Chemical, anatomical, and technology aspects of Eucalyptus benthamii *and* Eucalyptus dunii *for use in an integrated pulp and paper mill*

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ABSTRACT: *Eucalyptus dunii* has been commercially used in southern Brazil because of its relatively good frost tolerance and adequate productivity in the winter months. More recently, interest has grown in cultivating *Eucalyptus benthamii* Maiden & Cambage, which presents even superior frost tolerance compared to *E. dunii* and is highly productive as well. The quality of *E. benthamii* for pulp production is not yet proven. Thus, the chemical, anatomical, and technological aspects of pulp made from *E. benthamii* were compared with those of *E. dunii* for unbleached paper production. Samples of *E. benthamii* chips were obtained and analyzed for their basic density, chemical composition, higher heating value, trace elemental analysis, and chip size distribution. The chips were kraft cooked using conditions that produced a 74 ± 6 kappa number. The pulps were characterized for kappa number, yield, viscosity, and morphologic characteristics (e.g., length, wall thickness, and coarseness). Black liquor was analyzed for total solids, organics, inorganics, sodium sulfide, sodium hydroxide, and sodium carbonate. Brownstocks were beaten at five different energy levels in a Valley beater, and the physical strength properties of 120 g/m² handsheets were measured to develop a beater curve. The results of this study showed differences in delignification between the two woods and lower pulp yield for *E. benthamii* , which are related to their chemical compositions and basic densities. The *E. benthamii* studied in this work exhibited higher amounts of lignin and extractives, lower carbohydrate content, and lower basic density. However, cooking a blend of the two woods afforded good results in pulping and in physical pulp properties.

Application: By choosing tree species that grow well in the available land base and provide reasonable yield and strength properties in the mill, both parties can harvest benefit from the effort.

Eucalyptus is a major source of raw material for the pulp and paper industry. Over the last four decades [1], advances in forestry, plantation, and clonal management techniques have substantially improved the productivity and quality of several eucalypt species. The rapid growth of eucalypts (less than 7-year rotation for eucalypts compared to 12-21 years for *Pinus* species) has made these species desirable for plantation development [2].

To extend the range of eucalypts, recent research efforts have focused on the introduction and genetic improvement of new Eucalyptus species with more cold tolerant and frost resistant characteristics than those of species currently being grown in commercial plantations. *Eucalyptus benthamii* Maiden & Cambage is of interest in planting areas subject to severe frosts. This species originated from Camden, Australia, where only a few specimens of the species may still be found [3]. This genetic material may still be found in the region of New South Wales, and more restricted to the west of Sydney in the plains along the Nepean River [4]. This region is characterized by four to 10 frosts per year, with typical temperatures of 4°C to 26°C. The original population of *E. benthamii* Maiden & Cambage was cut because of the formation of flooded pastures and the construction of the Warragamba Dam. Fires in seed plantations have limited the collection of seeds. As a result, there is little natural occurrence of this species remaining [5].

In southern Brazil and in the southeastern United States, *E. benthamii* has been identified as a promising cold tolerant species. Cold weather and frosts are considered to be the defining characteristic feature of these areas. *E. benthamii* has shown a high tolerance to heavy frosts. Embrapa Forestry in the late 1980s was responsible for introducing the species in Brazil, where the species has been reported to grow well. According to Higa [5], 8-year-old *E. benthamii*, grown in Colombo, Paraná, Brazil, had a mean height of 18 m and an average diameter at breast height of 21 cm. Nisgoski [3] studied 15 trees from 7-year-old *E. benthamii* plantations at Embrapa Florestas, Colombo, and characterized the species as a moderately hard wood with specific gravity (basic density) of 0.47 g/cm³, reddish brown heartwood, and pinkish yellow sapwood. The samples had an irregular grain and very short to short libriform fibers with an average length of 818 μm; thin fiber walls with a thickness of 2.9 μm were also noted. Nisgoski concluded that this species was ideally suited for quality improvements through selective breeding management. A more recent study conducted by Alves et al. in 2010 [6] found that *E. benthamii* had an anatomical structure, basic density, and fiber dimensions similar to those of other species planted by the Brazilian pulp industry. However, it presented poorer wood quality characteristics, such as reduced physical properties and lower yield.

The chemical composition and wood quality of *E. benthamii* were studied by Higa and Pereira [7]. The chemical composition of *E. benthamii* was determined to be 3.2% extractives, 25.2% lignin, and 71.6% holocellulose. Higa and Pereira suggested that *E. benthamii* might best be used for firewood, charcoal, and pulp. Their study suggested this species was not suitable for sawmills because of significant amounts of top cracks, warping, and cracking in the structural lumber upon drying.

Pulping studies with *E. benthamii* by Hart and Nutter [2] showed low pulp yield at 16 kappa, as compared to other eucalypt species. The authors attributed this behavior to the lignin content. *E. benthamii* of the Australian region was studied by Clark and Hinks [8] and cited by Alves [9] as an underperforming species for pulp and paper because of low pulp yields. Alves also cited a scarcity of published papers studying *E. benthamii*.

Mokfieski et al. [10] studied the impact of wood quality parameters such as density, chemical composition, and anatomical parameters of 10 eucalypt species on yield and bleached pulp quality. Of all the parameters examined, density correlated with yield better than the other parameters. Lower incoming wood density was found to correlate to higher pulp yields.

Increasingly, collaborative studies between forestry and industry are becoming a powerful tool for defining strategies for long-term wood plantations. For instance, the economics of using short rotation hardwood plantations as green inventory for the replacement of satellite woodyards has been examined [11]. Additionally, forestry groups do not want to plant large stands of trees that are not desirable to the pulp mills they serve.

The current study examines the viability of *E. benthamii* as a potential wood species for commercial plantations serving the pulp and paper industry. The properties of *E. benthamii* are compared with those of *Eucalyptus dunii* for desirable forest or plantation productivity and for desirable pulp and paper qualities. Chemical and anatomical characteristics of wood, elemental analysis of wood and pulping liquor, higher heating value of wood and liquor, metals content, laboratory pulping conditions, kappa number, viscosity, yield, and physio-mechanical properties of fiber strength were examined.

MATERIALS AND METHODS

Materials

Two different species of 7-year-old eucalyptus wood were used: *E. benthamii* and *E. dunii*. The *E. benthamii* came from plantations in Água Doce, Santa Catarina, Brazil. The *E. dunii* was obtained from MWV Rigesa plantings in Mafra, Santa Catarina, Brazil. The logs were processed through an industrial chipper. Chip and wood samples were immediately collected to start the evaluation process.

Methods

Chemical characterization

Wood carbohydrates (glucans, xylans, galactans, mannans, and arabinans) were measured using high performance liquid chromatography (HPAEC-PAD), according to the method described by Wallis et al. [12]. The content of total extractives and ash were measured according to TAPPI Standard Test Methods T 264 "Preparation of wood for chemical analysis" and T 211 "Ash in wood, paper, and paperboard: combustion at 525°C," respectively. The uronic acid content was determined according to the method of Scott [13]. Metals content was measured by atomic absorption spectrophotometry according to procedure SCAN CM 38:96 [14]. The pulp viscosity was measured according to TAPPI T 230 cm-94 "Viscosity of pulp [capillary viscometer method]." Calorific value was determined by TAPPI T 684 om-97 "Gross heating value of black liquor." The basic density was determined by the maximum moisture content method [15]. The discs were collected in different diameters along the base to the top of the tree. Tests and bending stiffness were performed according to ABNT - Brazilian Association of Technical Standards, NBR 7190/1997 "Project Timber Structures" [16].

Morphological characterization

Morphological analysis of the fibers was performed using a computerized microscope video (image analyzer). For each sample, 100 pulp fibers were measured. The length, width, thickness, and diameter of the lumen and of the fiber walls were determined. The length of fibers, fiber coarseness, and number of fibers per gram were measured by a GALAI CIS-100 particle size and shape analyzer (Galai Production Ltd.; Migdal HaEmek, Israel).

Size classification

Chips were classified according to size and thickness using sieves with hole dimensions of 1 ¼ in. (31.75 mm), ¾ in. (19 mm), 5/16 in. (7.9 mm), 5/32 in. (4.0 mm), and 7/64 in. (2.7 mm).

Kraft pulping

Laboratory cooks were performed in a rotary digester with a capacity of 5 kg wet chips. The operating conditions used were as follows: chips = 2 o.d. kg, sulfidity = 23%, liquor/wood = 3.60 L/kg, maximum temperature = 155°C, time to temperature = 85-90 min from room temperature, and time at temperature = 40 min. Active alkali was varied to obtain the desired kappa number of 74 ± 6. Kappa number and viscosity were determined according to TAPPI T 236 om-85 “Kappa number of pulp” and TAPPI T 230 om-94, respectively.

Black liquor collected at the end of the cooks was measured for dissolved solids, organic and inorganic content, residual alkali (sodium sulfide, sodium hydroxide, and sodium carbonate), and pH. All analyses followed TAPPI T 625 cm-85 “Analysis of soda and sulfate black liquor.” The elemental analysis of the black liquor was performed by direct reading on a Leco elemental analyzer (Leco Corporation; St. Joseph, MI, USA). Calorific values were determined as higher heating value (HHV) and lower heating value (LHV) following TAPPI T 684 om-97.

Physio-mechanical testing of pulps

Fiber strength was assessed after refining in an Holandesa HV-10 laboratory beater (Rycobel; Deerlijk, Belgium) according to TAPPI T 200 sp-96 “Laboratory beating of pulp [Valley beater method]” with five levels of refining at 0, 5, 10, 15, and 20 min. After refining, Canadian Standard Freeness (CSF) was determined for each level and 120 g/m² handsheets were made. The handsheets were conditioned at 23 ± 1°C and 50 ± 2% relative humidity. Physical tests were performed according to relevant TAPPI Standards (**Table I**).

RESULTS AND DISCUSSION

Wood characterization

Basic density is an important property because it correlates well with other wood properties [10]. It also relates to specific wood consumption. For the samples studied, the average basic density values of wooden disks were 523 kg/m³ for *E. benthamii* and 500 kg/m³ for *E. dunni*. An acceptable range of eucalyptus basic density for pulp production is 450-550 kg/m³ [17]. The evaluated species were within these limits. Mokfieski et al. [10] determined that, at a given temperature and cooking time, low-density woods, with more open spaces in their structure, require lower alkali impregnation and removal of lignin than high density woods. Other studies show basic density values for *E. benthamii* of 477 kg/m³ [3,6] and 472 kg/ m³ [9].

Test	Standard	Title
Sheet formation	TAPPI T 218 sp-97	Forming handsheets for reflectance testing of pulp (Büchner funnel procedure)
Basis weight	TAPPI T 410 om-08	Grammage of paper and paperboard (weight per unit area)
Short span compression (SCT)	TAPPI T 826 pm-92	Short span compressive strength of containerboard
Ring crush (RCT)	TAPPI T 822 om-93	Ring crush of paperboard (rigid support method)
Concora medium (CMT) (flat crush)	TAPPI T 809 om-99	Flat crush of corrugated medium (CMT method)
Internal tear (Elmendorf)	TAPPI T 414 om-98	Internal tearing resistance of paper (Elmendorf-type method)
Tensile	TAPPI T 494 om-96	Tensile properties of paper and paperboard (using constant rate of elongation apparatus)

I. TAPPI tests performed.

Sample	Glycan (%)	Xylan (%)	Galactan (%)	Manan (%)	Arabinan (%)	Uronic Acid (%)	Cellulose (%)
Eucalyptus dunii	47.0	10.7	1.08	0.56	0.27	3.70	46.4
Eucalyptus benthamii	46.1	9.9	1.57	0.68	0.31	3.62	45.4

II. Analysis of carbohydrates (as a percentage of total oven dry wood).

Sample	Insoluble Lignin (%)	Soluble Lignin (%)	Total Lignin (%)	Extractives (%)	Higher Heating Value (MJ/Kg)	Lower Heating Value (MJ/Kg)
Eucalyptus dunii	26.0	4.36	30.4	3.07	19.3	18.0
Eucalyptus benthamii	28.3	3.18	31.5	3.62	19.3	18.0

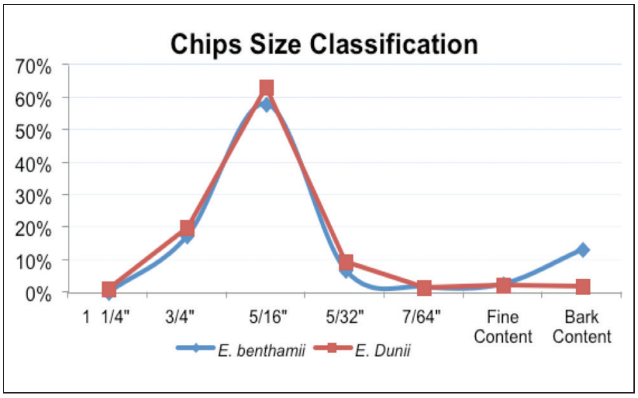
III. Lignin and extractives content and heating value of the wood.

Table II shows the carbohydrate chemical composition determined for *E. dunni* and *E. benthamii*. Carbohydrates, specifically cellulose plus hemicellulose, comprise the largest component of both species, followed by lignin (lignin results shown in **Table III**). The cellulose content of *E. dunni* was 2.1% higher than that of *E. benthamii*. Manan and arabinan were slightly higher for *E. benthamii*. Xylan, the hemicellulose component responsible for alkali consumption during the initial phase of pulping and for HexA formation, was slightly higher for *E. dunni*. The uronic acid content was similar for the two woods. Therefore, the carbohydrate effects on wood quality should be similar.

The lignin and extractives contents are considered to be fundamental chemical characteristics because they directly influence the consumption of alkali, yield, and production potential. Woods with high content of extractives tend to have low pulping performance [18]. Higa and Pereira [6] reported values of 3.2% extractives, lignin content of 25.2%, and 71.6% holocellulose for *E. benthamii*. Hart [2] found 4.47% extractives and 32.4% total lignin when evaluating *E. benthamii*. Alves [9] found 30.3% total lignin, and extractives of 2.25% soluble in acetone and 0.20% soluble in dichloromethane. In this study, *E. benthamii* had more extractives than *E. dunni*. The total lignin content was shown to be high for both *E. benthamii* and *E. dunii*, with values of 31.5% and 30.4%, respectively. *E. benthamii* had more total lignin. The heating values of the wood for both species were determined to be the same.

The inorganic fraction is about 1% of the constituents found in the wood for both species and can be directly related to the planting area by the specific minerals available at the planting sites. For this study, significant differences in metals content were found between the two species (**Table IV**). The silica content of the *E. benthamii* was found to be exceptionally high. The iron content was about double that of *E. dunni*. Levels of sodium and potassium were higher for *E. dunni* and might be reflective of fertilization with alkali, taking into consideration that the silvicultural methods directly influence the metals found.

The chips obtained were classified according to size (**Fig. 1**). *E. benthamii* and *E. dunni* had similar classifications, with the only major difference being that *E. dunni* had a lower bark content. Even though *E. benthamii* has a higher density, it was not difficult to chip. The results obtained for these woods are similar and in agreement with that expected for the process. Therefore, cooking variations might not be accounted for by chip quality.



1. Size classification of* Eucalyptus benthamii *and* Eucalyptus dunii *chips.

Morphology of fibers

Cooked pulps were analyzed for fiber length, fiber width, lumen diameter, and wall thickness. These characteristics are important in paper manufacture because fibers with larger lumen diameter and smaller wall thicknesses have greater potential to collapse, thus favoring inter-fiber bonds. Papers produced from these fibers typically have higher tensile and burst strength.

"High bulk," which is important for packaging paper and tissue, is influenced by the cell wall thickness and may also be correlated to the "coarseness" of the pulp fibers. In general, thicker-walled pulps produced from the same wood species tend to produce final products (paper and board) with higher apparent specific volume. These high bulk characteristics may contribute favorably to the stability of the stacked boxes in warehouses through improved column stiffness, roll softness in tissue grades, and opacity in paper for printing/writing grades [19].

E. benthamii had a shorter fiber length than *E. dunni* (0.97 mm vs. 1.14 mm, respectively). *E. benthamii* had about an 8% larger lumen diameter than *E. dunni*. **Table V** shows the average results obtained for the species studied here. Among other factors, paper quality is influenced by the amount of fibers per unit mass and the amount and size of the vessel segments in the pulp. These fiber biometrics were

Sample	Metals (mg/Kg)							
	Sílica	Na	K	Cu	Mn	Mg	Ca	Fe
E. dunni	122	208	925	1.5	38.5	281	403	20
E. benthamii	715	169	572	2.5	11.3	173	295	42
Na = sodium; K = potassium; Cu = copper; Mn = manganese; Mg = magnesium; Ca = calcium; Fe = iron.								

IV. Mineral analysis of* Eucalyptus dunii *and* Eucalyptus benthamii *wood.

Sample	Length (mm)		Diameter (µm)		Lumen (µm)		Wall Thickness (µm)	
	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation
Eucalyptus dunni	1.14	0.13	17.50	2.58	7.85	1.99	4.83	1.07
Eucalyptus benthamii	0.97	0.11	17.62	2.72	8.47	2.09	4.58	1.02

V. Results of morphology of fibers.

Sample	Coarseness (mg/100 m)	Fibers per Gram (million/g)	Length Weighted Average (mm)	Width Weighted Average (µm)	Fines (%)
Eucalyptus dunii	12.74	9.19	0.86	36.98	16.93
Eucalyptus benthamii	10.90	12.15	0.76	35.19	14.06

VI. Morphological characteristics of the studied* Eucalyptus *species.

Sample	*Eucalyptus benthamii*					*Eucalyptus dunii*				Mix
Cook number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Active alkali (%)	12.5	14.5	15.0	15.0	12.5	12.5	14.5	14.5	12.5	14.0
Results										
Kappa No.	99.5	79.1	68.1	68.2	80.2	88.8	70.2	69.1	78.5	78.1
Yield (%)	63.4	58.9	57.5	57.2	59.6	65.1	60.2	59.5	59.4	61.5
Residual alkali (g/L Na_2O)	6.8	9.3	10.5	9.3	5.6	6.8	9.0	9.0	6.2	8.1
Viscosity (mPa.s)	–	–	45.2	–	–	–	38.8	–	–	–

VII. Results and conditions of cooks. Time to temperature = 85-90 min, time at temperature = 40 min, cooking temperature = 155°C.

determined using a GALAI CIS-100 particle size and shape analyzer (Galai Production Ltd.; Migdal HaEmek, Israel) (**Table VI**).

Coarseness is defined as weight per unit length of pulp fibers, thus fibers with thicker cell walls tend to have a higher coarseness. *E. dunni* had thicker walls, longer fiber length, and a higher coarseness (17% higher) than *E. benthamii*.

The number of fibers per gram influences sheet formation during papermaking. Tensile and burst index depend on fiber bonding and show good correlation with the number of fibers per gram. For this property, the *E. benthamii* had better values than did the *E. dunni*.

Kraft pulping

Table VII shows the cooking results. The conditions were adjusted to achieve a kappa number of 74 ± 6. One mixed cook was performed with 70% *E. dunni* and 30% *E. benthamii* to estimate the impact of blending on the mill's operation.

The cooks were controlled to produce a specific kappa number. According to Smook [20], the amount of alkali used affects the reaction rate; accordingly, active alkali was changed to achieve the kappa number and to maintain a minimum level of residual to prevent lignin reprecipitation.

The results show that *E. benthamii* has a higher kappa and lower yield. Cooking of each wood under the same conditions showed significant differences between the pulps produced. The kappa achieved for *E. dunni* was 88.8, with a 65.1% yield. For *E. benthamii*, the kappa number was 99.5, with a 63.4% yield. After adjustments in active alkali to 14.5% on wood, the kappa yield comparison followed the same trend: the kappa for *E. dunni* was lower: 70.2 as compared to 79.1 for *E. benthamii*, with yields of 60.2% for *E. dunni* and 58.9% for *E. benthamii*.

For the same cooking conditions, the kappa number was 12% higher for *E. benthamii*, and the yield was about 2.4% lower. This behavior demonstrates the increased difficulty to delignify *E. benthamii* compared with *E. dunni* and is directly related to the higher lignin content in the chips of *E. benthamii*. The 1.9% increase in carbohydrate content of *E. dunni* certainly helped in the higher yield of this species.

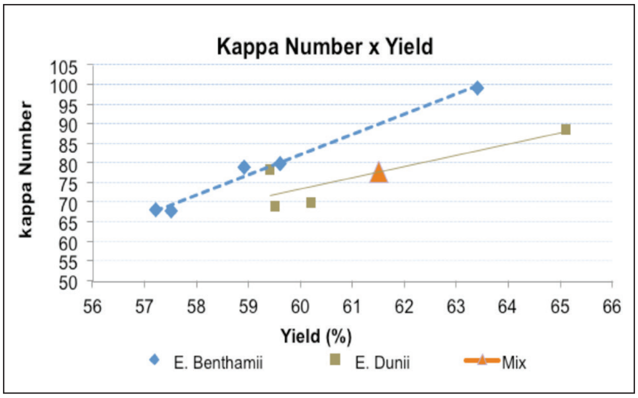
The pulping yield is related to the removal of carbohydrates, mainly hemicelluloses, and is an item of great importance for the industry because it directly affects the cost of wood consumption.

When choosing from different woods to grow for pulp production, it is important to make improvements to good quality woods that benefit forestry and the mill. Gomide and Colodette [17] observed that pulp yield is directly related to the anatomical structures and chemical composition of the wood, alkaline load demand, digester production, and the solids load to the recovery boiler; thus, yield could be considered as the main measure of quality wood. Wood of higher density, (*E. benthamii*) with higher lignin content requires harsher cooking conditions, with a higher chemical consumption and lower yield. The high active alkali charge contributes to carbohydrate degradation and an increase in black liquor solids to the recovery boiler.

Different behavior was found by Hart and Nutter [2] when they evaluated different species of 7-year-old Eucalyptus grown in the southern United States. The studies were conducted based on pulping to a kappa number 16. The authors found *E. benthamii* easier to pulp than *E. dunni* when using the same H-factor. The H-factor required in the bleachable grade study [2] for *E. benthamii* was 40 points lower, and the pulp yield was higher, possibly indicating the influence of planting in different regions. Another, more likely reason for the differences was that the *E. dunni* trees used in the study had experienced significant rot and die back as a result of extensive frost exposure. Better quality wood might have altered these findings significantly.

The results reported by Alves [9] were similar to the results obtained in the current work, and they point to higher alkali required to cook *E. benthamii* compared with cooking *E. grandis x Eucalyptus urophylla*, even for a kappa of 17, and lower pulp viscosity and yield.

The viscosity of the pulp is associated with the degree of polymerization of cellulose and hemicellulose polymers. It is an indication of the degradation of carbohydrates during pulping. High viscosity may indicate good pulp with improved drainage and washing. However, as Gomide et al. [18] observed, viscosity is not a good indicator of pulp strength. Viscosity is therefore a parameter used for quality control of the pulp in the production process, not as a measure of the ultimate pulp strength. For pulps obtained in cooks with kappa 68.1 (*E. benthamii*) and kappa 70.2 (*E. dunni*), *E. benthamii* pulp showed significant higher viscosity (16%) when compared with *E. dunni* pulp.



2. Kappa number vs. yield.

When cooking was performed with a mix of 70% *E. dunni* and 30% *E. benthamii* chips, the kappa number and yield were similar to that of pure *E. dunni* cooks. With 14% active alkali, the yield was 61.5% at a kappa of 78.1. As a comparison, after cooking pure *E. benthamii* using the same alkali charge and cooking temperature, with an additional 5 min at cooking temperature, the yield was 57.4% and kappa of 60.2. The marked decrease in kappa with a minimal decrease in yield is a notable finding.

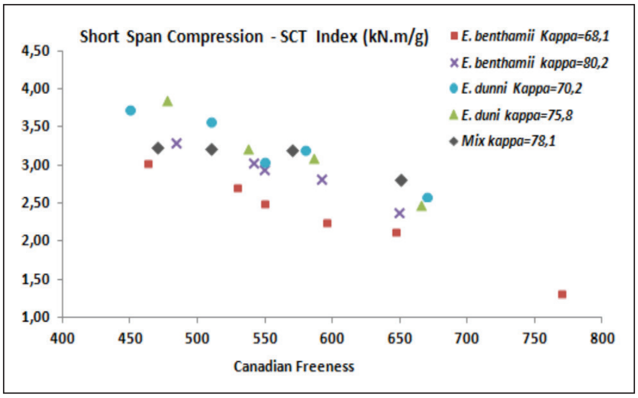
Blending is an alternative that could be used to exploit the benefits of both species. We observed that the resulting yield of 61.5% and kappa number for 78.1 for the mix of the two woods is near the curve of *E. dunni* (**Fig. 2**).The yield can vary up to 5 percentage points between the two species when compared at the same kappa number (Fig. 2). For example, comparing the yields at 78 kappa shows the yield of the blended cook was 60.8% and the yield of the control *E. dunni* cook was 61.5%. Thus, the yield of the blended cook was much closer to that of the pure *E. dunni* than to that of the *E. benthamii*.

Characterization of black liquor

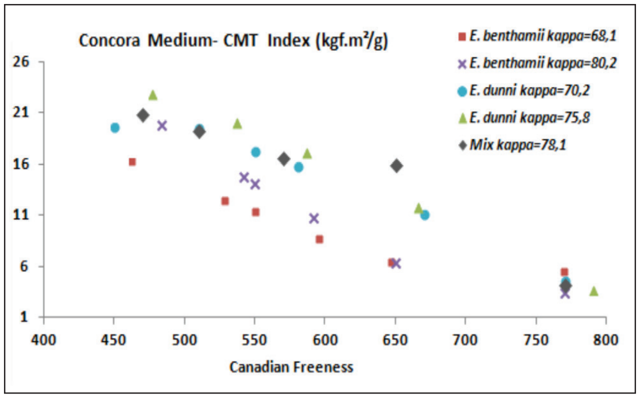
The pulps and liquors made from two of the cooks (kappa 68.1 for *E. benthamii* and 70.2 for *E. dunni*) were evaluated. **Table VIII** shows the results, which indicate higher total

Sample	Solids (%)			Residuals (g/L)				
	Total	Organics	Inorganics	Na_2S	NaOH	Na_2CO_3	Higher Heating Value (MJ/Kg)	Lower Heating Value (MJ/Kg)
Eucalyptus dunii	16.3	50.3	49.7	1.3	3.9	4.0	13.3	12.5
Eucalyptus benthamii	17.7	53.9	46.1	1.1	4.4	3.9	14.3	13.6

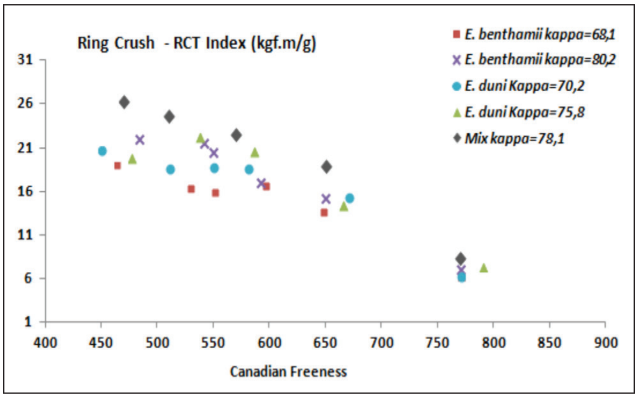
VIII. Solids content, residual alkali, and heating value of black liquor.



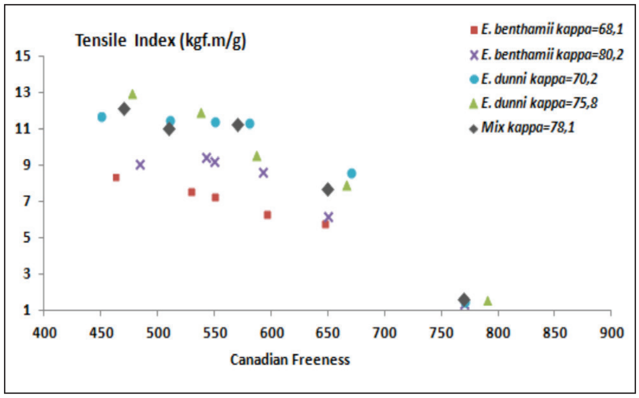
3. Short span compression (SCT) index (kN·m/g) vs. freeness (mL).



5. Concora medium (CMT) (flat crush) index (kgf·m²/g) vs. freeness (mL).



4. Ring crush (RCT) index (kgf·m/g) vs. freeness (mL).

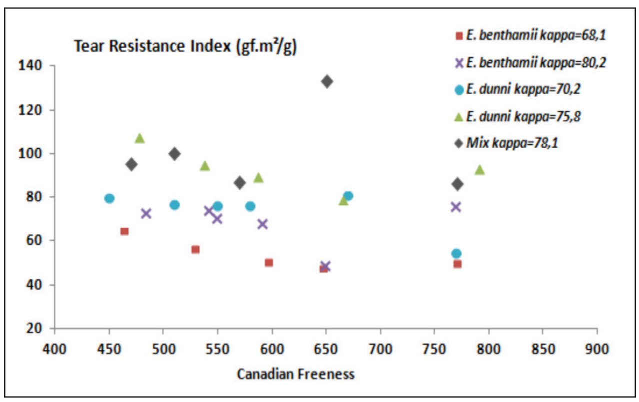


6. Tensile index (Kgf·m/g) vs. freeness (mL).

solids and organic material in the liquor resulting from cooking with *E. benthamii*, reflecting the lower pulping yield. The calorific values of the *E. benthamii* black liquor were higher, about 7.5% above for LHV and 9% above for HHV, compared to *E. dunni*. This indicated the potential use of *E. benthamii* for generating more power in chemical recovery, but also indicated the potential of overloading the recovery boiler.

Physical and mechanical properties of fibers

Figures 3-7 show physical properties of the pulps at different kappa numbers plotted against refined pulp freeness. The kappa number is directly related to yield, which is an indicator for the degradation of the carbohydrates. The results are reported in index form, normalized by sheet grammage. For all of the tests studied, the *E. benthamii* pulp at the lower kappa had the lowest values for physical properties. As the kappa number of the *E. benthamii* was increased, the physical strength properties increased. In none of the conditions studied did the strength of the *E. benthamii* pulps meet or exceed that of the *E. dunni* pulps. When the strength of the 30/70 blended chip cook was tested, the fiber strength was similar to the *E. dunni* pulp with the higher kappa number. These results suggested that pulping *E. benthamii* as a 30% component in the *E. dunni* chips would produce pulps of good quality and would be an acceptable way to use *E. benthamii* in the pulp mill.



7. Tear resistance index (gf·m²/g) vs. freeness (mL).

The properties of compressive strength, measured by short compression (SCT), ring crush (RCT), Concora medium (CMT) (flat crush), and STFI tests, are dependent on the strength of the cell wall and the stiffness of the fibers, and are directly related to the collapse of the fibers. The degree of collapsed fibers is related to the flexibility and conformation of the fibers, thereby improving the contact area between them.

The tear test is related to fiber length and the bonds between the fibers and showed better performance for *E. dunni* pulps with higher kappa number (75.8). When the kappa was the same for both species (70.2), the tear decreased about 35% when compared at the same pulp freeness. The greater tear resistance for *E. dunni* can be explained by the pulp's longer fiber lengths.

Looking at the charts, it is obvious that refining typically improved the physical properties for both species. However, when evaluating the varying results with different species and with different kappa numbers, the *E. benthamii* pulp with the lower kappa number (68.1) afforded the lowest physical strengths for all properties evaluated, which indicated low fiber strength. When the kappa for this species increases to 80.2, all properties are about equal to the properties for the 70.2 kappa *E. dunni* pulp.

For *E. dunni*, increasing the kappa number to 75.8 also improved most of the physical properties as compared to the results from the kappa 70 pulps.

When observing the pulp made from 70% *E. dunni* and 30% *E. benthamii* that had a kappa 78.1, the test values were very similar to the *E. dunni* with a kappa 75.8. These results demonstrate that blending *E. dunni* and *E. benthamii* can be a good alternative to pulping either species alone. Raising the kappa number for *E. benthamii* from 68.1 to 80.2 showed higher pulp strength values.

CONCLUSIONS

Wood and kappa 74 ± 6 pulp obtained from 7-year-old *E. benthamii* and *E. dunni* were evaluated anatomically, chemically, and technologically in this study. The *E. benthamii* showed higher chemical demand during pulping than did *E. dunni*. When cooked under identical conditions, the *E. benthamii* exhibited a lower yield and a higher kappa number compared to *E. dunni*. This behavior can be explained by the higher amount of lignin (+3.6%), higher extractives (+3.3%), lower carbohydrate and higher density of *E. benthamii* as compared to *E. dunni*. Black liquor from *E. benthamii* had higher HHV and LHV values (+7.5% and +9%) than *E. dunni*. *E. benthamii* black liquor, and higher total solids (+8.6%) and organic content (+7%) resulting from the lower pulp yield and higher lignin content of the starting wood.

The pulp from *E. benthamii* at kappa 68.2 showed low fiber strength characteristics, but when pulped to a higher kappa (80.2), SCT, CMT, RCT, tensile, and tear results were comparable with the kappa 70.2 *E. dunni* pulp, suggesting a possibility for use in papermaking. When pulping the two species as a blend containing 70% *E. dunii* and 30% *E. benthamii*, a kappa of 78.1 was obtained with equal or improved physical properties as compared to *E. dunii* with a kappa 75.8. These results suggest that blending the two species may be a good alternative for the papermaking process. Future work should be conducted with different blends of these species to support this finding. Different species could also be included in these blending studies.

The results from the fiber morphology analysis shows that *E. benthamii* fibers have a shorter fiber length, thinner wall thickness, larger lumen diameter, lower coarseness, and a significantly greater number of fibers per gram. Undoubtedly, the quality of wood affects the final product and the purpose of this review is to help the forestry department obtain higher productivity and better quality pulp and paper manufacturing from these species.

The current work suggests that selectively planting some amount of *E. benthamii* in the colder, more frost prone areas available to a mill may be a viable method of extending the amount and range of eucalyptus plantation acreage available for a mill. When harvesting and processing this wood, it will be important to uniformly blend the two species in specified ratios noted previously to ensure high quality pulp is produced for the papermaking process without compromising the back-end processes of the mill, such as white liquor demand and recovery boiler capacity. **TJ**

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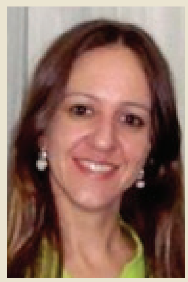

Samistraro

Colodette

Forestry is typically tasked with providing fiber to the mills. The mill is tasked with converting that raw fiber into useful products. In the past, these two groups have typically operated independently of each other and, as a result, have developed conflicting program goals. Forestry tries to produce fast growing, high volume, straight trees with a limited number of branches. The mill typically desires high pulp yield, easy to pulp and bleach trees of reasonably high density. The current effort is an attempt to have the two groups work together to evaluate wood species with respect to their mutual goals. By making minor concessions on both sides, an optimal plantation program might be developed to achieve the goals of forestry and the goals of the mill.

Past efforts in this area have examined multiple cold-tolerant eucalypt species. The current work focuses on a detailed comparison between a current commercially viable species with a potential new species that can enable plantations to be moved to higher elevations and to more frost-prone areas.

As with all plantation development work, identification and production of samples for testing is a time-consuming, long-term process. The current work showed that *Eucalyptus benthamii* was inferior to *Eucalyptus dunni* from a pulping and papermaking viewpoint. However, when pulped as a 30% blend with *E. dunni*, reasonable strength properties and pulp yields were obtained.

The current work suggests that extending *E. benthamii* plantations into higher elevations and to more frost-prone areas might be a viable solution to providing a portion of the short fiber demand for a pulp mill, with reasonable quality. The work also shows limitations to the total amount of these plantations with respect to other species.

The next steps consist of actually planting some of these plantations and using the resulting fiber under commercial scale conditions.

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