp and Paper Research Institute (PAPRI)

Executive Vice President (Works)
JK Paper Ltd. (Unit: JK Paper Mills)
Jaykaypur-765 017 (Orissa), INDIA

(Dr.B P Thapliyal)
Director
Central Pulp and Paper Research Institute
Saharanpur-247 001 (UP), INDIA

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6.	Other participating/ interacting agencies	:	i) Central Pulp and Paper Research Institute, Saharanpur 247 001 (UP) ii) M/s JK Paper Ltd., Unit JK Paper Mills Jaykaypur 765 017, Dist. Rayagada (Orissa)

7. Principal Investigator :

i) Name — Dr. Surendra Pratap Singh
Designation — Scientist-B
Dept./Institution — Pulp & Paper Research Institute
Address — Jaykaypur 765 017, Dist. Rayagada, Orissa.

ii) Name — Dr. Priti S Lal
Designation — Sc-E-II
Institution — CPPRI
Address — Sharanpur

8. Co- Investigators :

i) Name — Sri B P Ratho
Designation — GM (Plantation)
Dept./Institution — J K Paper Mills,
Address — Jaykaypur 765 017, Dist. Rayagada, Orissa

ii) Name — Dr. Arvind Kr. Sharma
Designation — Scientist-B
Institution — CPPRI
Address — Saharanpur

iii) Name — Mr.Sunil Pradhan
Designation — Scientist -C
Dept./Institution — Pulp & Paper Research Institute
Address — Jaykaypur 765 017, Dist. Rayagada, Orissa

9. Other investigators

i) Name — Dr. U.P. Tripathy
Designation — Scientist-B
Dept./Institution — Pulp & Paper Research Institute
Address — Jaykaypur 765 017, Dist. Rayagada, Orissa

ii) Name — Mr. Biswajit Mansingh
Designation — Scientist - A
Dept./Institution — Pulp & Paper Research Institute
Address — Jaykaypur 765 017, Dist. Rayagada, Orissa

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Executive summary

Today there are 759 pulp and paper mills in India producing 10 million ton of paper and paper boards which is 2.52 per cent of the total world production. Indian paper industry is highly fragmented in terms of product wise segmentation and produces 38.58 per cent printing or writing, 53.61 per cent packaging and 7.81 per cent newsprint papers. Depending upon the production capacity paper mills are classified as large (33,000 TPA), small (7,500 TPA) and medium (between 7,500 to 33,000 TPA). The paper production from small and medium mills accounts for 60 per cent while 40 per cent comes from large mills. Out of 759 mills, 114 (15%) are large, 342 (45%) small and 303 (40%) medium [1] . The forest and tree cover in India has been assessed as 23.4 per cent of the total geographical area. The tree cover was estimated as 9.17 million ha which constitutes about 2.8 per cent of the geographical area [2]. The wood based paper mills in India continue to face challenges with wood based raw material. Pulp and paper industry consumes 3 per cent of total national requirement of wood. The annual pulp production is 3.03 MT from, 10 MT of wood, agricultural wastes and waste paper. Nearly 20 per cent of wood is procured from government sources while, 80 per cent from agro-forestry sources. The strategy adopted by the industry to meet the ever growing demand of wood on a sustainable basis is to obtain wood from farm forestry plantations. Eucalyptus is becoming the most important fiber source for papermaking worldwide. Eucalyptus is the largest single global source of market pulp.

In 1988, the Centre introduced the National Forest Policy, which restricted commercial plantations in forests and asked industries to source wood from farmers instead. The paper industry with its eye on cheap wood from captive forests opposed the policy, claiming that farm forestry would not be sufficient to meet its needs. However, in the absence of choice, the industry turned to farmers for wood. The movement of farm forestry began to pick up towards the late 1990s [3].The government is also trying to create an enabling framework for planting degraded forest lands through industry. The overall limited availability of raw materials will force the paper industry to rely more and more on imports of pulp or final paper products.The gap between demand and supply of pulpwood is not made up; it will further result in loss of natural tree cover. The sustainable forestry is all about silviculture, which includes proper management, reforestation, growth and nurturing of forests. The bulk of the requirement of the industries is met from farm forestry. There is need to improve productivity of pulpwood through well designed tree improvement programmes and planting fast growing species to bridge the demand and supply gap.

The tree-improvement programme is traditionally focused on growth, stem form, and branch quality. Future efforts in tree improvements for wood based industries should target wood properties such as basic density, fibre length and chemical parameters. The following are the major areas where tree improvement initiatives on eucalyptus and subabul have been taken up with success:

- Introduction of species and their provenances
- Evaluation and identification of adaptable and productive provenances of successful species
- Identification/selection of superior phenotypes
- Clonal reproduction/propagation, testing and selection
- Establishment of seed orchards and production of quality seeds
- Development of hybrids through controlled crossing and their evaluation
- Establishing breeding populations

Eucalyptus and Subabul are fast-growing trees, and can be made available for pulp production within four to five years after planting. The increasing demand for wood partly results from the attractive economic return from their plantations.

The major interest in Eucalyptus and Subabul wood come from its low production cost in certain regions, mainly because of high productivity and high pulp yield. However, more recently the outstanding quality of Eucalyptus and Subabul fibers has been recognized. The use of bleached eucalyptus fibers to manufacture paper grades previously made only with bleached softwoods is growing quickly. The ongoing scientific and technical advances achieved in production of eucalyptus fibers, from forest to product, and the increasing understanding of their applications in various paper grades have made these the preferred fibers worldwide. Eucalyptus and Subabul pulp fibers produced from clonal plantations have emerged as the most desirable fibers in the market, not only for the production of tissue and printing and writing papers, but also for the manufacture of “new products.” Eucalyptus wood-fiber characteristics may vary substantially among the various species and clones as well as with age. By acting on these parameters and the pulping process, it is possible to prepare eucalyptus pulps that are of good quality and suitable for most paper-manufacturing applications. This study discusses the main wood properties and their impact on specific wood consumption, kraft pulping yield, and pulp use for a variety of Eucalyptus wood species. The main aim of this study is to observe the influence of minimum tree age of Eucalyptus and Subabul for harvesting to maximize profitability of farmer as well as pulp yield.

The knowledge of its chemical composition, depending on the age of the trees, can be of potential practical importance for its further application. In this study, it is observed that influence of tree age of eucalyptus on chemical pulping. In this research 2-3, 3-4 and 4-5 years old eucalyptus and subabul wood were pulped under different active alkali of 16 to 22 % maintaining 25 % sulfidity and pulp desired kappa number 17-18. Since, the consumption of chemicals during ECF bleaching of kraft pulp correlates reasonably well with kappa number. The delignification and bleached pulp yield were investigated. The results show, the content of extractive, lignin, alpha-cellulose and hemi-cellulose increase to different content along with the increase of tree age. There are also some differences of pulping properties with different tree age. Pulp yield of 3-4 years old eucalyptus is higher than other ages of eucalyptus trees. Pulp wood of 3-4 years Eucalyptus and Subabul are more suitable for pulping, compared to that 4-3 and 4-5 years. The results of the present research may be give useful information to determine the most appropriate harvesting rotation of Eucalyptus and Subabul tree to produce high quality wood pulp. In this study, it is found that the eucalyptus clone namely, CTA-7-2, ECxED, MPM26, JK2135 and CTA8-GS8 produced high pulp wood and bleached pulp per hectare. This study addressed the influence of pulping conditions on eucalyptus kraft pulp yield, quality, and bleachability. With proper knowledge of the complexity present in the raw material, the various quality requirements could be met with more accuracy.

1 Introduction

1.1 Industry and Raw material

JKPM was established during 1962 at Rayagada in Orissa with an installed capacity of 18000 TPA. The mill production capacity has expanded in phases (shown in **Table 1**). The mill was initially run only on Bamboo up to 1992. The bamboo was not sufficient to meet the increasing raw material requirement of increasing production and hence started finding alternative sources of wood as raw material. Pulping characteristics of wood species were studied and compared with Bamboo for their suitability. The Pulping Characters of different wood raw material in comparison with bamboo were tested (**Table 2**) [4-6]. Based on these studies the mill started using hardwoods from 1992 to meet the increased demand of raw material. Dependence on Bamboo raw material was reduced to 50% in 2000, 10% in 2010 and 2% in 2014.

Table 1 : Production capacity and Raw material requirement of the mills

Year	Capacity (TPA)	Raw Material (MT)
1962	18000	60000
1972	26000	100000
1982	46000	150000
1992	70000	188000
2000	91000	200000
2010	136000	450000
2014	295000	800000

Table 2: Comparison of pulping characteristics of different wood materials

Particulars	Unit	Casuarina	Eucalyptus	Acacia	Subabul	Cashew	Sal	Bamboo
Lignin	%	28.6	31.2	27.4	27.2	27.8	29.1	31.4
Holo cellulose	%	69.4	68.2	68.5	65.7	66.4	67.7	65.7
Brightness	% ISO	88.1	88.3	89.2	88.5	87.9	88.6	88.1
Bulk Density	kg/m^3	229	197	258.9	207	196	265.4	234
Fiber length	mm	0.8	0.9	0.9	0.9	0.7	1.1	1.6
Fiber diameter	micron	13.9	13.4	14	15.9	14.9	14.1	12.8

1.2 Pulpwood Plantations

Unlike naturally available bamboo in native forests pulp wood species of Eucalyptus, Casuarina and Subabul are exotics and need to be raised as plantations. Hence the mill launched Farm Forestry programme from 1990 under which the mill produced and distributed clones and seedlings of Eucalyptus, Casuarina and Subabul to farmers in Orissa and Andhra

Pradesh. The mill also started Plantation Research and Development wing to increase the productivity of plantations.

1.2.1 Eucalyptus

The Eucalyptus is native to Australia and exotic to India[7]. The Eucalyptus was introduced in India during the time of Tippu Sultan in Nandi Hills of Mysore in late eighteenth century (1790). From these stands in Nandi hills Eucalyptus plantations have spread all over India which were of inferior in productivity and slow growing due to great variability in stands and poor growth.

To increase the productivity of plantations the Plantation Research and Development started identifying "Plus Trees" in existing plantations and developing clonal plantations with clones selected from plus trees and tested their pulping characters through one of the IPMA project titled "Identification of suitable clonal propagated hard wood for higher pulp yield, optimum chemical consumption for pulping and suitability for mass multiplication with required advantages". These clonal plantations identified under IPMA project listed above were severely affected on epidemic scale by gall insect till 2010. The effect of gall insect was so severe that the plantations failed completely and the clonal plantation activity came to a standstill affecting raw material supply to the industry. IPMA project supported to the rescue of this problem by financing a project to gall insect problem.

To overcome the gall insect problem the Plantation Research wing of JKPM took up new initiative for development & production of resistant Eucalyptus clones for plantation. Plantation Research Wing sourced about 130 new clones from Karnataka, Tamilnadu, Kerala, Andhra Pradesh, Maharashtra and Odisha in 2011 which were fairly resistant to gall insect damage. The trials for suitability of new clones in different agro climatic conditions were taken up in 2011, 2012 and 2013. In 2014 about 25 clones among these 130 clones were found to be more suitable and high yielding for raising plantations.

1.2.2 Subabul

Subabul is native to central American countries like Mexico, Gautemala, El Salvador and exotic to India[8, 9]. It was introduced to India during 1970 as a miracle tree because of its success as a long lived and highly nutritious forage tree and variety of other uses including pulp wood. The Subabul plantations for pulpwood is a recent concept and Forest Research Wing has taken up trials on raising clonal Plantations. Plantation Research Wing has sourced two high yielding clones from Gujrat during 2013, standardized multiplication process and started raising plantations during 2014. There is lot of potential for high yielding Subabul clonal plantations since they can be harvested within 2-3 years.

1.3 Brief Review of Literature

Brazilian paper industry identify and select the genotypes of pulp wood species like Eucalyptus based on superior wood quality and fibre properties for pulping [10, 11].

1.3.1 Variability in wood Properties of different clones

Brazilian Paper Industry has analysed 21 Eucalyptus clones for wood properties like Basic Density, Extractive content, Lignin content, Alkali charge for pulping, Pulp viscosity, Pulp yield and found considerable variability among them as shown in **Table 3**[12-14].

Table 3 : Variability in wood properties of 21 clones analyzed by TAPPI

Wood Characteristics	Range among 21 clones
Basic Density, kg/m^3	374 – 601
Extractives content, % (alcohol / toluene)	1.5 – 3.2
Lignin content, %	25.1 – 28.4
Alkali charge for pulping, %	17 – 24
Pulping yield, %	44 – 51.6
Pulp viscosity, cP	20.4 – 48.3

1.3.2 Variability in wood quality of heart wood and sap wood

Brazilian paper industry [15] has analysed wood quality and pulping characteristics of heartwood and sap wood of two clones and observed that heartwood has more extractives, higher alkali demand, more pitch, lower permeability owing to more tylose, lower pulp yield and difficult for chips impregnation (shown in **Table 4**).

Table 4 : Properties of heart wood and sap wood of two Eucalyptus clones

Clone	Properties	Heartwood	Sapwood
A	Basic Density, kg/m^3	459	480
	Extractives, % (alcohol/toluene)	2.54	0.8
	Lignin content, %	27.7	23.9
B	Basic Density, kg/m^3	485	484
	Extractives, %(alcohol/toluene)	3.5	1.51
	Lignin content, %	26.4	24.7

1.3.3 Wood Composition during Eucalyptus Growth

Lignin changes during plant growth were investigated by Spanish scientists in a selected *Eucalyptus globulus* clone [16].They studied the contents of the main wood constituents (i.e. acetone extractives, water-soluble material, Klason lignin, acid-soluble lignin, crystalline cellulose, amorphous glucan, xylan, arabinan, galactan, mannan, rhamnan, fucan, total uronic acids, and ash) in the selected *E. globulus* clone at different stages of growth. Their observation is as follows. The total lignin content (Klason lignin plus acid-soluble lignin) increased during growth (from 16% in the 1-month-old sample to 25% in the 9-year-old wood), whereas the content of other constituents (namely acetone extractives, water-soluble material, and ash) decreased with maturity. Interestingly, there is also a great variation in the composition of polysaccharides (from neutral sugar analysis) during maturation, with a depletion of Ara, Gal, and Man and a progressive enrichment of Xyl. The amount of crystalline cellulose has the highest content (37%) after 18 months, while that of amorphous glucan was lower and showed a progressive increase during growth. Finally, the uronic acid content was the highest after 1 month (7%) and showed only a moderate decrease during growth.

2 Objective

i) To assess wood quality (pulping parameters) and fibre qualities of 25 promising Eucalyptus and 2 Subabul clones through detailed proximate analysis and fibre properties studies.
ii) To establish optimum harvesting age of plantations based on wood quality, wood properties with special reference to lignin content, pulp yield and chemical requirement in pulping process.
iii) To examine the possibility of reducing bleaching chemical consumption and increase bleached/unbleached pulp yield by selecting clones with desired wood properties.
iv) To establish desired mixture of the selected clones with other wood raw material so that there is uniformity in the pulping process, uniformity in the use of chemicals.
v) To assess holo-cellulose characterization before cooking and hemi cellulose retained after pulping for the wood raw material consisting the mixture of the selected clones with other wood.

vi) To assess and standardize additives in pulping process for the wood raw material consisting the mixture of the selected clones with other wood.

2.1 Industrial application

Minimize the cost of production (Pulp / Paper) by developing suitable Eucalyptus & Subabul clones such that these help in,

i. Reducing raw material consumption per MT of pulp / Paper
ii. Reduce chemical demand for pulping.
iii. Help in reducing effluent load from pulp mill.
iv. Recommend the desirable mix of these Eucalyptus/ Subabul) with other hardwood.
v. Recommend the right age of these species.

2.2 Technical Programme

2.3 Research Methodology

i). 130 new gall resistant clones were sourced from Karnataka, Tamilnadu, Kerala, Andhra Pradesh, Maharashtra & Odisha in 2011 and 25 promising clones were shortlisted and trial plots were raised during 2011, 2012, 2013 onwards. Along with Eucalyptus clones two Subabul clones from Gujarat were introduced and plantations were raised from 2014 onwards by JKPM forest wing. Clones developed by other mills also be accepted and evaluated. PAPRI informed the other mills for supplying the clones for study. Other mills also send wood chips for testing at PAPRI.

ii). Two trees each for shortlisted 25 Eucalyptus clones felled from trial plots at the age of 2-3, 3-4 and 4-5 years. Similarly two trees each of 2 Subabul clones felled from plantations at the age of 2-3 and 3-4 year.

iii). The felled trees cut into 3 meter long logs in the field and transported to the mill site by JKPM research wing.

iv). At mill site the logs chipped in the industrial chipper.

v) The chips sent to PAPRI for further processing

viii) CPPRI analyzed the samples for wood characteristics like basic density, extractive content, lignin content etc.

vii). PAPRI analyzed the samples for wood characteristics like alkali charge for pulping, pulp viscosity and pulp yield.

xi). Wood characteristics data of all clones and for different ages from PAPRI and CPPRI compiled, compared and discussed.

x). Based on the wood characteristics data, a few clones selected for desirable pulping quality, less effluent discharge, low cost of pulping and higher pulp yield.

x) PAPRI shared the information and guide the Clone Production Department and Plantation Department about the selected clone with desirable wood quality for raising plantation and the age for felling.

xi) The Clone Production Department and Plantation Department raised plantations of only the clones selected by PAPRI so that the raw material with desired wood quality will be supplied to the mill.

xii). In addition to testing the wood quality of selected clones for pulping, PAPRI standardized the raw material mixture of the selected clones with other wood through pulping analysis of different mixture.

xiii). PAPRI guide the mill about the right mixture to be adopted in paper production.

xiv) With the consent of IPMA the information shared with all Pulp & Paper Industries in India and also publishes the information in national and international magazines.

3 Material and methods

3.1 Selection of trees

25 clonal materials of Eucalyptus spp. (at the age of 2-3, 3-4, and 4-5 years) were evaluated (**Table 5**). The biological material was obtained from JKPM trial plot and different districts of Odisha and Andhra Pradesh. The distance between the trees 3 meters and with in rows 1.5 meters which hold 2222 plants per hectare for block plantation. The *Eucalyptus* and *Subabul* plantations were measured in the period November–December each year. Twenty trees for each genetic material were sampled, obtaining their diameter at breast height (DBH; 1.30 m from the ground).The tree having average DBH were selected for the study. The same procedure was carried out at the age of 2-3, 3-4, and 4-5 years respectively.

3.2 Diameter at breast height

Diameter at breast height (DBH) is measured at 1.35m with diameter-tape or caliber gives figure directly without conversion.

Using Tape:

Notice "0" point, which is usually 4-5" from the end of the tape.

Using a calibre:

Two measurements at right angles to compensate for variation in cylindrical form, Record the average of the two measurements. Circumference measured with ordinary tape needs conversion according to the formula:

$$D = C/\pi \text{ where } D = \text{diameter}$$

$$C = \text{circumference and}$$

$$\pi = \text{constant } (3.1416)$$

3.3 Tree processing

The freshly cut 2-3,3-4 and 4-5 age tree were collected from JKPM trial plot and different districts of Odisha and Andhra Pradesh. The tree was cut in fixed positions in every 2 m until the merchantable height (when the diameter reaches 4 cm). Subsequently, the individual weight, with and without bark, was estimated. Discs with thick of 2.5 cm were obtained in five longitudinal positions upto the commercial height, considered up to a minimum diameter of 4.0 cm with bark, as recommended by Stackpole et al.[17]. These were debarked and chipped separately using a commercial chipper. The logs of each individual tree were chipped in chipper, as a batch and in random order, and the chips from each tree were well mixed with a frontend loader. Bulk samples (5 kg OD) were taken for kraft pulping.

3.4 Raw material processing

The chips of eucalyptus and subabul were screened in an L&W vibrating chips classifier to remove oversized and pin chips. Finally, the screened chips were hand sorted to remove all pieces of knots, barks and decayed wood. The accepted chips were about 20±0.15 mm in length, 10±0.13 mm in width and 3±0.06 mm in thickness. The chips were then air dried and stored in sealed polythene bag for pulping. The moisture content was determined by the difference in weight as received and after drying at 105± 2 ^{o}C.

3.5 Chemical analysis

Chemical composition of the plant gives an idea of how feasible the plant is as raw material for papermaking. The fibrous constituent is the main important part of the plant. Since plant fibers consist of cell walls, the composition and amount of fibers is reflected in the properties of cell walls. Cellulose is the principal component in cell walls and fibers .The amount and composition of the cell wall compounds differ among plant species and even among plant parts and they have an effect on the pulping properties of plant material. The exact standards that were followed for chemical analysis are presented in **Table 5**. The samples were oven-dried and used to determine chemical characterization. 300 g (OD equivalent) of chips from each tree were air-dried for three days prior to grinding. *Eucalyptus* and *Subabul* chips for proximate chemical analysis was ground to a fine particle size (40-60 mesh) with Wiley mill to permit complete reaction of wood dust with the reagents used in the analysis. The wood dust samples were stored in an air-tight container for chemical analysis. Chemical analyses were made on all 25 Nos. eucalyptus and 2 Nos. Subabul chip samples at age of 2-3, 3-4 and 4-5 years respectively.

Table 5 :Standard TAPPI Protocols for proximate chemical analysis

S. No.	Standard Methods	TAPPI No.
1	Cold-water Solubility	T 207 cm-99
2	N/10- NaOH Solubility	T 212 cm-02
3	Alcohol-Benzene Solubility	T 204 cm- 97
4	Holocellulose	Useful method-249-75
5	Klason's Lignin	T 222 cm-02
6	Ash Content	T 211 cm-02
7	Basic density	T 258 om-94

3.5.1 Alcohol-benzene solubility

The extraction apparatus consisted of a soxhlet extraction tube which is connected with a reflux condenser on the top and joined at the bottom to a boiling round bottomed flask 2.0 g (O.D) samples were placed into filter paper extraction thimbles. The thimbles were placed in a soxhlet extraction tubes. The boiling flasks contained a 2:1 solution of benzene and distilled alcohol respectively were placed on heating mantles. The extraction was conducted for four hours at the rate of approximately six siphoning per hour. $ier extraction, the thimbles were removed from soxhlet tubes and dried at 105 ± 2°C for overnight. The materials were removed from thimbles and weighed. The following formula was used to obtain the alcohol-benzene solubility content of wood dust.

$$\text{Alcohol - Benzene Solubility },\% = 100 - \frac{(W_2 - W_1)}{W_2} \times 100$$

W_2 - Stands for O.D. weight of the sample before extraction, **g**

W_1 - Stands for O.D. weight of the sample after extraction,**g**

3.5.2 Cold-water solubility

2.0 g (O.D) samples of wood dust were placed into 500 ml flat bottom flasks with 300 ml of distilled water. The flasks were kept at room temperature for 48 hours. Samples were then filtered by vacuum suction into G2 glass crucibles of known weight. The residues were washed with distilled water. The crucibles were oven-dried at 105 ± 2°C for overnight. Crucibles were then cooled in a desiccator and weighed until a constant weight was obtained. The following formula was used to obtain the cold water solubility as,

$$\text{Cold Water Solubility },\% = \frac{(W_1 - W_2)}{W_1} \times 100$$

W_1 =initial weight of the test specimen, **g** oven dry (O.D)

W_2= weight of test specimen after extraction, **g** (O.D)

3.5.3 N/10 NaOH solubility

2.0 g (O.D) samples of wood dust were placed into 500 ml flat bottom flasks with 300 ml of N/10 NaOH solution. Fix the condenser and boil the mixture in the flask for one hour. Samples were then removed from the hot plate and filtered by vacuum suction into G2 glass crucibles of known weight. The residues were washed with distilled water. The crucibles were oven-dried at 105 ± 2°C for overnight. Crucibles were then cooled in a desiccator and weighed until a constant weight was obtained. Calculate the percentage N/10 NaOH solubility as follow:

$$\text{N/10 NaOH Solubility },\% = \frac{(W_1 - W_2)}{W_1} \times 100$$

W_1 =oven-dry weight of the test specimen before extraction, **g**

W_2= oven-dry weight of the test specimen after extraction, **g**

3.5.4 Holo-cellulose estimation

2.5 g (O. D.) extractive-free samples of wood dust were placed into 250 ml flasks with small watch glass covers. The samples were then treated with 80 ml of distilled water, 0.5 ml of cold glacial acetic acid, and one gram of $NaClO_2$.The flasks were then placed into a water bath maintained between 70°- 80°C. Every hour for three hours 0.5 ml of cold glacial acetic acid and 1.0 g of $NaClO_2$ were added and the contents of the flasks were stirred constantly. At the end of three hours, the flasks were cooled until the temperature of the flasks was reduced to 25°C. The contents of the flasks were filtered into G-2 glass crucibles of known weight followed by recycling. The residues were washed with acetone. The crucibles were then oven-dried at 105 ± 2°C, then cooled in a desiccator, and weighed until a constant weight was reached. The following formula was used to determine the holo-cellulose content *Eucalyptus* and *Subabul*:

$$\text{Holo - cellulose, } \% = \frac{W_1}{W_2} \times 100$$

W_1=weight of holo-cellulose, **g**

W_2=weight of test specimen, **g** moisture-free

3.5.5 Klason lignin

1.0 g oven-dried extractive-free dusts were placed in 100 ml beakers. 15 ml of cold sulfuric acid (72%) was added slowly in each beaker while stirring and mixed well. The reaction proceeded for two hours with frequent stirring. When the two hours had expired, the specimens were transferred by washing it with 560 ml of distilled water into 2,000 ml flasks, diluting the concentration of the sulfuric acid to three percent. The flasks were placed on hot plates for four hours. The flasks were then removed from the hot plates and the insoluble materials were allowed to settle. The contents of the flasks were filtered by vacuum suction into G3 glass crucibles of known weight. The residues were washed with distilled water and then oven-dried at 105 ± 2°C. Crucibles were then cooled in a desiccator and weighed until a constant weight was obtained. The following formula was used to obtain the klason lignin content in *Eucalyptus* and *Subabul*:

$$\text{lignin,\%} = 100 - \frac{(W_2 - W_1)}{W_2} \times 100$$

W_1 - Stands for O.D. weight of the sample after extraction, **g**

W_2 - Stands for O.D. weight of the sample before extraction, **g**

3.5.6 Ash content

Empty crucibles were ignited in the muffle furnace upto 575°±25°C until constant weight reach. After ignition crucibles were placed in a desiccator. When cooled to room temperature weighed the crucibles on the analytical balance. 2.0 g (O.D) samples of *Eucalyptus* and *Subabul* were placed in the crucible. Crucibles with contents were placed in the muffle furnace and ignite for 3 hours. The temperature of final ignition was 575°±25°C. Removed the crucibles with its contents to a desiccator, replaced the cover loosely, cooled and weighed accurately. Calculate the ash content as follows:

$$\text{Ash,\%} = \frac{W_1}{W_2} \times 100$$

W_1=weight of ash, **g**

W_2=weight of test specimen, **g** moisture-free

3.5.7 Basic density

The basic density of wood samples was determined using the water displacement method (TAPPI 258-om-16).

3.6 Pulp wood evaluation from different developed clones

Pulpwood is variable in structure. Structural differences in wood are encountered from species to species and even between various clones of the same species. The pulping process separates the wood into its individual components and paper is formed from cellulose matted together. Paper industry needs pulpwood of uniform quality as an important factor related to the efficiency of process system. The pulping conditions are shown detail in the **Table 6**.

Table 6 : General pulping conditions

Sl. No.	Particulars	Unit	Value
1	Sulfidity of white liquor	%	25
2	Bath ratio	-	1:3
3	Time to temperature (50 -165ºC)	hr.	2
4	Time at temperature. (165ºC)	hr.	1.13
5	H - factor	-	850

3.6.1 Active Alkali

Pulping converts wood chips into separate fibres by the chemical reaction between lignin and the active chemicals in the cooking liquor, NaOH and Na_2S (expressed as Na_2O). Active alkali was supplied to obtain kappa 18 and the liquor/wood ratio was 3: 1.

3.6.2 Kappa Number

For comparative purposes, all species were cooked to a comparable grade of pulp by the kraft process (Kappa number range of 17-18).It is a measure of the lignin content (bleach ability) of pulp, hardness and degree of delignification. It is the volume (in ml) on 0.1 N Potassium permanganate solution consumed by 1.0 gm of moisture free pulp.

3.6.3 Screened yield

This is the percentage of unbleached pulp obtained from moisture-free chips. It is obtained by dividing the weight of dry unbleached pulp (after removing rejects) by the weight of the dry chips and multiplied by 100.

3.6.4 Rejects

In screening process, the pulp is separated from large shives, knots, dirt and other debris. The accept is the pulp. The uncooked and foreign materials separated from the pulp are called rejects. It is expressed as percentage of dry chips taken for pulping. The lower reject value is always preferable.

3.6.5 Delignification of pulp

In order to get the highest possible oxygen delignification(OD) degree in a two-stage OD system the temperature of the second reactor should be higher than that of the first reactor and the oxygen charge split into each reactor, although the alkaline medium can be wholly added in the front of the system. The selection of the temperature of the second reactor should be based on both the final Kappa number and brightness value of the resultant pulp. The two stage OD was conducted in a rotary autoclave under the general conditions given in Table 7.

Table 7 : General conditions of the laboratory two-stage oxygen delignification

S.No.	Oxygen delignification stage	1^{st} stage	2^{nd} stage
1	Consistency (%)	10	10
2	NaOH (%)	2.4	-
4	O_2 pressure(kg/cm^2)	7	3
5	Temperature(^oC)	90	100
6	Retention time(min.)	10	60

3.6.6 Bleaching

Two stages oxygen delignified pulp was used in the bleaching experiments. The **$A/D_O/E_{OP}/D_1$** bleaching sequences were followed in this study, which is used in JK Paper Mills Ltd. All the bleaching stages were carried out at 10 % pulp consistency. The general bleaching conditions and chemical doses are shown in Table 8.

3.6.7 Bleached yield

It is the percentage of dry bleached pulp obtained from dry chips. This is given by weight of the bleached pulp (OD basis) divided by the weight of the dry chips multiplied by 100. Higher brightness pulp with higher bleached yield preferred.

3.6.8 Brightness

Brightness is a commonly used industrial term for the value of reflectance factor when blue light is used at 457 nm wave length. Brightness values of pulp provide an excellent measure of the maximum whiteness that can be achieved.

3.6.9 Shrinkage

It is the amount of pulp lost during the bleaching process. It is calculated from the amount of pulp initially taken for bleaching and the final pulp produced. Minimum shrinkage value is acceptable.

3.6.10 Pulp fiber fractionation

A laboratory Bauer–MacNett classifier with screen sizes of 16, 30, 50,100 and 200 mesh was used to separate pulp fibers according to TAPPI T233-cm-06. For fibre separation, 10 g of pulp were disintegrated in 3000 mL of water and poured into the first chamber. A continuous flow of water passes through this chamber. The pulp, carried by the water flow, is consecutively collected in the screens. The fraction passing through the screen with the 200 mesh sieve was considered as fines. After 20 min of operation the flow of water was stopped and the three fractions were recovered and the content of each one was determined.

Table 8 : ECF bleaching conditions and chemicals dose

ECF Bleaching ($AD_O/EOP/D_1$)		
A Stage		
1	Consistency (%)	10
2	Temperature(°C)	80
3	H_2SO_4 (%)	2.5
4	Retention time(min.)	180
D_0 Stage		
1.	Consistency (%)	10
2.	Temperature(°C)	75
3.	Retention time (min.)	15
4.	ClO_2 applied as Cl_2 (%)	3.3
E_{op} Stage		
1.	Consistency(%)	10
2.	Temperature(°C)	85
3.	Retention time	90
4.	O_2 pressure(kg/cm2)	2
5.	NaOH(%)	1.5
6.	H_2O_2 on 100 % basis (%)	1
D_1 Stage		
1	Consistency (%)	10
2	Temperature(°C)	75
3	Retention time (min.)	180
4	ClO_2 applied as Cl_2 (%)	1.3
SO_2 washing		
1	SO_2 water (%)	0.1

3.6.11 Fiber morphology

Morphological measurements of pulp fiber were made before beating. The length and width of fiber were determined by putting pulp suspension at 0.03 consistency with the help of dropper at the centre of microscope slides. The microscope slide was moved horizontally and non-fibrous cells crossing the mark in the microscope eyepiece were counted.

3.6.12 Viscosity

It gives an indication of the average degree of polymerization of the cellulose. It also gives a relative indication of the degradation (decrease in cellulose molecular weight) resulting from the pulping and/or bleaching process.

4 Results and Discussion

4.1 Planting Materials

JKPM plantation & R&D wing has outsourced 130 gall resistant clone from Karnataka, Tamilnadu, Kerala Andhra Pradesh, Maharashtra and Odisha in 2011 and 2012. These base clones were planted in different soil and agro-climatic conditions for further selection of promising clones.

At age 2-3 years

At age 3-4 years

At age 4-5 years

Figure 1 : View of different age Eucalyptus tree at Rayagada trial plot

Figure 2 :Biomass & pulpwood yield analysis and sample collection from trial plot for chemical analysis and pulp evaluation

Figure 3 : Pulpwood sample collection (cutting and debarking) from trial plot

Table 9 : DBH (Diameter at Breast Height, 1.35m), tree height and biomass (O.D basis) per hectare of selected clones in different sites at age of 2-3 years

S.No.	Source	Clone	Species	DBH (cm)	Height (m)	Biomass(O.D basis) per Hectare (MT)
1	JKPM	CTA-7-2	*E. camaldulensis*	12.09	16.4	85
2	JKPM	CTA-8GS-3	*E. camaldulensis*	9.06	14.6	41
3	JKPM	CTA8-GS274	*E. camaldulensis*	9.50	15.3	47
4	JKPM	CTA9-22	*E. camaldulensis*	9.90	15.0	51
5	JKPM	CTA9-24	*E. camaldulensis*	9.20	14.0	45
6	JKPM	CTA10-2	*E. camaldulensis*	9.00	14.4	48
7	JKPM	KFRI-25	*E. camaldulensis*	8.90	15.4	43
8	JKPM	URO-1	*E.urophylla*	11.50	17.2	67
9	Laos	EC*ED	*E. camal X E.deglupta*	14.80	16.2	160
10	MPM	HPF-330	*E.urophylla X E. grandis*	10.50	15.7	55
11	MPM	MU8P	*E.pellita*	10.00	16.0	62
12	MPM	MPM26	*E. camaldulensis*	10.20	16.9	73
13	MPM	MPM44	*E. camaldulensis*	10.50	15.2	68
14	MPM	MPM225	*E. camaldulensis*	11.30	16.0	77
15	MPM	MPM325	*E. camaldulensis*	10.20	14.9	54
16	IFGTB	IFGTB4	*E. camaldulensis*	11.30	16.7	71
17	ITC	clone2	*E.tereticornis*	9.50	17.6	54
18	ITC	clone7	*E.tereticornis*	9.50	15.0	44
19	ITC	clone288	*E.tereticornis*	9.20	14.2	35
20	ITC	clone7526	*E. camaldulensis*	9.90	16.0	48
21	ITC	JK2135	*E. Hybrid*	10.70	17.7	75
22	CPM	SRO16	*E. camaldulensis*	10.20	15.8	59
23	JKPM	CTA7-270	*E.tereticornis*	9.50	16.3	57
24	JKPM	CTA8-GS8	*E.tereticornis*	9.50	16.5	64
25	JKPM	CTA8-GS5	*E. camaldulensis*	10.50	15.2	58
26	CPM	Subabul11	*Leucaena leucocephala*	10.50	13.2	68
27	CPM	Subabul16	*Leucaena leucocephala*	9.20	12.6	46

Table 10 : DBH (Diameter at Breast Height, 1.35m), tree height and biomass (O.D basis) per hectare of selected clones in different sites at age of 3-4 years

S.No.	Source	Clone	Species	DBH (cm)	Height (m)	Biomass(O.D basis) per Hectare (MT)
1	JKPM	CTA-7-2	*E. camaldulensis*	12.6	18.0	94
2	JKPM	CTA-8GS-3	*E. camaldulensis*	10.0	16.3	45
3	JKPM	CTA8-GS274	*E. camaldulensis*	9.40	15.7	52
4	JKPM	CTA9-22	*E. camaldulensis*	12.3	18.7	57
5	JKPM	CTA9-24	*E. camaldulensis*	11.2	15.6	50
6	JKPM	CTA10-2	*E. camaldulensis*	11.6	17.3	53
7	JKPM	KFRI-25	*E. camaldulensis*	10.1	17.0	48
8	JKPM	URO-1	*E.urophylla*	11.9	18.2	74
9	Laos	EC*ED	*E. camal X E.deglupta*	16.0	18.4	178
10	MPM	HPF-330	*E.urophylla X E. grandis*	11.1	16.0	61
11	MPM	MU8P	*E.pellita*	12.1	18.6	69
12	MPM	MPM26	*E. camaldulensis*	11.5	19.0	81
13	MPM	MPM44	*E. camaldulensis*	12.0	16.2	75
14	MPM	MPM225	*E. camaldulensis*	13.0	16.8	86
15	MPM	MPM325	*E. camaldulensis*	12.2	16.0	60
16	IFGTB	IFGTB4	*E. camaldulensis*	12.5	17.9	79
17	ITC	clone2	*E.tereticornis*	11.3	18.5	59
18	ITC	clone7	*E.tereticornis*	10.0	18.5	49
19	ITC	clone288	*E.tereticornis*	12.3	18.1	39
20	ITC	clone7526	*E. camaldulensis*	13.4	16.1	54
21	ITC	JK2135	*E. Hybrid*	12.7	19.5	83
22	CPM	SRO16	*E. camaldulensis*	11.6	16.0	65
23	JKPM	CTA7-270	*E.tereticornis*	11.7	18.6	63
24	JKPM	CTA8-GS8	*E.tereticornis*	11.5	17.2	71
25	JKPM	CTA8-GS5	*E. camaldulensis*	11.7	17.7	64
26	CPM	Subabul11	*Leucaena leucocephala*	10.2	12.9	75
27	CPM	Subabul16	*Leucaena leucocephala*	11.1	14.7	51

Table 11 : DBH (Diameter at Breast Height, 1.35m), tree height and biomass (O.D basis) per hectare of selected clones in different sites at age of 4-5 years

S.No.	Source	Clone	Species	DBH (cm)	Height (m)	Biomass(O.D basis) per Hectare (MT)
1	JKPM	CTA-7-2	*E. camaldulensis*	15.9	20.4	219
2	JKPM	CTA-8GS-3	*E. camaldulensis*	13.7	20.0	147
3	JKPM	CTA8-GS274	*E. camaldulensis*	12.9	19.2	154
4	JKPM	CTA9-22	*E. camaldulensis*	15.8	19.2	215
5	JKPM	CTA9-24	*E. camaldulensis*	13.7	20.0	168
6	JKPM	CTA10-2	*E. camaldulensis*	14.2	18.0	130
7	JKPM	KFRI-25	*E. camaldulensis*	12.7	18.8	123
8	JKPM	URO-1	*E.urophylla*	13.7	19.0	119
9	Laos	EC*ED	*E. camal X E.deglupta*	17.8	19.8	246
10	MPM	HPF-330	*E.urophylla X E. grandis*	13.8	19.6	125
11	MPM	MU8P	*E.pellita*	14.5	20.7	167
12	MPM	MPM26	*E. camaldulensis*	15.8	21.9	238
13	MPM	MPM44	*E. camaldulensis*	15.6	19.5	183
14	MPM	MPM225	*E. camaldulensis*	16.9	20.0	210
15	MPM	MPM325	*E. camaldulensis*	15.0	18.8	145
16	IFGTB	IFGTB4	*E. camaldulensis*	16.4	20.6	187
17	ITC	clone2	*E.tereticornis*	17.8	20.5	205
18	ITC	clone7	*E.tereticornis*	15.4	20.3	146
19	ITC	clone288	*E.tereticornis*	15.6	21.5	195
20	ITC	clone7526	*E. camaldulensis*	16.4	19.1	206
21	ITC	JK2135	*E. Hybrid*	15.4	21.4	222
22	CPM	SRO16	*E. camaldulensis*	15.4	18.8	172
23	JKPM	CTA7-270	*E.tereticornis*	14.8	21.4	186
24	JKPM	CTA8-GS8	*E.tereticornis*	16.1	22.6	242
25	JKPM	CTA8-GS5	*E. camaldulensis*	15.0	20.5	170
26	CPM	Subabul11	*Leucaena leucocephala*	15.1	16.9	153
27	CPM	Subabul16	*Leucaena leucocephala*	17.0	15.2	190

Based on the observation of Tree Height and DBH (Diameter at Breast height) 79 clones planted at JKPM campus in September 2013 for further selection. These 79 clones were raised in line planting. 40 plants of each clone planted in a single row / line in the plot. The spacing of clonal trial was 3x1.5 m. The soil of the plantation site was sandy loam. 27 clones selected for the study. The details of clones are given in Table 9 to Table 11 along with twenty five Eucalyptus clones and two Subabul clones from Gujarat were introduced and plantations raised from 2014 onwards by JKPM Plantation Department.

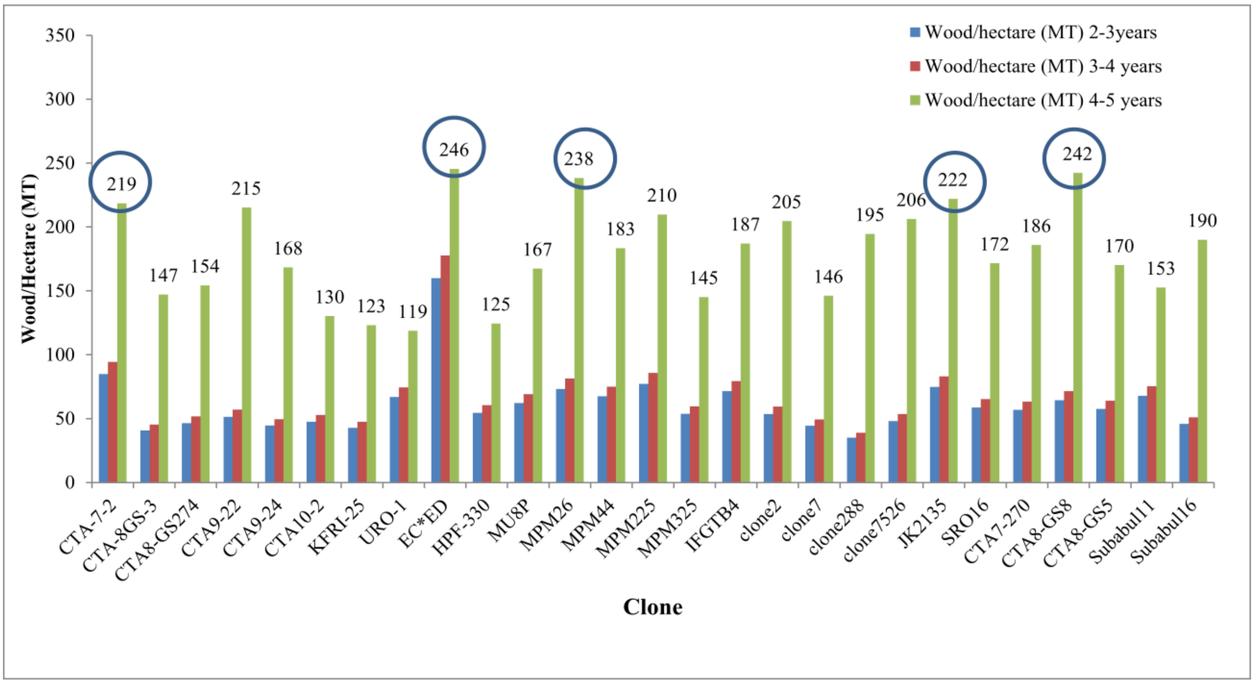

Figure 4 : Over all wood (O D Basis) production per hectare at age 2-3, 3-4 and 4-5 years

The basic wood properties show major impact on pulp quality and the cost associated with pulp production. Frequently, accounting data which looks at green tons of wood across the mill scales and the tons of pulp produced suggests that the pulp mill has impacted the pulp yield because the tons of purchased wood divided by the tons of pulp produced changes. A higher pulpable wood observed mainly in increasing with age. It is found that the eucalyptus clone namely, CTA-7-2, ECxED, MPM26, JK2135 and CTA8-GS8 produced high pulpwood per hectare (shown in Figure 4). In general, growth and branch quality clones presented moderate to high broad and narrow sense heritabilities, which indicates that significant genetic gains could be achieved for these clones through selection, although additional gains could be captured through vegetative multiplication.

4.2 Chemical Characterization of Eucalyptus and Subabul clone

Proximate chemical analysis was carried out for *Eucalyptus* and *Subabul* clone samples. The results of proximate chemical analysis are given in Table 12. Water solubles indicate the presence of inorganic compounds, tannins, gums, sugars and coloring materials in the cellulosic raw materials. Both cold and hot water extractives are more in *Eucalyptus* and *Subabul* as shown in Table 11. It indicates that *Eucalyptus* and *Subabul* require slightly more alkali to solubilize extractives. Wood chips with a hot-water soluble content exceeding 7 to 8% (as seen with *Eucalyptus* and *Subabul* in this study) result in obstruction of delignification due to competition of extractives with lignin for active cooking chemicals during pulping [18].The low molecular weight carbohydrates, which are dissolved in N/10 NaOH solution, approximate the N/10 NaOH solubility. N/10 NaOH solubles (max.20.8%) are more in *Eucalyptus* and *Subabul*. Therefore, *Eucalyptus* and *Subabul* can't store more than three months due to degradation caused by the exposure to heat, solar radiation and fungal attack [19]. Thus, *Eucalyptus* and *Subabul* stored for a longer period after harvesting much adverse effect on pulp yield.

The alcohol-benzene solubles are more in *Eucalyptus* and *Subabul* are more resinous and enriched with substances like waxes, fats, flavanoids, phytosterols, non-volatile hydrocarbons, low-molecular-weight carbohydrates, salts, and other water-soluble compounds. These substances are converted into pitch during pulping and are carried over with the pulp, thereby affecting the runnability of paper machine adversely. Choking of Fourdrinier wire increases the moisture carry over after couch roll and this requires more retention time on press and dryer parts to get desired dryness at pope reel. It also affects the quality of paper due to shadow marking.

The holo-cellulose content is more in *Eucalyptus* and *Subabul*. The presence of holo-cellulose content in fibers helps in improving the overall strength of the paper. α–Cellulose is that portion of cellulose which is insoluble in 17.5% NaOH solution and it represents the long chain part of cellulose polymer .α–cellulose is more in *Eucalyptus* compared to *Subabul* (42.35%). It means that the pulp produced by *Eucalyptus* will be stronger compared to *Subabul*. Raw materials having 34% α–cellulose contents or higher have been characterized as promising raw materials for pulp and papermaking.

The consumption of cooking liquor and total time required for pulping depends upon amount of lignin present in wood. The higher the lignin content in wood fibers, the greater will be the stiffness of the cellulosic fibers. Pulp hardness, bleachability of pulp and other pulp properties such as colour, are also associated with the lignin content. *Eucalyptus* contains lower lignin content (21.8%) compared to *Subabul* (28.8%). It indicates that *Eucalyptus* requires shorter cooking cycle (less cooking chemicals, low temperature and minimum cooking time) to produces chemical grade pulp compared to S*ubabul.* The ash content in all the three hardwoods varies from 0.24 to 0.31%.

Proximate chemical composition and Fiber characteristics of *Eucalyptus* and *Subabul* have been studied in this research work to assess their suitability for paper production. Based on the analysis results of proximate chemical composition and Fiber characteristics of *Eucalyptus* and *Subabul*, it may say that it has good potential as a pulping material. *Eucalyptus* and *Subabul* are better in utilization, because of its higher specific gravity, better Fiber length and its distribution, higher wall/lumen ratio. *Eucalyptus* and *Subabul* are more suitable for the papermaking.

Table 12: Proximate chemical analysis of Eucalyptus and Subabul clone samples

S. No	Parameter	Unit		CTA-7-2	CTA-8GS-3	CTA8-GS274	CTA9-22	CTA9-24	CTA10-2
1.	Cold water solubility	**%**	Age 2-3 years	2.10	1.00	1.60	1.30	1.70	1.00
			Age 3-4 years	0.89	0.61	3.45	0.31	0.19	0.81
			Age 4-5 years	0.90	0.72	3.71	1.15	0.83	3.75
2.	Hot water solubility	**%**	Age 2-3 years	3.00	1.50	2.40	3.20	4.40	2.20
			Age 3-4 years	1.30	1.70	1.20	1.60	1.70	1.60
			Age 4-5 years	5.62	2.84	8.56	3.07	4.24	7.46
3.	Alcohol benzene	**%**	Age 2-3 years	2.10	2.20	2.50	3.00	2.30	3.30
			Age 3-4 years	1.70	1.10	1.30	1.40	1.20	2.10
			Age 4-5 years	1.20	2.30	1.96	1.62	1.65	1.81
4.	N/10 Solubility	**%**	Age 2-3 years	11.80	13.10	16.80	12.50	14.70	16.50
			Age 3-4 years	13.60	14.80	13.70	12.70	14.10	19.00
			Age 4-5 years	12.70	17.90	13.70	11.20	16.70	13.50
5.	Ash content	**%**	Age 2-3 years	0.60	0.60	0.70	0.60	0.70	0.80
			Age 3-4 years	0.50	0.58	0.63	0.60	0.56	0.65
			Age 4-5 years	0.48	0.57	0.73	0.61	0.56	0.56
6.	Lignin content	**%**	Age 2-3 years	26.40	27.20	24.50	28.30	31.00	28.60
			Age 3-4 years	28.60	27.50	28.10	29.00	27.70	29.00
			Age 4-5 years	25.70	29.80	28.40	28.80	28.50	29.10
7.	Holo cellulose	**%**	Age 2-3 years	82.00	79.10	77.10	78.10	80.20	79.00
			Age 3-4 years	80.80	80.30	79.30	79.80	78.00	77.30
			Age 4-5 years	76.70	72.20	73.50	73.40	70.00	72.80
8.	Basic density	Kg/m^3	Age 2-3 years	425.00	455.50	425.00	469.00	455.50	425.00
			Age 3-4 years	571.00	488.00	500.00	513.00	465.00	455.00
			Age 4-5 years	541.00	472.00	506.00	472.00	519.00	462.00

Continue…

S. No	Parameter	Unit		KFRI-25	URO-1	EC*ED	HPF-330	MU8P	MPM26
1.	Cold water solubility	**%**	Age 2-3 years	0.30	0.20	2.58	1.30	0.80	1.00
			Age 3-4 years	0.68	0.58	2.85	0.54	0.31	0.39
			Age 4-5 years	1.51	1.41	1.98	0.21	2.29	1.92
2.	Hot water solubility	**%**	Age 2-3 years	2.70	1.90	5.57	3.20	2.70	2.20
			Age 3-4 years	2.00	1.20	3.47	1.84	1.26	1.72
			Age 4-5 years	6.32	5.52	5.59	4.22	8.97	3.26
3.	Alcohol benzene	**%**	Age 2-3 years	1.90	2.70	2.02	3.00	3.10	3.30
			Age 3-4 years	1.90	2.60	1.53	1.37	2.53	1.96
			Age 4-5 years	1.13	2.10	2.09	1.82	2.11	2.44
4.	N/10 Solubility	**%**	Age 2-3 years	14.70	16.20	14.42	12.50	15.40	16.50
			Age 3-4 years	14.30	17.10	15.20	16.00	14.40	13.30
			Age 4-5 years	13.00	18.10	19.50	14.60	14.80	11.40
5.	Ash content	**%**	Age 2-3 years	0.70	0.50	0.60	0.60	0.63	0.80
			Age 3-4 years	0.58	0.47	0.65	0.54	0.46	0.36
			Age 4-5 years	0.61	0.39	0.70	0.50	0.39	0.48
6.	Lignin content	**%**	Age 2-3 years	28.20	28.20	27.40	28.30	29.30	28.60
			Age 3-4 years	26.00	27.60	29.50	27.70	31.10	30.70
			Age 4-5 years	28.40	28.20	26.50	28.50	27.60	29.30
7.	Holo cellulose	**%**	Age 2-3 years	80.20	80.40	80.70	78.10	76.50	79.00
			Age 3-4 years	84.60	76.90	77.20	78.70	75.10	78.10
			Age 4-5 years	72.40	75.30	69.30	71.00	72.30	75.80
8.	Basic density	Kg/m^3	Age 2-3 years	488.20	500.00	415.00	469.00	455.50	425.00
			Age 3-4 years	465.00	426.00	420.40	437.36	466.10	482.00
			Age 4-5 years	462.00	391.00	405.00	433.00	450.00	468.00

Continue….

S. No	Parameter	Unit		MPM44	MPM225	MPM325	IFGTB4	clone2	clone7
1.	Cold water solubility	%	Age 2-3 years	0.75	1.80	0.75	0.33	0.43	0.46
			Age 3-4 years	0.67	0.27	0.32	1.09	0.43	0.8/3
			Age 4-5 years	1.21	2.19	3.54	1.26	2.78	0.44
2.	Hot water solubility	%	Age 2-3 years	1.70	1.30	1.00	0.90	1.50	2.00
			Age 3-4 years	1.39	1.04	2.54	1.63	1.50	1.33
			Age 4-5 years	3.52	7.23	5.23	7.51	7.35	5.11
3.	Alcohol benzene	%	Age 2-3 years	1.40	1.83	1.56	2.46	1.04	1.30
			Age 3-4 years	1.38	1.78	2.13	1.78	1.04	1.14
			Age 4-5 years	1.26	1.36	2.56	2.19	2.14	1.91
4.	N/10 Solubility	%	Age 2-3 years	14.00	14.60	12.50	18.50	11.70	14.20
			Age 3-4 years	10.20	13.20	14.90	12.30	11.70	13.10
			Age 4-5 years	14.70	13.80	16.90	14.70	19.80	12.40
5.	Ash content	%	Age 2-3 years	0.70	0.65	0.50	0.70	0.66	0.75
			Age 3-4 years	0.52	0.61	0.58	0.54	0.61	0.58
			Age 4-5 years	0.73	0.49	0.42	0.82	0.58	0.76
6.	Lignin content	%	Age 2-3 years	27.30	27.10	27.20	27.00	25.70	26.20
			Age 3-4 years	2.70	28.30	29.50	30.60	25.70	23.70
			Age 4-5 years	28.50	28.80	27.80	29.20	29.30	26.90
7.	Holo cellulose	%	Age 2-3 years	78.50	78.30	78.00	77.00	81.60	80.40
			Age 3-4 years	83.10	79.00	77.30	77.60	81.60	83.10
			Age 4-5 years	72.20	73.00	73.10	69.90	71.90	71.50
8.	Basic density	Kg/m^3	Age 2-3 years	414.30	478.00	512.00	461.00	431.00	453.00
			Age 3-4 years	476.50	460.90	463.30	438.00	601.00	484.60
			Age 4-5 years	450.00	462.00	490.00	474.00	449.00	492.00

Continue…

S. No	Parameter	Unit		clone288	clone7526	JK2135	SRO16	CTA7-270	CTA8-GS8
1.	Cold water solubility	**%**	Age 2-3 years	0.71	0.64	0.64	1.01	1.35	0.24
			Age 3-4 years	0.48	0.58	0.64	1.43	0.58	1.23
			Age 4-5 years	1.62	0.90	2.32	1.55	2.24	2.04
2.	Hot water solubility	**%**	Age 2-3 years	2.00	1.90	1.90	2.12	2.15	1.50
			Age 3-4 years	1.56	1.41	1.90	2.41	1.33	3.02
			Age 4-5 years	4.85	5.66	5.95	7.74	5.25	4.49
3.	Alcohol benzene	**%**	Age 2-3 years	1.82	1.78	1.36	1.25	1.94	1.37
			Age 3-4 years	1.84	1.58	1.36	1.46	1.42	1.95
			Age 4-5 years	2.01	3.46	1.26	1.74	1.94	1.99
4.	N/10 Solubility	**%**	Age 2-3 years	14.2	14.4	14.4	14.4	12.7	8.95
			Age 3-4 years	10.4	19.8	14.4	13.8	13.4	13.0
			Age 4-5 years	12.9	13.6	16.1	16.7	16.6	15.8
5.	Ash content	**%**	Age 2-3 years	0.75	0.56	0.56	0.92	0.82	0.54
			Age 3-4 years	0.50	0.64	0.54	0.73	0.81	0.60
			Age 4-5 years	0.58	0.63	0.72	0.68	0.52	0.48
6.	Lignin content	**%**	Age 2-3 years	26.2	28.2	28.0	27.4	29.4	30.6
			Age 3-4 years	30.0	30.3	28.0	23.7	27.9	31.9
			Age 4-5 years	26.8	28.2	28.4	29.6	27.0	28.2
7.	Holo cellulose	**%**	Age 2-3 years	81.4	80.3	78.2	80.2	79.3	77.3
			Age 3-4 years	77.4	80.2	78.2	79.0	80.9	77.1
			Age 4-5 years	74.2	71.4	73.7	70.4	74.4	78.5
8.	Basic density	Kg/m^3	Age 2-3 years	433	464	480	469	421	434
			Age 3-4 years	485	490	423	454	465	478
			Age 4-5 years	429	580	409	440	450	474

Continue …..

S. No	Parameter	Unit		CTA8-GS5	Subabul11	Subabul16
1.	Cold water solubility	**%**	Age 2-3 years	1.15	5.34	3.60
			Age 3-4 years	1.49	1.20	6.84
			Age 4-5 years	1.53	1.14	1.76
2.	Hot water solubility	**%**	Age 2-3 years	4.40	8.90	5.70
			Age 3-4 years	2.63	2.70	7.63
			Age 4-5 years	3.82	4.21	5.65
3.	Alcohol benzene	**%**	Age 2-3 years	1.97	3.98	3.13
			Age 3-4 years	0.62	4.71	4.75
			Age 4-5 years	1.72	2.87	2.66
4.	N/10 Solubility	**%**	Age 2-3 years	12.3	18.5	19.5
			Age 3-4 years	22.5	18.8	20.3
			Age 4-5 years	20.8	19.6	18.3
5.	Ash content	**%**	Age 2-3 years	0.74	0.90	1.14
			Age 3-4 years	0.82	0.80	0.42
			Age 4-5 years	0.32	2.11	1.64
6.	Lignin content	**%**	Age 2-3 years	30.8	26.1	26.7
			Age 3-4 years	28.4	26.0	29.0
			Age 4-5 years	28.7	27.3	26.4
7.	Holo cellulose	**%**	Age 2-3 years	75.3	75.8	77.5
			Age 3-4 years	79.8	77.9	76.5
			Age 4-5 years	72.0	72.7	73.3
8.	Basic density	Kg/m^3	Age 2-3 years	433	469	489
			Age 3-4 years	390	500	463
			Age 4-5 years	474	472	473

4.3 Pulping Studies

Pulping of eucalyptus and subabul clone samples were conducted in the laboratory digesters to produce kraft, pulp. The studies focused on optimization of different operating parameters viz. temperature, sulphidity, active alkali charge, cooking time, etc. The effects of different parameters on pulps of *Eucalyptus* and *Subabul* are discussed below.

4.3.1 Influence of temperature

Temperature is the important driving force for pulping reactions. Optimization of temperature during pulping is crucial as the pulping is not complete at low temperature whereas at high temperature, cellulose degradation is prominent. Therefore, optimization experiments were carried out for pulping over a temperature range 160-165 ºC for of eucalyptus and subabul clone samples.

The decrease in pulp yield may be explained based on depolymerisation mechanisms of carbohydrates degradation that can vary from pure endwise degradation to pure chain scission. The major contribution to the amount of degraded cellulose is caused by the endwise peeling reaction [20]. On the other hand, chain scission can lead to an increase in the number of chains with little or no weight loss. For wood carbohydrates, the nature of the degradation process lies between these two extremes.

Literature review showed that during pulping of lignocellulosic raw materials, residual lignin is difficult to remove without severe cellulose and hemicelluloses degradation resulting in drop of pulp strength. In the lignocellulosic raw materials, cellulose is contained at its highest percentage in the S2 layer (~50%), and lignin is mostly located in the middle lamella region (~90%), which in principle, is free of cellulose .Although, the reaction patterns have not been fully understood, most kinetic models describe delignification as the successive or simultaneous dissolution of three types of lignin present in wood from the beginning: initial, bulk, and residual lignin. Three distinct phases of delignification have been observed in most of the systems: an initial phase that involves the rapid removal of about 20% of the lignin, a slower stage of bulk delignification, and finally, an even slower residual delignification. Other researchers have also mentioned that in alkaline pulping, two sets of delignification reactions, termed as bulk and residual delignification having different velocity constants are involved. The fast process (bulk delignification) solubilizes on an average of 80% of the whole lignin dissolved, and this process occurs more rapidly at 100 ºC. The delignification is also associated with the solubilisation of significant amounts of hemicelluloses. Various research groups have reported that temperature of 165 ºC and cooking time of 90 min was found optimum for kraft pulping for variety of lignocellulosic raw materials. In this study, *Eucalyptus* and *Subabul* clone samples kraft pulping was conducted at 165 ^oC as optimum cooking temperature.

4.3.2 Influence of sulphidity

Sulphidity, the ratio of sodium sulphide (Na_2S) to active alkali in the cooking liquor, affects both cooking rate and pulp quality. However, critical low level of sulphidity is not defined and varies depending on other cooking parameters. The screened pulp yield increases upto a sulphidity level of 20% and beyond that there is a slight decrease in screened pulp yield. *Eucalyptus produces* a screened pulp yield of 45.4%, of kappa number 18 with screening rejects 0.90%. The improvement in screened pulp yield and reduction in kappa number during kraft pulping of *Eucalyptus* can be explained based on the principle that high sulphide content at the first stage of cooking improves both pulp quality and the selectivity of delignification. The maximum cooking time has relatively little influence upon the ratio of Klason lignin to carbohydrates solubilized during the course of kraft pulping. This supported the suggestion that during alkaline delignification of wood, there is a definite relationship between the solubilization of lignin and cellulosic portions. The studies conducted have shown that a sulphidity level varies 20- 22% for desired kappa number 17 to 18.

4.3.3 Influence of active alkali charge

Optimization of active alkali charge confirms that sufficient chemicals are available to carry the reactions upto completion. Pulping studies were conducted on eucalyptus and subabul *using* chemical charge 16-20%, while keeping other variables like maximum cooking temperature, maximum cooking time and H factor constant during kraft pulping .Studies have shown that for both *Eucalyptus* and *Subabul the* screened pulp yields obtained are 40 to 46% for kappa number 17-18.

4.3.4 Effect of cooking time

The studies showed that the maximum cooking time of 90 and 60 min may be considered as optimum cooking time for kraft pulping of *Eucalyptus* and *Subabul*.

Table 13 : Pulping analysis of Eucalyptus and Subabul clone samples at age 2-3 years

S.No.	Clone	Active alkali (as Na_2O), gpl	Kappa No.	Screen yield (%)	Reject (%)
1	CTA-7-2	16.50	17.70	47.00	0.99
2	CTA-8GS-3	16.64	18.00	47.73	0.68
3	CTA8-GS274	16.50	18.30	47.00	0.72
4	CTA9-22	17.50	17.00	44.64	1.76
5	CTA9-24	20.00	17.40	42.20	0.71
6	CTA10-2	18.00	17.10	44.06	1.34
7	KFRI-25	16.50	17.10	47.02	1.00
8	URO-1	17.50	18.00	48.40	0.50
9	EC*ED	19.00	17.40	45.90	0.64
10	HPF-330	19.00	17.00	47.07	0.01
11	MU8P	19.50	17.20	46.15	0.85
12	MPM26	18.50	17.00	48.80	0.54
13	MPM44	16.00	17.10	45.81	0.56
14	MPM225	18.00	17.00	46.22	0.87
15	MPM325	18.50	17.00	45.01	0.84
16	IFGTB4	18.00	17.90	45.60	0.95
17	clone2	18.00	17.10	54.70	1.39
18	clone7	17.00	17.20	48.40	0.52
19	clone288	18.00	17.00	46.10	1.18
20	clone7526	16.00	17.00	45.00	1.70
21	JK2135	18.00	18.40	46.90	1.32
22	SRO16	17.00	17.30	45.70	0.60
23	CTA7-270	19.50	17.80	44.10	1.50
24	CTA8-GS8	18.00	17.10	42.00	1.20
25	CTA8-GS5	20.50	17.30	43.25	1.11
26	Subabul11	22.00	18.00	41.90	1.80
27	Subabul16	22.00	18.00	46.54	1.08

Table 14 : Pulping analysis of Eucalyptus and Subabul clone samples at age 3-4 years

S.No.	Clone	Active alkali (as Na_2O)	Kappa no	Screen yield (%)	Reject (%)
1	CTA-7-2	18.0	18.0	47.8	0.7
2	CTA-8GS-3	21.0	17.1	46.9	0.4
3	CTA8-GS274	19.0	17.0	47.0	1.0
4	CTA9-22	19.0	18.0	47.5	0.7
5	CTA9-24	20.0	17.8	45.0	0.5
6	CTA10-2	18.5	17.4	45.4	1.8
7	KFRI-25	17.5	16.5	48.2	2.1
8	URO-1	19.0	18.0	48.7	1.4
9	EC*ED	19.0	17.6	45.6	0.2
10	HPF-330	19.5	17.9	48.7	1.8
11	MU8P	19.0	17.4	47.9	1.4
12	MPM26	19.0	17.6	48.0	1.6
13	MPM44	19.0	17.9	47.2	0.7
14	MPM225	20.5	17.5	46.9	0.8
15	MPM325	20.5	18.0	44.6	0.9
16	IFGTB4	19.0	17.8	43.9	0.9
17	clone2	17.0	16.1	49.8	1.3
18	clone7	17.0	17.1	49.4	1.1
19	clone288	18.5	17.6	47.0	1.5
20	clone7526	22.0	18.7	45.7	1.1
21	JK2135	18.5	17.4	46.0	1.5
22	SRO16	18.5	17.5	45.1	1.4
23	CTA7-270	19.0	17.8	48.6	0.8
24	CTA8-GS8	21.0	17.1	42.8	1.4
25	CTA8-GS5	22.0	18.5	43.8	1.3
26	Subabul11	22.0	21.6	43.3	1.6
27	Subabul16	22.0	19.1	42.4	1.9

Table 15 : Pulping analysis of Eucalyptus and Subabul clone samples at age 4-5 years

S.No.	Clone	Active alkali (as Na_2O)	Kappa No.	Screen yield (%)	Reject (%)
1	CTA-7-2	22	17.60	45.01	0.67
2	CTA-8GS-3	22	18.90	47.21	1.18
3	CTA8-GS274	21	17.20	44.98	0.89
4	CTA9-22	22	18.30	42.10	1.05
5	CTA9-24	22	20.20	46.82	1.80
6	CTA10-2	22	19.10	43.40	1.50
7	KFRI-25	22	18.30	43.54	1.22
8	URO-1	22	18.10	46.60	1.37
9	EC*ED	21	18.00	46.92	0.37
10	HPF-330	22	18.50	44.80	1.74
11	MU8P	22	19.10	44.50	1.00
12	MPM26	19.5	17.10	50.10	0.80
13	MPM44	20	17.30	45.10	1.40
14	MPM225	20	17.10	44.80	1.50
15	MPM325	22	18.00	44.44	0.94
16	IFGTB4	22	17.60	42.86	0.85
17	clone2	22	18.10	43.80	0.98
18	clone7	22	18.80	44.80	1.83
19	clone288	21	17.90	44.10	0.85
20	clone7526	21	17.30	45.06	1.09
21	JK2135	20	17.60	43.50	1.02
22	SRO16	22	18.30	44.63	1.61
23	CTA7-270	21	17.60	44.53	1.10
24	CTA8-GS8	20	17.40	48.72	1.57
25	CTA8-GS5	22	17.60	43.40	0.58
26	Subabul11	22	19.20	44.40	1.02
27	Subabul16	22	18.00	45.10	2.60

4.4 Bleaching Studies

In mill scale there are however normally differences in the number of bleaching stages for conventional and oxygen delignified pulps when bleaching to 90 %ISO brightness. Conventional pulps are mainly bleached in a five stages sequence with peroxide reinforcement in the alkaline stages, D (E_{OP}) D (EP) D. Oxygen delignified pulps are mainly bleached in a four stages sequence, D (E_{OP}) D D, especially softwood pulps. A three or four stages sequence, D (E_{OP}) D D or D (E_{OP}) D, is usually used when bleaching oxygen delignified *Eucalyptus* pulps. For brightness levels of 88 %ISO a three stages sequence can be used for oxygen delignified *Eucalyptus* and *Subabul* pulps.

Chlorine gas or hypochlorite bleaching is the traditional way of bleaching pulp. The method is efficient but has the drawback of producing harmful effluent. In aqueous solutions chlorine reacts with water and forms hypochlorous acid. Both chlorine and hypochlorous acid are oxidative components and react with aromatic compounds in the lignin via substitution reactions. After the chlorine substitution the lignin will become soluble in water, to a limited extent. But after introduction of hydroxide groups (NaOH) the solubility increases dramatically. The amount of chlorine determines the bleaching effect. Increased amounts of chlorine will also generate increased amounts of high chlorinated organic compounds, which is well known to have a negative impact on the environment.

Chlorine dioxide has high oxidation power and is used commercially for pulp bleaching. The reaction pattern is different from chlorine in the way that it has mainly addition reactions with aromatic lignin compounds. The amount of chlorinated organic compounds is only 20 % of what is found in chlorine bleaching but most important is that not high chlorinated toxic compounds are formed.

The ECF laboratory bleaching trials were carried out on both oxygen delignified *Eucalyptus* and *Subabul* clone pulps. The bleach chemical doses for bleaching the unbleached pulp are shown in **Table 7.** The charges of chlorine dioxide are calculated as active chlorine throughout this paper. The pulps were bleached to a final brightness of above 89% ISO, using optimum bleaching conditions and a typical three stages bleaching sequence.

Table 16 : Bleach pulp analysis of Eucalyptus and Subabul clone at age of 2-3 years

S.No.	Clone	Bleach yield (%)	Shrinkage (%)	Brightness (ISO%)	P.C. No.	Pulp viscosity (cps)
1	CTA-7-2	42.60	9.30	89.40	0.38	5.90
2	CTA-8GS-3	44.23	6.07	87.60	0.75	7.30
3	CTA8-GS274	43.10	8.80	89.80	0.31	5.90
4	CTA9-22	41.68	6.63	87.20	0.94	5.90
5	CTA9-24	38.50	9.07	89.10	0.23	6.00
6	CTA10-2	41.52	5.75	89.00	1.07	5.30
7	KFRI-25	43.75	6.94	88.10	0.85	6.30
8	URO-1	44.95	7.10	89.70	0.50	5.90
9	EC*ED	42.75	5.60	88.60	1.24	6.20
10	HPF-330	44.23	5.85	89.25	0.38	6.10
11	MU8P	43.70	5.30	88.70	1.60	7.20
12	MPM26	45.30	6.40	88.40	0.48	6.20
13	MPM44	42.69	6.80	88.90	1.07	7.90
14	MPM225	42.82	7.35	88.70	1.20	5.60
15	MPM325	42.22	6.19	89.00	0.90	6.30
16	IFGTB4	42.67	6.42	89.20	1.15	5.90
17	clone2	50.20	8.20	88.70	0.52	7.90
18	clone7	44.57	8.00	89.40	0.85	5.80
19	clone288	43.20	5.90	89.40	0.75	6.10
20	clone7526	42.10	6.50	88.70	0.58	5.80
21	JK2135	44.08	6.00	90.40	0.90	6.10
22	SRO16	42.90	6.05	89.20	0.40	5.20
23	CTA7-270	39.50	9.40	88.70	0.50	5.90
24	CTA8-GS8	39.20	6.65	88.20	0.25	5.80
25	CTA8-GS5	39.10	9.60	90.70	0.97	5.20
26	Subabul11	39.03	6.85	86.10	1.10	5.70
27	Subabul16	43.44	6.66	87.60	1.50	5.80

Table 17 :Bleach pulp analysis of Eucalyptus and Subabul clone at age of 3-4 years

S.No.	Clone	Bleach yield (%)	Shrinkage (%)	Brightness (ISO%)	P.C. No.	Pulp viscosity (cps)
1	CTA-7-2	44.56	6.76	89.20	1.14	6.30
2	CTA-8GS-3	44.20	5.80	88.10	0.52	8.80
3	CTA8-GS274	44.20	5.86	88.70	0.39	7.80
4	CTA9-22	44.70	5.80	88.30	0.79	5.60
5	CTA9-24	42.08	6.48	89.20	1.20	6.10
6	CTA10-2	41.65	8.25	88.80	0.42	9.10
7	KFRI-25	45.70	5.12	88.10	1.60	7.60
8	URO-1	46.20	5.00	87.40	0.59	8.50
9	EC*ED	40.43	11.50	87.10	0.58	7.20
10	HPF-330	43.00	10.40	89.70	0.35	8.70
11	MU8P	44.96	6.10	88.90	1.07	7.10
12	MPM26	43.97	8.45	88.90	0.35	8.70
13	MPM44	43.14	8.65	89.80	0.30	8.80
14	MPM225	42.56	9.25	90.10	0.30	8.60
15	MPM325	41.07	7.90	92.30	0.60	5.10
16	IFGTB4	40.70	7.25	89.00	0.48	8.70
17	clone2	46.40	6.80	90.70	1.20	6.00
18	clone7	44.90	9.02	89.60	0.52	8.70
19	clone288	43.47	7.50	88.90	0.50	9.10
20	clone7526	41.74	8.60	88.50	1.02	6.30
21	JK2135	41.40	10.00	90.20	0.52	8.70
22	SRO16	40.70	7.25	89.00	0.48	8.70
23	CTA7-270	44.09	9.27	89.10	0.48	8.90
24	CTA8-GS8	38.80	9.25	89.20	0.48	8.90
25	CTA8-GS5	40.00	8.60	90.00	0.51	7.90
26	Subabul11	39.77	8.11	86.50	1.50	7.00
27	Subabul16	40.20	5.10	87.10	0.58	8.20

Table 18 : Bleach pulp analysis of Eucalyptus and Subabul clone at age of 4-5 years

S.No.	**Clone**	Bleach yield (%)	Shrinkage (%)	Brightness (ISO %)	P.C. No.	Pulp viscosity (cps)
1	CTA-7-2	42.50	5.50	88.70	0.53	8.80
2	CTA-8GS-3	43.30	8.27	89.80	0.85	7.80
3	CTA8-GS274	41.93	6.78	88.60	5.20	8.60
4	CTA9-22	39.20	6.85	89.10	0.51	8.40
5	CTA9-24	43.10	7.95	89.20	0.91	7.40
6	CTA10-2	39.30	9.42	87.60	0.45	8.80
7	KFRI-25	40.36	7.30	90.57	0.44	7.80
8	URO-1	42.97	7.79	89.30	0.66	5.40
9	EC*ED	44.08	6.05	86.90	0.90	9.00
10	HPF-330	41.20	8.08	89.10	0.40	7.60
11	MU8P	41.50	6.65	88.70	0.51	8.80
12	MPM26	46.40	7.35	87.00	1.08	6.50
13	MPM44	41.70	7.50	89.20	0.52	8.90
14	MPM225	42.15	5.90	89.00	0.48	8.80
15	MPM325	41.24	7.18	87.60	1.10	7.70
16	IFGTB4	40.18	6.23	90.30	0.55	6.80
17	clone2	41.46	5.33	88.60	0.52	7.20
18	clone7	41.30	7.78	90.20	1.05	8.10
19	clone288	40.90	7.35	90.10	0.48	8.70
20	clone7526	42.00	6.81	91.80	0.78	6.60
21	JK2135	42.40	9.25	90.20	0.48	8.90
22	SRO16	41.23	7.60	88.10	0.90	7.20
23	CTA7-270	40.78	8.40	92.10	0.84	6.10
24	CTA8-GS8	44.84	7.96	89.90	0.80	6.80
25	CTA8-GS5	39.50	9.03	90.70	0.48	8.40
26	Subabul11	42.09	5.20	89.10	0.23	7.90
27	Subabul16	41.70	7.50	87.94	0.48	8.80

This study addressed the influence of pulping conditions on *Eucalyptus* kraft pulp yield, quality, and bleachability. The main conclusion was that pulps of highest bleachability are obtained by cooking at high residual alkali and temperature, whereas low residual alkali and temperature favors process yield and pulp quality.

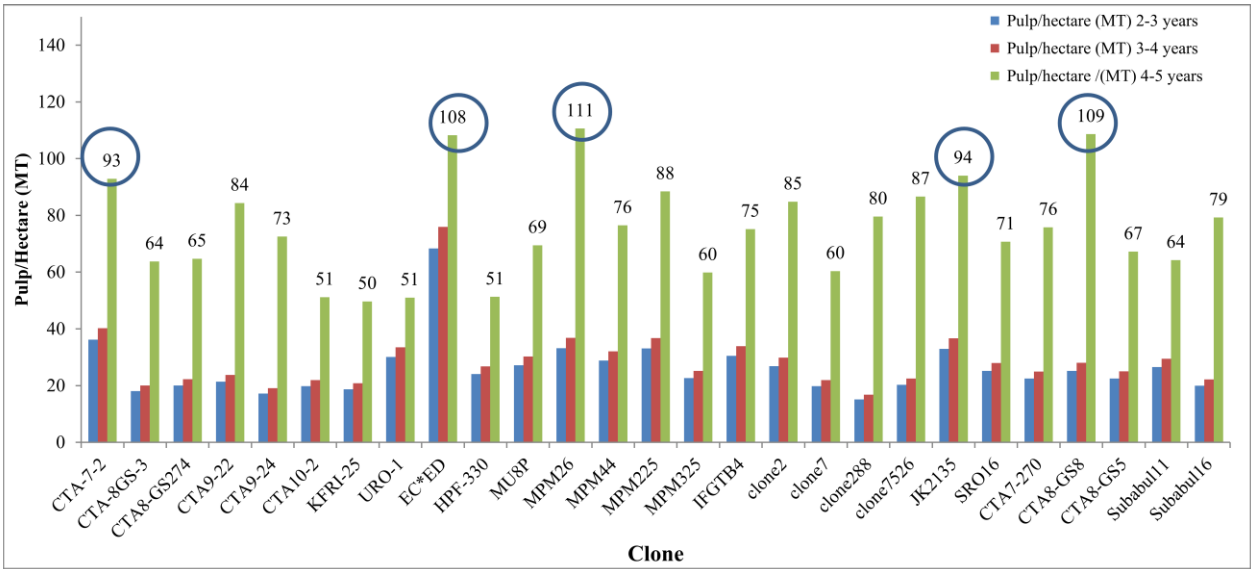

Figure 5 : Over all bleached pulp production per hectare at age 2-3, 3-4 and 4-5 years

pulping yield and pulp quality decrease pulp bleachability and *vice versa*. It is found that the eucalyptus clone namely, CTA-7-2, ECxED, MPM26, JK2135 and CTA8-GS8 produced high yield bleached pulp per hectare (see Figure 5).Proper manipulation of pulping conditions allows for the achievement of the most suitable process economics and pulp quality.

4.5 Fiber morphology

The average fiber length of *Eucalyptus* and *Subabul* is 1.03 mm and average fiber width 12.10 µm. The fibers are uniformly thick to thin-walled with gradually tapering pointed ends, smooth walls, narrow to wide lumen and very sparse slit-like pits. They are often bent, curved or folded and invariably show compressed, somewhat buckled areas with transverse markings, which stand out rather prominently in the thick-walled fibers. The walls sometimes may be as much as 10 µm thick, often showing a distinct multi-lamellated or multi-layered structure. Fiber length affects the tearing strength of paper. The greater the length of fiber, the higher will be the tearing strength of paper. Cell wall thickness of fibers is related to the fiber flexibility. The fibers thickness affects the bursting strength, tensile strength and double fold number of paper negatively. The reason is that thick-walled fibers when pressed after delignification tend to retain their tubular structure as such without forming double walled ribbon structure. In this way, they provide less surface contact area for bonding. Therefore, the paper made from thick-walled fibers will be porous, more opaque, bulky and coarse-surfaced with a large void volume.

5 Conclusions

The rise of India's large-scale pulp and paper sector to both domestic and global has been accompanied by important environmental benefits and societal impacts associated with raw material production from tree plantations. Plantations, strategically placed in the waste and barren land are recognized for their importance for sustainable production and improved soil, water quality and salinity mitigation, carbon and biodiversity benefits. Eucalyptus plantations with different cultivation years had significantly different soil quality and soil microbial community structure and diversity. In general, we can conclude that high-quality eucalyptus wood for kraft pulping should have a reasonably high density, low extractives and low lignin contents. This study also addressed the influence of pulping conditions on eucalyptus kraft pulp yield, quality, and bleachability. The main conclusions are that pulps of highest bleachability are obtained by cooking at high residual alkali and temperature, whereas low residual alkali and temperature favors process yield and pulp quality. Some more specific conclusions include:

- Specific wood consumption is more strongly influenced by wood density than by pulping yield.
- Pulping yield does not correlate well with any one wood property in isolation.
- Woods containing high quantities of lignin are harder to process during kraft pulping. Easily soluble lignin may reduce the needed alkali charge, temperature, and/or retention time. In such cases an increase in production (yield) and fiber quality is expected [21].
- Age significantly affects wood chemistry and morphology and its behavior in kraft pulping and pulp use.
- Eucalyptus hemicelluloses are composed mainly of a xylan unusually rich in uronic acids which is reasonably stable in kraft pulping.
- Xylans retain about half their molecular weight during kraft pulping.
- The xylans retained in the kraft pulps substantially improve their refinability.
- An increase in wood age and density increases fiber coarseness, which negatively affects pulp refinability, but increases pulp drainability.

Based on study of established clones of *Eucalyptus* and *Subabul* developed under this project, 5 clones of *Eucalyptus* have been shortlisted. It is found that the eucalyptus clone namely, CTA-7-2, ECxED, MPM26, JK2135 and CTA8-GS8 produced high pulpwood and bleached pulp per hectare. It will be possible to achieve multi-fold increase in the yield of pulpwood plantation using the fast growing clones developed under this project. Ultimately this will help not only the industry in meeting their raw material requirement but also make the tree cultivation more remunerative for the farmers.

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