Pulping potential of young eucalypts: a comparative study of wood and pulp properties of 12 eucalypt species

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Abstract

The *Eucalyptus* genus includes over 700 species and hybrids, of which a few are among the most important hardwoods used worldwide for the pulp and paper industry. The large biological variety of the genus suggests a very strong possibility for diversification, which meets a present goal for forests and natural resources.

Wood from 6-year-old trees of *Eucalyptus botryoides, E. camaldulensis, E. globulus, E. grandis, E. maculata, E. ovata, E. propinqua, E. resinifera, E. rudis, E. saligna, E. sideroxylon* and *E. viminalis*, was used for chemical and pulping experiments.

The summative chemical composition showed substantial differences between species: extractives content varied from 6% (*E. viminalis, E. globulus* and *E. ovata)* to 19% (*E. camaldulensis)*, lignin content from 22% (*E. maculata)* to 31% (*E. resinifera)*, and holocellulose content from 55% (*E. camaldulensis)* to 70% (*E. globulus).*

Kraft pulping was conducted in microdigestors. *E. globulus* showed the highest yield (50%) and residual alkali (2.9%), and the lowest kappa number (12) and solids in black liquor (17.2%).*E. camaldulensis* presented the lowest yield (39%) and residual alkali (1.2%) and *E. maculata* pulps presented the highest kappa number (24).

Pulp morphological features (fiber population, length, width, coarseness) and handsheet properties (°SR, water retention value, bulk, air permeability, tear and tensile indices and Scott bond) were determined. The handsheet properties of pulps from *E. botryoides, E. saligna, E. grandis, E. ovata* and *E. globulus* were similar to those of unbeaten unbleached industrial *E. globulus* used commercially for printing and writing papers. *E maculata* (and to some extent *E. propinqua*) pulps showed specific characteristics that are valued for highly porous and tissue papers and *E. viminalis* for specialty papers such as glassine, bible paper or other high density papers. *E. globulus* produced the best pulping and handsheet combined results while on the other side, *E. camaldulensis, E. rudis, E. resinifera* and *E sideroxylon* showed limited value either because of low pulp yield or deficient handsheet properties.

Wood density appears to be an influential parameter that is correlated with the degree of delignification, coarseness and bulk, while bulk is determinant to strength properties.

Keywords: eucalyptus; chemical composition; kraft pulping; handsheet properties.

Introduction

Within the short fiber pulp and paper industries, eucalypt species are considered especially interesting due to various characteristics that lead to good quality of pulp and papers. The fast growth and wood quality as well as the possibility to have short rotation (sometimes coppice) forests with controlled phenotypic characteristic provide the industry with a more consistent supply.

The genus comprises several hundred species including their hybrids, some of which are extensively used for pulp and paper production. In southern Europe, South America, China and South Africa, *E. globulus, E. nitens, E. grandis, E. saligna* and *E. urophylla* are the major planted pulpwood species.[1] Although several other species are used worldwide (e.g, *E. camaldulensis, E. tereticornis, E. smithii*), four species alone provide 80% of the world plantations (*E. grandis, E. urophylla, E. camaldulensis* and *E.globulus*).[2]The large biological variety of the genus suggests a very strong possibility for diversification, which meets a present goal for forests and natural resources: apart from suitability in tree growth and adaptation, as well as wood quality for pulping, the enlarging of species to be used in commercial plantations strengthens their overall environmental context and overcomes some economic risks e.g. of pests and diseases.

For the evaluation of the pulping potential of a raw-material several parameters must be studied, such as the chemical composition and anatomy of wood and pulps, the pulping process and the pulp and paper properties and quality. Several studies have focused on the morphological characteristics of wood and their influence in pulping [3,4], on the influence of chemical composition or different delignification processes [5]. Most studies were made with the commercially used pulpwoods and, although there is some literature for several other eucalypt species [6-9], little is known for the majority of the genus.

In the present work we studied and compared the pulping potential of young eucalypts of 12 species (*E. botryoides, E. camaldulensis, E. globulus, E. grandis, E. maculata, E. ovata, E. propinqua, E. resinifera, E. rudis, E. saligna, E. sideroxylon and E. viminalis*) regarding chemical composition, kraft pulping aptitude and handsheet properties. Correlations between properties were derived to better understand the influence they have on each other.

Experimental

Wood samples from six-year-old eucalypt trees grown in a Portuguese arboretum (*Eucalyptus botryoides, E. camaldulensis, E. globulus, E. grandis, E. maculata, E. ovata, E. propinqua, E. resinifera, E. rudis, E. saligna, E. sideroxylon and E. viminalis*) were collected and chipped to an average dimension of 8 x 4 x 3 mm. For the summative analysis a sample of wood was further milled and sieved, and the 40-60 mesh fraction was used for analysis. Ash, and lignin content were determined according to TAPPI standard methods (T15 os-58, T222 om-88 and UM250 om-83), extractives through successive extraction with dichloromethane, ethanol and water in a Soxhlet apparatus and holocellulose through the modified chlorite method. Neutral monosacharides and acetates were determined in the klason lignin hidrolysate through Pressure Ion Chromatography. Kraft pulping was made in microdigestors with 100 ml capacity under rotation in a thermostat oil bath under the following conditions: 10 g oven-dry wood with 4:1 liquor-to-wood ratio; 22% active alkali, 30% sulfidity and one hour of reaction time at 165ºC. Four trials were made for each species. Pulp yield was gravimetrically determined, kappa number determined through TAPPI UM 246, black liquor solids and sulphated ash following T625 cm-85 and residual alkali by titrating 10 ml of black liquor diluted in 30 ml of water and 20 ml of $BaCl_2$ (20%) to 10.5 pH. Fiber morphological properties (number of fibers per gram, length, width and coarseness) were determined with MORFI LB01 (TECHPAC), Schopper Riegler following ISO 5267-1, water retention value (WRV) through a method reported elsewhere [10]. Handsheet properties of unbeaten/unbleached kraft pulps with 60 gm^{-2} basic weight were determined using standard norms. The correlations determined for several wood and pulp properties were obtained using the software R.

Results and Discussion

Chemical analysis

Figure 1 presents the chemical analysis for the 12 eucalypt species. Holocellulose content varied between 56% and 70% for *E camaldulensis* and *E. globulus* respectively, with *E. viminalis* and *E ovata* presenting values almost as high as *E. globulus*. *E. resinifera* showed the highest lignin value (31%) while on the lower end was *E. maculata* with only 22%. The extractives content showed the highest variation among species with *E. camaldulensis* (19%) presenting more than three times the lowest value presented by both *E. globulus* and *E. viminalis. E. rudis* and *E. sideroxylon* also presented high extractive values with 15% and 14% respectively. Ash content was similar to all species (between 0.4-0.8%) except for *E. maculata* with over 2%.

The main aim of the pulping process is to remove the lignin while conserving the carbohydrate polymers as much intact as possible. Therefore, high holocellulose and low lignin content are desirable. In terms of extractives and ash content, lower values are preferable since both have undesirable effects in the pulping process, increasing and affecting the normal alkali consumption as well as causing operational problems [4,11].

Figure 2 presents the monosaccharides and acetate relative percentage in wood and pulp for each species. Arabinose and galactose represent a small percentage of wood monosaccharides (between 1-2% each), acetates (resulting from the acetyl groups of hemicelluloses [12]) account for 6-9%, and xylose between 22-28%. After pulping the relative proportion of glucose increases, xylose decreases and the remaining monosaccharides and acetates become too small to be accounted. Nevertheless xylose still accounts for 13-

20% of all monosaccharides in the pulps which means that a substantial part of the hemicelluloses were able to endure the delignification process.

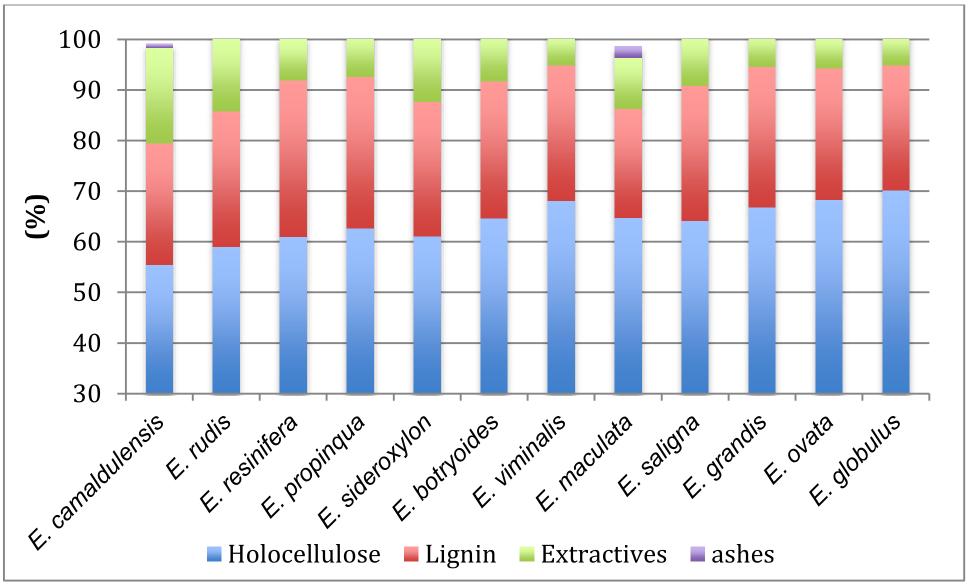

Figure 1. Wood summative chemical analysis for the eucalypt species (adapted from [9])

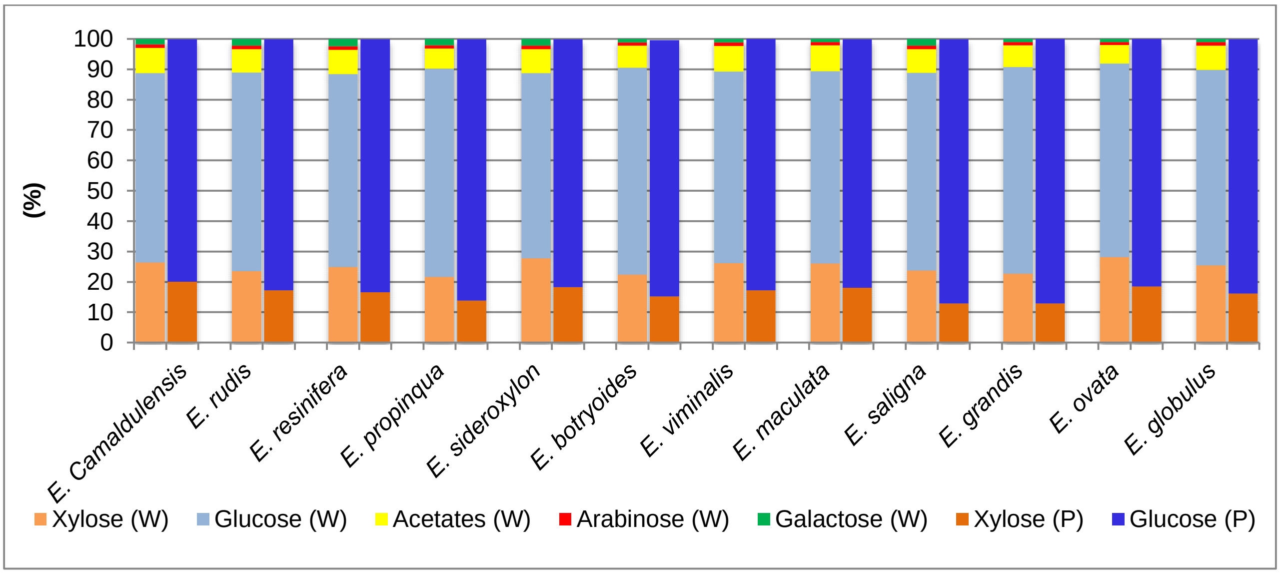

Figure 2. Monosaccharides and acetates proportion in wood (W) and pulp (P) for the eucalypt species

Pulping

The active alkali and sulfidity used in the present kraft pulping were somewhat higher than the normal industrial practice, so as to obtain pulps with kappa number around or below 17 (as targeted by the industry). Due to the large between species variability in extractives and lignin, some pulps felled short of this objective while others were clearly overcooked, for which milder conditions would allow higher yields and probably better handsheet properties.

Figures 3 and 4 present the pulp and black liquor characterization with the species ordered from lowest (*E. camaldulensis*) to highest (*E. globulus*) yield. *E. maculata* pulp achieved the highest kappa number (24) despite having the lowest lignin content but high extractives (10%). *E. sideroxylon* also presented a high kappa number (20) in relation to the yield achieved. Both these species have high wood density [9], which might prevent a good liquor impregnation and result in deficient delignification.

In terms of residual alkali, it is possible to verify that the pulping of several species almost exhausted the white liquor reagent e.g. *E. camaldulensis* black liquor had the lowest residual alkali 1.2% while *E. globulus* still had 2.9%. In the first case, extending the reaction time would not improve the delignification. As expected, the content of solids in the black liquor is inversely proportional to the pulping yield and therefore *E. camaldulensis* presented the highest solids content (19.3 m/m) and *E. globulus* the lowest (17.2 m/m). On the contrary, the inorganic content of black liquor, determined as sulphated ash, increased from *E. camaldulensis* to *E. globulus*.

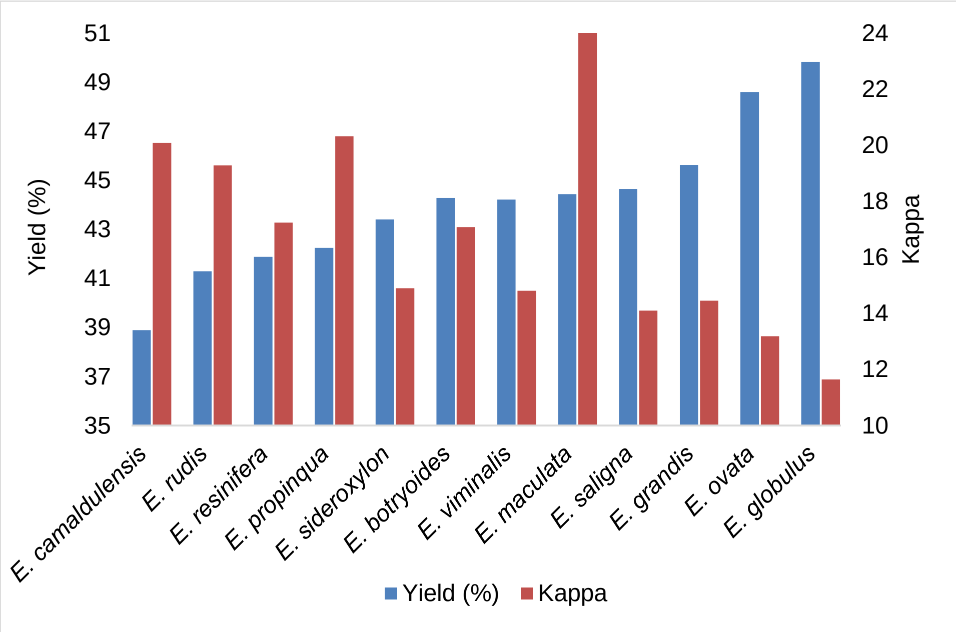

Figure 3. Pulp characterization for the eucalypt species (adapted from [9])

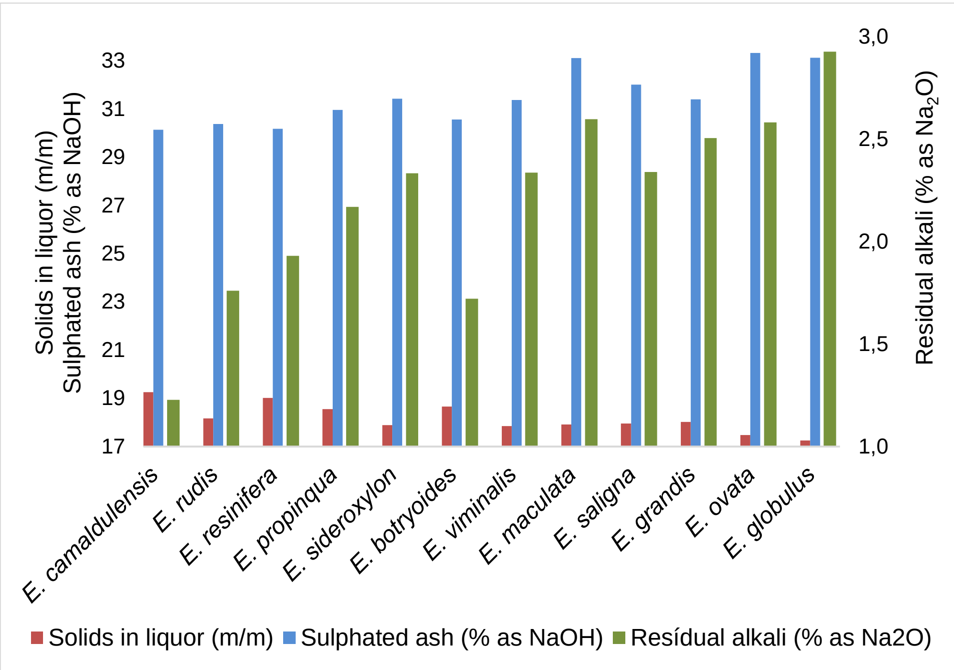

Figure 4. Black liquor characterization for the eucalypt species (adapted from [9])

Pulp morphological and handsheet properties

Table 1 shows the morphological properties of the pulp fibers and handsheet properties for the 12 species. According to Foelkel [13], properties for unbeaten unbleached eucalypt pulps should range as follows: fiber population 12-30 millions/g of pulp, fiber length 0.6-0.85 mm, coarseness 4.5-11 mg/100m, Schopper Riegler (ºSR) 16-24 and water retention value (WRV) for previously dried pulps (present case) 100-130%. Most of the pulps produced fall in these intervals or in their proximity, with only a few exceptions e.g. *E. viminalis* fiber population (41 millions/g), *E. camaldulensis* and *E. rudis* WRV (137%).

Among the 12 species *E. propinqua, E. viminalis* and *E. maculata* presented different characteristics. *E. viminalis* showed the highest number of fibers per gram (41 million/g) and tear and tensile indexes (12 and 43 respectively), and the lowest bulk (1.4 cm^3/g) and air permeability (376 mL/min). These characteristics, with special regard to the low bulk and air permeability that appear to be related to high fiber collapsing, are desired in the production of specialty papers such as glassine, bible paper or other high density papers. As for *E maculata* and to some extent *E. propinqua*, the low fiber population (18 and 24 million/g respectively) and WRV (99 and 114) along with high coarseness (8.4 and 7.6) and low overall handsheet strength might indicate a good propensity for highly porous and tissue paper.

Using *E. globulus* as a standard raw-material for printing and writing paper, typical results from a Portuguese mill for unbleached unrefined pulps with kappa number between 12-17 and 18 ºSR showed a tear and tensile index of 4.4 mN m^2/g and 32.9 N m/g. Except for *E. camaldulensis, E. propinqua, E. sideroxylon* and *E. maculata* all the other species obtained better or similar results. If considering the range for fiber population, coarseness and WRV as well as the overall kraft pulping characterization, *E. botryoides, E. saligna, E. grandis, E. ovata* and *E. globulus* appear to be the most suited for printing and writing papers. With the highest yield, lowest kappa number and good fiber and handsheet properties, *E. globulus* appears to be the best species for this end use.

Table 1. Fiber morphological and pulp handsheet properties for the eucalypt species (adapted from [9])

	E. camaldulensis	***E. rudis***	***E. resinífera***	***E. propinqua***	***E. sideroxylon***	***E. botryoides***	***E. viminalis***	***E. maculata***	***E. saligna***	***E. grandis***	***E. ovata***	***E. globulus***
Fibers (millions/g)	29	30	32	24	33	26	41	18	25	25	32	24
Length (µm), weighted in length	569	626	629	614	568	719	598	748	708	759	608	727
Width (µm)	20	19	19	19	17	20	18	18	20	19	19	18
Coarseness (mg/100m)	6.8	6.0	5.7	7.6	5.9	6.3	4.6	8.4	6.6	6.1	5.9	6.7
°SR	24	26	27	21	21	21	24	16	20	22	25	19
WRV (%)	137	137	133	114	107	127	126	99	118	113	133	112
Bulk (cm^3/g)	1.7	1.6	1.5	2.1	2.0	1.6	1.4	2.1	1.7	1.7	1.6	1.8
Air permeability (mL/min)	656	447	365	2029	1883	700	376	2490	1143	1171	350	1500
Tear index ($mN.m^2/g$)	6	9	12	4	3	12	12	3	9	13	10	9
Scott bond (J/m^2)	192	166	181	90	72	142	166	63	103	122	169	116

Tensile Index (Nm/g)	28	41	40	19	21	39	43	16	38	37	40	33

Wood, fiber, pulp and handsheet properties correlations

Table 2 presents the best statistical correlation between chemical composition, pulping, fiber and handsheet properties in order to give a general perspective on the influence that some properties have on others.

Variability in yield can be explained to an extent of 84% by the variability in holocellulose and a positive variation in holocellulose will be reflected in a higher yield. This result is expected since the delignification process aims at removing lignin and extractives from the wood matrix while conserving carbohydrates as much as possible. Therefore, higher carbohydrate polymer content would be expected to result in higher pulp yields.

Under the same reaction conditions, kappa number is negatively correlated to holocellulose content and positively to wood density. Higher holocellulose means lower extractives and lignin resulting in pulps with a lower kappa number. On the opposite direction, higher wood density results in higher kappa number, probably due to a deficient impregnation of white liquor in the wood during pulping.

Coarseness is negatively correlated to fiber population and positively correlated to wood density. Since the fiber length weighted in length of these eucalypt species had a small variation (568-759 µm), higher number of fiber per gram means that the weight of each fiber is lower, decreasing the coarseness. On the other hand, higher wood density is normally associated with thicker cell wall fibers [14], which increases coarseness.

Bulk increases with coarseness and wood density since thicker cell wall fibers are less prone to collapse. Bulk correlates negatively with all paper strength parameters (Scott bond, tear and tensile indexes). Higher bulk means less collapsed fibers and therefore lower fiber bonding. Inversely, bulk correlates positively with air permeability due to the higher porous network between uncollapsed fibers.

Table 2. Correlation of chemical, pulping, morphological and handsheet properties

Variable 1	Variable 2	Signal	Variable 3	Signal	Determination coefficient
Yield	Holocellulose	(+)			0.84
Kappa number	Holocellulose	(-)	Wood density	(+)	0.71
Coarseness	Fibers	(-)	Wood density	(+)	0.89
Bulk	Coarseness	(+)	Wood density	(+)	0.80
WRV	Air permeability	(-)	Bulk	(+)	0.97
Air permeability	Bulk	(+)			0.89
Tear index	Bulk	(-)			0.71
Scott bond	WRV	(+)			0.89
Scott bond	WRV	(+)	Bulk	(-)	0.92
Tensile index	Bulk	(-)			0.92

Conclusions

The six-year-old trees of 12 *Eucalyptus* species grown in the same site and under the same edaphoclimatic conditions showed high variability in terms of chemical composition, kraft pulping characteristics, fiber and handsheet properties of unbleached and unrefined pulps.

Overall the result show:

- *E. maculata* and *E. propinqua* presented fiber and handsheet characteristics desired for highly porous and tissue paper
- *E. viminalis* appears to show good fiber and handsheet quality for specialty papers such as glassine, bible paper or other high density papers
- *E. botryoides, E. saligna, E. grandis, E. ovata* and *E. globulus* appear to be the most suited for printing and writing papers

- *E. globulus* presented the best overall combined results in terms of kraft pulping, fiber morphology and handsheet properties
- Holocellulose content highly influences kraft pulping yield
- Wood density influences the degree of delignification, coarseness and bulk
- Bulk is the most influential parameter when regarding to handheet strength properties

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