ANATOMICAL, MORPHOLOGICAL, AND CHEMICAL CHARACTERIZATION OF *BAMBUSA TULDA*, *DENDROCALAMUS HAMILTONII, BAMBUSA BALCOOA, MALOCANA BACCIFERA, BAMBUSA ARUNDINACEA* AND *EUCALYPTUS TERETICORNIS*

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Due to scarcity of cellulosic wood fibers five bamboo species, namely *B. tulda, D. hamiltonii, B. balcooa, M. baccifera,* and *B. arundinacea*, and two eucalyptus species, namely *E. tereticornis* and *E. grandis*, were grown under North Indian climatic conditions in order to sustain fiber supply through social forestry. After four years of cultivation, these cellulosic raw materials were evaluated for anatomical structures, fibre dimensions, chemical characterization, and pulp and paper making characteristics. *B. balcooa* and *M. baccifera* contained higher holocellulose and α-cellulose contents compared to other bamboo species and lower ash contents, indicating that they are likely to pose less problem during chemical recovery. *E. grandis* contained higher holocellulose, α-cellulose, and lower lignin contents than that of *E. tereticornis*. Morphologically, bamboo species did not show much difference in fiber dimensions and their derived values. *E. grandis* showed problems of kink and curl due to longer fiber length than *E. tereticornis.* Based on pulp yield, brightness, and pulp viscosity *B. balcooa*, *M. baccifera* and *E. grandis* are better options for social forestry among other species.

Keywords: Bamboo species; E. tereticornis; Anatomy; Morphology; Proximate chemical analysis; Pulp and paper

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Abbreviations: SEM= Scanning electron microscopy, C= Chlorination, E= Alkali extraction stage, H= Hypochlorite stage, D= Chlorine dioxide, EDTA= Ethylene diamine tetra acetic acid, DTPA= Dithylene triamine penta acetic acid, T.S.= Transverse section, CED= Cupriethylenediamine

INTRODUCTION

The search for new alternative sources of cellulosic fibers has been underway for a long time due to the shrinking of forest resources. In order to bridge over the extended gap between demand and supply of pulp products as a consequence of scarcity of wood fiber, plans of actions have been put into effect to valorize various agricultural crops, for example in Tunisia (Gezguez et al. 2009; Khiari et al. 2010), India (Agnihotri et al. 2010; Dutt and Upadhyaya 1994; Dutt et al. 2004, 2005, 2007, 2008, 2009a,b, 2010a,b,c,d; Kaur et al. 2011; Singh et al. 2011; Tyagi et al. 2004), Iran (Hedjazi et al.

2008), and Sudan (Khristova et al. 2005) and fast growing hardwoods through social forestry, for example in India (Lal et al. 2010; Malik et al. 2004). Bob Flynn, Director, International Timber, RISI, stated in Brussels (Viewpoint) in 2007 that forest cover in India is reported to be 67.8 million ha, or 20.6% of the country's surface area, which translates into a per capita forest area of only 0.8 ha/person, one of the lowest in the world. Total fibre consumption for the production of paper and paperboard in India will nearly be doubled between 2006 and 2016, growing from 7.4 to 13.7 million tonnes. India's total wood fibre deficit is forecast to increase at an annual rate 11.3% by 2016 (Flyn 2007). The present work aims at cultivating different bamboo species and *E. tereticornis* under north Indian topological conditions where most of the paper mills are located so that their plantation through social forestry may provide a sustainable supply of fibrous raw materials to the paper industry. The present studies include anatomical studies, fibre dimensions, chemical characterization, and pulping and paper making characteristics.

EXPERIMENTAL

Proximate Chemical Analysis

Five culms each of *B. tulda, D. hamiltonii, B. balcooa, M. baccifera,* and *B. arundinacea,* were collected from Forest Research Institute, Dehradun, and likewise *E. tereticornis* and *E. grandis* from ITC Bhadrachalam (AP). After four years of cultivation, the trunk was cut into three 4-m pieces from the base and was converted into chips in a laboratory chipper. From each part of the trunk, 25 g of wood chips were milled into powder in a laboratory Wiley mill and mixed. Mesh size 40/80 was used to fractionate ash (TAPPI T 244 cm-99 "Acid-insoluble ash in wood, pulp, paper, and paperboard), water solubility (TAPPI T 207 cm-99 "Water solubility of wood and pulp"), 1% NaOH soluble (TAPPI T 212 om-02 "One percent sodium hydroxide solubility of wood and pulp"), alcohol-benzene soluble (TAPPI T 204 cm-97 "Solvent extractives of wood and pulp"), pentosan (TAPPI T 223 cm-01 "Pentosan in wood and pulp"), holocellulose (TAPPI T 249 cm-00 "Carbohydrate composition of extractive-free wood and wood pulp by gas-liquid chromatography"), α-, β- and γ-cellulose (TAPPI T 203 cm-99 "α-, β- and γ-cellulose in pulp), and lignin (TAPPI T 222 om-02 "Acid-insoluble lignin in wood and pulp"). Some of the lignin dissolved in acid solution during the test known as acid-soluble lignin was determined in a solution, after filtering off the insoluble lignin, by a spectrophotometric method based on absorption of ultraviolet radiation (Anonymous 2007). The most often used wavelength is 205 nm (Schoening and Johansson 1965).

Anatomy, Fiber Morphology and Derived Wood Properties

Fiber length was determined by macerating the small slivers with 10 mL of 67% HNO_3 and boiled in a water bath at 100±2^{o}C for 10 min (Ogbonnaya et al. 1997). The slivers were then washed, placed in small flasks with 50 mL distilled water, and the fiber bundles were separated into individual fibers using a small mixer with a plastic end to avoid fiber cutting. The macerated fiber suspension was finally placed on a standard microscope glass slide (25 mm × 75 mm) by means of a medicine dropper of about 10 cm length and 8 mm internal diameter with one end fitted with a rubber bulb and the other carefully smoothened but not tapering. The tube was graduated to deliver 0.5 mL. All fiber samples were viewed under a calibrated microscope; a total of 25 randomly chosen fibers were measured from each sample for a total of 75 fiber measurements from each trunk. For fiber diameter, lumen diameter, and cell wall thickness determinations, cross-sections of 25 μm thickness were cut on Leitz base sladge microtome 1300 and were stained with 1:1 aniline sulphate–glycerine mixture to enhance cell wall visibility (cell walls retain a characteristic yellowish color). The detailed anatomical study of different species of bamboo and eucalyptus was carried out using scanning electron microscopy (SEM, Leo 435 VP, England). The cross sections were subjected for fixation using 3% (*v*/*v*) glutaraldehyde-2% (*v*/*v*) formaldehyde (4:1) for 24 h. Following the primary fixation, cross sections were washed thrice with double distilled water and then treated with alcohol gradients of 30%, 50%, 70%, 80%, 90% and absolute for dehydration and kept for 15 min each up to 70% alcohol gradient, thereafter treated for 30 min each for subsequent alcohol gradients. After treating with absolute alcohol, cross sections were air dried and examined under SEM using a gold shadowing technique (Gabriel 1982). Electron photomicrographs were taken at 15 kV using detector SE1 at desired magnifications.

A suspension of different species of bamboo and eucalyptus fibers (0.02% consistency) was used for detailed anatomical features including fiber length, fiber width, curl index, and kink index by using Hi-Resolution Fiber Quality Analyzer (Optest Equipment Inc. model: LDA 2002). The derived wood properties of Runkel ratio (2×fiber cell wall thickness/ lumen diameter) (Runkel 1949), Luce's shape factor [(fiber diameter^2−fibre lumen diameter^2)/ (fiber diameter^2 −fiber lumen diameter^2)] (Luce 1970), slenderness ratio (fiber length/fiber diameter) (Varghese et al. 1995), and solids factor [(fiber diameter^2−fibre lumen diameter^2)−fiber length)] (Barefoot et al. 1964) were calculated.

Pulping Studies

The logs of various bamboo species and debarked *E. tereticornis* were disintegrated individually into chips in a Vecoplan Chipper (Vecoplan LLC, High Point, North Carolina, USA) at Star Paper Mills Ltd., located in the vicinity of the institute. These chips were digested in WEVERK electrically heated rotary digester of 0.02 m^3 capacity having four bombs of one litre capacity, each by kraft pulping process at different cooking conditions, as mentioned in Table 3. After completion of cooking, the pulps were washed on a laboratory flat stationary screen having 300 mesh wire bottom for the removal of residual cooking chemicals. The pulp was disintegrated and screened through WEVERK vibratory flat screen with 0.15 mm slits and the screened pulp was washed, pressed and crumbled. The pulps were analyzed for kappa number (TAPPI T 236 cm-85 "Kappa number of pulp"), pulp yield and screening rejects as per TAPPI Standard Test Methods Anonymous, 2007).

Chemical Bleaching of Pulp

The unbleached kraft pulps of various bamboo species and *E. tereticornis* was bleached by CEHED bleaching sequence. The bleaching conditions are mentioned in

Table 3. The pulp was evaluated for brightness (TAPPI T452 om-02 "Brightness of pulp, paper and paperboard [Directional reflectance at 457 nm]"), (Anonymous 2007) and intrinsic viscosity (SCAN C-15:65 "CED viscosity of pulp") (Anonymous 2007).

RESULTS AND DISCUSSION

Proximate chemical analyses of various species of bamboo and eucalyptus are presented in Table 2 in order to assess their suitability for pulp and papermaking. The sample ignited at 525°C gives an estimation of oxides and residues, for which the highest sum was found in *B. tulda*, while it varied from 1.9 to 2.3 in the rest of the bamboo species. On the other hand, *E. tereticornis* contained only 0.45% ash content, compared to *E. grandis* (0.72%). High ash contents are undesirable for pulping, as they have an effect on normal alkali consumption and give problems during recovery of the cooking liquor (evaporation, combustion, and lime mud reburning) and operational problems in material handling, pulp washing, and pulp beating. Ash as trace elements interferes with H_2O_2 and O_2 delignification, and alkali earth metals pass onward as a component of the pulp (Dutt et al. 2009). The treatment with chelating agents such as DTPA or EDTA and $NaHSO_3$ (Q-stage) is quite effective for removing transition metals from kraft pulps (Gellerstedt and Pettersson 1982). The cold-water soluble treatment removes a part of extraneous components, such as inorganic compounds, tannins, gums, sugars, and colored matter present in wood and pulp, whereas the hot-water procedure removes, in addition, starches. The lowest amounts of cold and hot water soluble substances were found in *M. baccifera* compared to other bamboo species, and slightly more in *E. grandis* compared *to E. tereticornis.* The higher is the water solubility; the lower will be the pulp yield. The ethanol-benzene extractable content of the wood is a measure of such substances as waxes, fats, resins, photosterols, non-volatile hydrocarbons, low-molecular-weight carbohydrates, salts, and other water-soluble substances. In all the bamboo species and *E. tereticornis*, the alcohol benzene soluble portion was found to be between 2.1 to 3.02%.

Table 1. Proximate Chemical Analysis of Various Bamboo and Eucalyptus Species

Particulars, as weight %	*B. tulda*	*D. hamiltonii*	*B. balcooa*	*M. baccifera*	*B. aurandacea*	*E. grandis*	*E. tereticornis*
Ash	3.2	2.6	2.0	1.9	2.1	0.72	0.45
Cold water soluble	3.5	3.7	3.4	2.8	3.8	2.19	1.87
Hot water soluble	6.8	6.7	7.0	5.8	6.0	4.59	4.87
1/10N NaOH solubility	22.6	24.7	20.8	19.5	23.7	17.9	18.8
Alcohol: benzene soluble	2.3	2.3	2.6	2.4	2.5	2.89	3.02
Pentosan	15.9	16.0	16.9	16.2	16.7	16.8	15.8
Holocellulose	73.0	73.8	74.9	74.1	74.1	72.8	71.6
α-cellulose	47.0	45.1	47.2	47.0	44.9	44.3	42.1
β-cellulose	14.9	17.9	17.4	19.7	18.5	16.6	17.5
γ-cellulose	11.1	10.8	10.3	7.4	10.7	11.9	12.0
Acid soluble lignin	25.7	23.9	24.8	25.8	24.1	27.1	28.8
Acid insoluble lignin	0.90	0.84	1.03	1.0	0.76	0.71	0.89

Alcohol-benzene extractable substances can precipitate and retard drainage on a paper machine due to blocking of openings in a Fourdrinier wire and leaving stains in the resulting paper sheets. The 1/10N solubility was the lowest in *M. baccifera* and showed an increment of 1% in *B. balcooa*, 3% in *B. tulda*, 4% in *B. aurandacea*, and 5% in *D. hamiltonii* compared to *M. baccifera.* Likewise, *E. tereticornis* showed an increase of 1% solubility over *E. grandis.* Hot alkali solution extracts low-molecular-weight carbohydrates consisting mainly of hemicelluloses and degraded cellulose in wood and pulp, and it indicates the degree of a fungus decay or of degradation by heat, light, oxidation, etc. (Procter and Chow 1973). As the wood decays or degrades, the percentage of the alkali-soluble material increases, and it is directly related to the length of storage of a raw material in a wood yard. The solubility of pulp indicates the extent of cellulose degradation during pulping and bleaching processes and has been related to strength and other properties of pulp (Anderson 1937). Pentosan contents in all the bamboo and eucalyptus species showed a narrow difference. All the bamboo species contained α-cellulose at about 47%, except for *D. hamiltonii* and *B. aurandacea*, which showed α-cellulose contents in the vicinity of 45%, and *E. grandis* (44.3%) too. The lowest α-cellulose content was found in *E. tereticornis* (42.1%). According to the rating system designated by Nieschlag et al. (1960), plant materials with 34% and over α-cellulose content are characterized as promising for pulp and paper manufacture from a chemical composition point of view because the α-cellulose indicates undegraded, higher-molecular-weight cellulose content in pulp; the β-cellulose indicates degraded cellulose, and the γ-cellulose consists mainly of hemicelluloses. A pulp with high α-content generally shows better strength properties. Acid-soluble lignin contents in all the studied bamboo species varied from 23.9% to 25.8% and were observed to be 27.1 and 28.8% in *E. grandis* and *E. tereticornis*, respectively. Determination of lignin content in wood provides information about application of the processes, i.e. consumption of cooking liquor and completion of cooking cycle. Hardness, bleachability, and other pulp properties, such as color, are also associated with the lignin content. Some of the lignin dissolves in acid solution during the test along with carbohydrates; this ranged between 0.71 to 1% in all the bamboo and eucalyptus species.

Plate 1A shows that the conductive tissues in *B. tulda* are surrounded by a strong sheath of sclerenchyma cells, the xylem, and the phloem fibers, forming the characteristic shape of the vascular bundle. T.S. of *D. hamiltonii* shows small parenchymatous cells with lignified primary walls is forming the cortex tissue. The cortex zone functions as a supporting and protecting tissue, and gives additional rigidity to the stem (Plate1B). The sclerenchyma cells have a small diameter and a thick fiber wall with narrow lumen and represent a valuable source of fibers for the paper industry (Plate1C). In *M. baccifera* there is a dense tissue of sclerified parenchyma (sclerenchyma), which is characterized by a high degree of woodiness, making a rapid growth to considerable heights possible; this is the main strengthening elements in a bamboo stem (Plate1D). The most important cells are the tracheary elements. A strong sheath of sclerenchyma fibers surrounds the vascular cells shows an extra source of fibers in *B. arundacea* (Plate1E). Plates F (*E. grandis*) and G (*E. tereticornis*) show that vessel elements are surrounded by paranchymatous and lignified sclerenchymatous cells. Being thin-walled and highly perforated, the vessel elements are broken down to fragments in the pulping process. If the vessel is not well

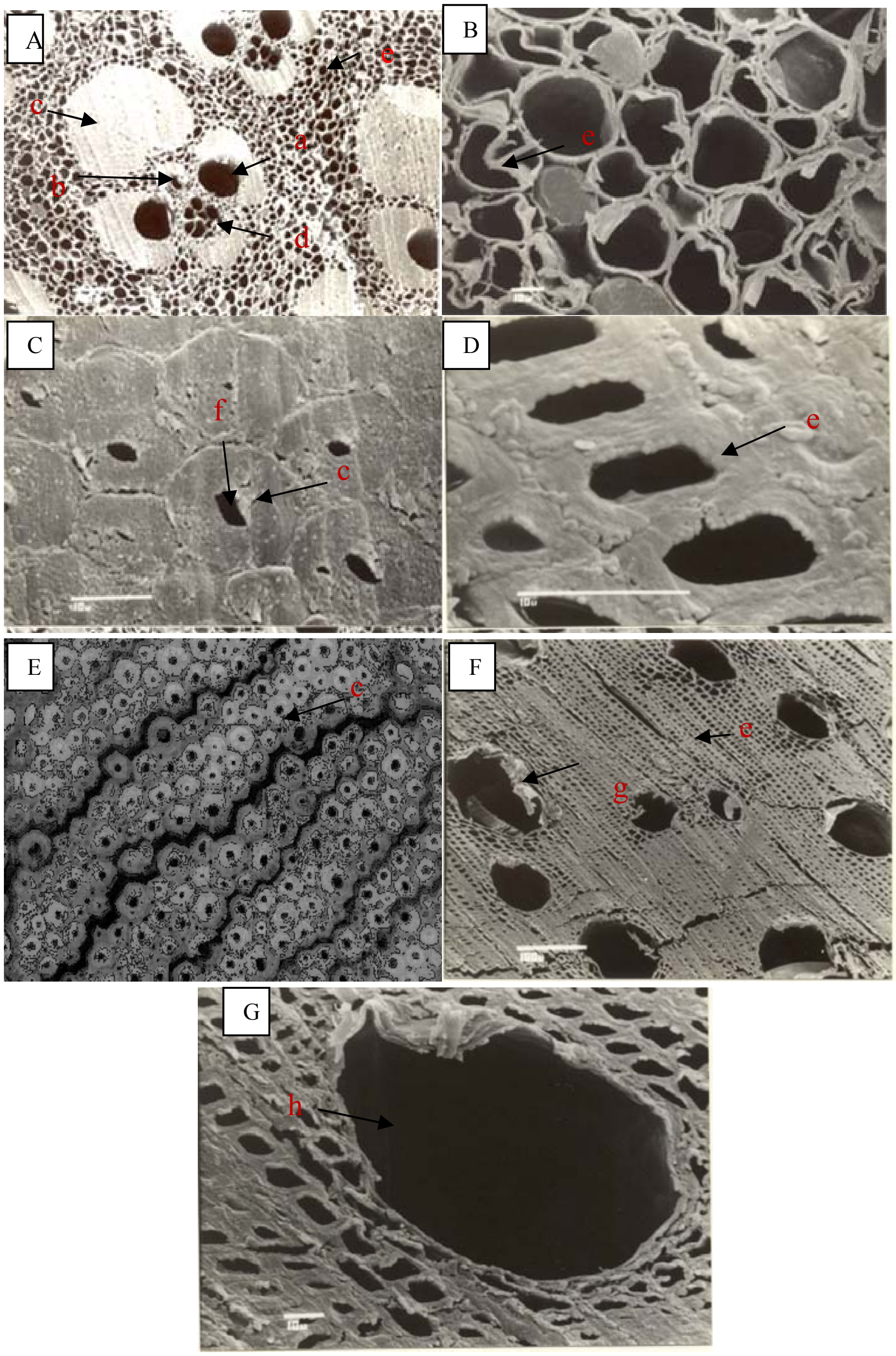

Plate 1. (A) T.S. of *B. tulda* stem showing vascular bundles surrounded by a sheath of sclerenchyama [1500X]; (B) Magnified view of parenchyma cells of *D. hamiltonii* [2000X]; (C) *B. balcooa* shows thick walled hexagonal sclerenchymatous cells [1000X]; (D) Sclerenchymatous cells of *M. baccifera* [500X]; (E) Sclerenchymatous cells of *B. aurandacea* [500X]; (F) Sclerenchymatous cells of *E. grandis* [2500X]; and (G) *E. tereticornis* shows vessel [4000X] (a=meta xylem, b= protoxylem, c=sclerenchymatous cells, d= phloem cells, e= parenchyma cells, F= fiber lumen, g= vessel, h= magnified view of vessel).

bonded to the base sheet, then a pick-out can occur during offset printing. The ability of any fiber or vessel to collapse is controlled by its lumen-to-fiber-diameter ratio. Wood density affects this ratio. The vessel picking problems are influenced by vessel width, length, and numbers per unit weight.

The highest fiber length (weighted) was found in the case of *B. balcooa*, while *B. tulda*, *D. hamiltonii*, *M. baccifera*, and *B. arundacea* showed slight increase in fiber length. In contrast to this, fiber length (by number) was found to be highest in case of *B. tulda*, whereas *D. hamiltonii*, *M. baccifera*, *B. balcooa*, and *B. arundacea* showed similarities in fiber length. On the other hand, the fibers of *E. grandis* are longer both by weight as well as by number than those of *E. tereticornis*. Fiber length generally influences the tearing strength of paper. The greater the fiber length, the higher will be the tearing resistance of paper. Lumen diameter and cell wall thickness showed variations from 3.31 to 3.84 μm and 6.75 to 7.16 μm, respectively (Table 2). The fibers of *E. grandis* are wider and thick walled compared to *E. tereticornis*. Cellwall thickness governs the fiber flexibility. Thick-walled fibers adversely affect the bursting strength, tensile strength, and folding endurance of paper. The paper manufactured from thick-

Table 2. Morphological Characteristics of Fibrous and Non-fibrous Cells of Various Species of Bamboo

Particulars	*B. tuda*	*D. hamiltonii*	*B. balcooa*	*M. baccifera*	B. aurandacea
Fibrous cells					
Fiber Length (weight weighted) (L = 0.20 – 4.0), mm	1.89	1.91	2.18	1.91	2.01
Minimum fiber length, mm	0.46	0.51	0.57	0.48	0.51
Maximum fiber length, mm	5.67	4.13	4.87	4.13	4.89
Mean fiber width (7 – 45), μm	17.0	16.8	17.4	17.6	18.0
Lumen diameter, μm	3.45	3.31	3.60	3.84	3.69
Cell wall thickness, μm	6.78	6.75	6.90	6.88	7.16
Luce's shape factor (fiber diameter^2–fibre lumen diameter^2)/ (fiber diameter^2 + fiber lumen diameter^2)	0.90	0.92	0.92	0.91	0.92
Slenderness ratio (fiber length/fiber diameter)	111.2	114	125.3	108.5	111.7
Solids factor, (fiber diameter^2 –fiber lumen diameter^2) * fiber length	0.52	0.52	0.63	0.56	0.62
Runkel ratio, 2 cell wall thickness/ lumen diameter	3.93	4.08	3.83	3.58	3.88
Fiber curl index (length weighted) (L = 0.50 – 5.0mm), 1/mm	0.19	0.23	0.20	0.20	0.19
Fiber kink index (L = 0.50 – 5.0mm)	1.79	1.85	1.69	1.72	1.82
Total kink angle, degree	45.68	48.62	49.50	49.0	51.5
Kink per mm	0.78	0.87	0.90	0.81	0.86
Non-fibrous cells					
Length of vessel, μm	256.3	265.7	202.1	213.0	267.4
Width of vessel, μm	34.4	36.3	41.9	54.1	48.4
Length of parenchyma, μm	58.1	59.9	48.3	72.1	67.8
Width of parenchyama,μm	31.9	34.4	36.5	32.7	34.2
Arithmetic fines (L=0.01-0.20 mm)	39.8	42.17	38.7	38.9	46.7
Length weighted fines (L=0.01-0.20 mm)	4.34	5.59	4.23	4.85	5.17

walled fibers will be bulky, coarse surfaced, and containing a large amount of void volume. By contrast, paper from thin-walled fibers will be dense and well formed. Fiber lumen width affects the beating of pulp. Larger the fiber lumen diameter better will be the beating of pulp because of the penetration of liquids into the fiber lumen.

Table 3. Morphological Characteristics of Fibrous and Non-fibrous Cells of *E. tereticornis* and *E. grandis*

Particulars	*E. tereticornis*	*E. grandis*
Fibrous cells		
Fiber Length (Weight Weighted) (L = 0.20 – 4.0), mm	0.72	0.92
Minimum fiber length, mm	0.26	0.23
Maximum fiber length, mm	1.81	2.12
Mean fiber width (7 – 45), μm	14.6	19.2
Lumen diameter, μm	5.12	6.67
Cell wall thickness, μm	4.74	6.27
Luce's shape factor (fiber diameter^2–fibre lumen diameter^2)/ (fiber diameter^2 + fiber lumen diameter^2)	0.78	0.78
Slenderness ratio (fiber length/fiber diameter)	49.3	47.9
Solids factor, (fiber diameter^2 –fiber lumen diameter^2) *fiber length	0.133	0.298
Runkel ratio, 2 cell wall thickness/ lumen diameter	1.85	1.88
Fiber curl index (length weighted) (L = 0.50 – 5.0mm), 1/mm	0.16	0.21
Fiber kink index (L = 0.50 – 5.0mm)	2.19	2.05
Total kink angle, degree	29.97	31.8
Kink per mm	0.95	0.88
Non-fibrous cells		
Length of vessel, μm	376	401
Width of vessel, μm	145	132
Length of parenchyma, μm	71.0	67.8
Width of parenchyama, μm	26.3	32.8
Arithmetic fines (L=0.01-0.20 mm)	27.59	28.21
Length weighted fines (L=0.01-0.20 mm)	5.87	6.13

Ratios calculated from the fiber dimensions help to assess physical and structural properties of paper. Luce's shape factor did not show much difference among various bamboo and eucalyptus species. Likewise, solid factors of *B. tulda* & *D. hamiltonii* and *B. balcooa* & *B. aurandacea* showed similarities, and the solid factor value of *M. baccifera* was between the values of *B. tulda* & *D. hamiltonii* and *B. balcooa* & *B. aurandacea*. On the other hand, the solid factor of *E. grandis* was found to be much higher (124%) than that of *E. tereticornis*. Luce's shape factor and solids factor were found to be related to paper sheet density and could significantly be correlated to breaking length of paper in eucalyptus by Ona et al. (2001). The Runkel ratio ranged from 3.58 to 4.08 in various studied bamboo species, whereas the fibers of *E. grandis* and

E. tereticornis were found to be much softer than bamboo. The Runkel ratio is expected to have an inexorably positive effect on tensile and burst indexes as well on double fold numbers (Ogbonnaya et al. 1997). The short and thin walled fibers exhibit plastic formation, thus they offer more surface contact and fiber bonding (Dutt et al. 2005). The fibers with Runkel ratio below 1.0 are considered as thin walled fibers (Istek 2006), and good mechanical strength properties are usually obtained when Runkel ratio rests below 1.0. Runkel ratio is also related to paper

Table 4. Pulping and Bleaching Conditions and Results of Studied Bamboo and Eucalyptus Species

Parameters	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Active alkali, % (as Na_2O)	18	17	16	17	18	18	19
Unscreened pulp yield, %	46.4	47.9	51.0	48.6	44.1	45.8	43.8
Screening rejects, %	1.4	1.5	–	–	0.8	0.67	0.32
Screened pulp yield, %	45.0	46.4	51.0	48.6	43.3	45.13	43.48
Kappa number	17.8	17.1	18.9	17.8	18.4	18.7	17.6
Pulp bleaching							
Chlorination stage (C)							
Cl_2 added,% (as avail cl_2)	4.45	4.28	4.73	4.45	4.60	4.70	4.40
Cl_2 consumed,% (as avail cl_2)	4.31	4.13	4.59	4.23	4.46	4.61	4.21
Extraction stage (E_1)							
NaOH applied,% (as such)	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Hydrogen peroxide ,%	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Hypochlorite stage (H)							
$Ca(OCl)_2$ applied, %	2.0	2.0	2.0	2.0	2.0	2.0	2.0
$Ca(OCl)_2$ consumed, %	1.72	1.75	1.90	1.75	1.71	1.87	1.91
NaOH applied ,% as buffer	0.3	0.3	0.3	0.3	0.3	0.3	0.3
ClO_2 stage (D_1)							
ClO_2 applied, % (as avail Cl_2)	0.75	0.75	0.75	0.75	0.75	0.75	0.75
ClO_2 stage (D_2)							
ClO_2 applied, % (as avail Cl_2)	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Pulp brightness, % (ISO)	81.5	84.0	82.5	83.7	83.9	86.1	85.2
Intrinsic viscosity, cm^3/g	378	418	423	397	420	289	275

Bleaching conditions	**C**	**E_p**	**H**	**D_1**	**D_2**
Consistency,%	3	8	8	10	10
Reaction time, min	30	60	120	80	80
Reaction temperature, ^{0}C	ambient	65	45	180	180
pH	<2	11.5	10.9	3.0	3.2

Time from ambient temperature to 100^{o}C = 30 min, time from 100 to 165^{o}C= 90 min, time at 165^{o}C= 120 min Sulphidity 20%, 1= *B. tulda,* 2= *D. hamiltonii*, 3= *B. balcooa*, 4=*M. baccifera*, 5= *B. aurandacea*, 6= *E. grandis* 7=*E. tereticornis*.

conformability and pulp yield (Ona et al. 2001). Fiber curl index (length weighted) and fiber kink index in studied bamboo species varied from 0.19 to 0.23 and 1.69 to 1.85. Not much difference was found in kink per mm and total kink number (Table 2). Fiber curl index (length weighted) and fiber kink index of *E. grandis* and *E. tereticornis* were found to be 0.21 and 0.16, and 2.05 and 2.19, respectively. Total kink angle is on lower side, while kink per mm is slightly on higher side (Table 3). Fiber curvature is defined by Kibblewhite's Kink Index (1975). As curl and kink in fiber increase, tensile and burst indexes and double fold number will be increased, while tear index will decrease with an improvement in light scattering properties. However, Seth (1998) points out that low consistency/low intensity refining only removes curl from lower coarseness fibers and that high coarseness pulps are very resistant to curl removal. He has also shown that laboratory beaters are very effective at removing curl and kink from pulp.

In order to obtain bleachable grade pulp of kappa number in the vicinity of 19±1, various bamboo and eucalyptus species were cooked at different alkali doses while keeping other conditions constant as mentioned in Table 4. The highest screened pulp yield of 51% with a kappa number of 18.9 was obtained in the case of *B. balcooa*, and the second highest pulp yield (48.6% and kappa number 17.8) was obtained in case of *M. baccifera*. Likewise, maximum pulp yield was obtained in case *E. tereticornis* (45.3% of kappa number 18.7). Bleaching studies reveal that *B. balcooa* produced a pulp brightness of 82.5% (ISO) with intrinsic viscosity of 423 cm^3/g, and *M. baccifera* produced a pulp brightness of 83.7% with intrinsic viscosity of 423 cm^3/g by CEHDD bleaching sequence. The two eucalyptus species achieved pulp brightness values of 86.1 and 85.2% (ISO), respectively, for *E. tereticornis* and *E. grandis*, but intrinsic viscosity was improved in case of *E. tereticornis* than *E. grandis*.

CONCLUSIONS

1. Proximate chemical analysis showed that *B. balcooa* and *M. baccifera* contain higher holocellulose and α-cellulose contents among other bamboo species. Ash contents are also on the lower side, so they can be expected to be less problematic from the chemical recovery point of view. 1% NaOH solubility indicates that both these raw materials can be stored for a longer period compared to the other species considered. Likewise, both the eucalyptus species contain more than 71% holocellulose, but lignin contents are slightly higher.
2. According to morphological analysis of various bamboo species, fiber dimensions and their derived values showed little difference. Morphologically, all the bamboo species are suitable for social forestry in north Indian climatic condition to produce pulp mainly for writing and printing grades. On the other hand, morphological studies revealed the greater suitability of *E. grandis* compared to *E. tereticornis*.
3. Pulping and bleaching studies indicate that *B. balcooa*, *M. baccifera*, and *E. grandis* can achieve the highest pulp yield, giving and brighter and stronger pulp.

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