Effects of Eucalyptus nitens *heartwood in kraft pulping*

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ABSTRACT: The heartwood of *E. nitens* was separated from its sapwood, and the physical and chemical properties of each were measured. The heartwood and sapwood densities were similar, but the fiber length averaged 12.6% longer for sapwood, and the fiber wall was thicker for sapwood. The most important differences in the chemical composition were that the sapwood had 15% more lignin and 20% more hemicellulose. Chips of the heartwood and sapwood were mixed in weight-based proportions of 0:100, 25:75, 50:50, 75:25, and 100:0 for kraft pulping. The black liquor and pulp properties were evaluated. The mechanical strength, tensile strength, and burst index were found to be higher for pure heartwood pulp than for pure sapwood pulp. The tearing index and bulk were lower in the pure heartwood pulp. Increasing the heartwood to over 50% resulted in a higher kappa number and an increase in the rejects rate.

Application: Managers of kraft pulp mills in Chile can improve the pulping process and the quality of the pulp by setting the optimum percentage of heartwood when E. nitens is used as the raw material.

Among fast-growing tree species introduced into Chile for pulp, species of eucalyptus account for 312,000 hectares in plantations, with *Eucalyptus globulus* covering about 74% of this area. The rest is made up of *Eucalyptus nitens* [1], which appears to be a favorable alternative because it grows well in the Districts IX and X of southern Chile (38° to 42°S). *E. nitens* provides pulp with a higher bulk yield, the species has rotation cycles of 8–14 years, and the plants are highly resistant to cold and frost [2].

Research on eucalyptus species as raw material for pulping has centered on assays of age, stem height, site productivity, and other parameters, expecially for *E. globulus*. The unique properties of the heartwood of *E. nitens* have not been considered with regard to how they affect kraft pulping. Our goals were to study the physical and chemical differences between the heartwood and sapwood and to evaluate the effects of these differences on the kraft pulping process.

CHARACTERISTICS OF *E. NITENS*

The wood of *E. nitens* can be up to 11% less dense than that of *E. globulus*, and the *E. nitens* fibers are shorter and not as coarse. *E. nitens* also has up to 24% higher extractives content and 7–14% more lignin content. These differences influence the pulping processes. The screened yield can be 4% to 8.3% less, and pulp production is lower. The pulp is less porous and is difficult to drain. It is also low in bulk, which increases its opacity [3–6].

According to recent surveys, the wood of *E. nitens* varies considerably with its age. Peredo found, for example, that a six year increase in the age of the tree increases the wood density by 10%, the fiber length by 24%, and the extractives content by 67% [5]. Kibblewhite *et al.* worked with *E. nitens* samples from New Zealand and observed that an increase in age of three years gives rise to a 7% increase in fiber length and a 3% increase in cell wall thickness [7].

Moving from the base to the top of the tree stem also increases wood density, though not as much as age increases it [8]. From the base to the top of the stem, Kibblewhite *et al.* found that the fiber length fell by about 12% in *E. nitens* trees that were 15 years old [9]. Studying *E. nitens* from District VII of Chile (35°S), Molina found a similar pattern but also observed that the percentage of screened rejects increases as the material processed is taken from higher on the stem [10].

Another characteristic of *E. nitens* is that it generates heartwood after only a few years of growth. By contrast, 8-year-old *E. globulus* did not exhibit heartwood formation, according to Melo *et al.* [4]. Furthermore, *E. globulus* that is 10–12 years old may have up to 42% of its heartwood in the stem [11]. In another survey, the heartwood volume varied from 30% to 44% for *E. globulus* between 11-13 years old [12], whereas an 8-year-old *E. nitens* already has 12% heartwood by volume, which can be verified through the color change of the central zone in a cross section of the stem.

Other studies have indicated that variations in chemical and physical properties between heartwood and sapwood influence the pulping characteristics of the raw material. For pulps obtained from *Nothofagus dombeyi* (chilean beech), different ratios of heartwood and sapwood led to direct effects on the rejects percentage, the pulp yield, the delignification rate, and the mechanical pulp strength [13].

Despite evidence that the age and stem position influence the amount of heartwood found in samples, few comparative studies have been carried out on *E. nitens* to provide information about the effects of its heartwood on the pulping process. In this study, we wanted to evaluate the effects of heartwood on the fiber quality and pulping characteristics of this particular species.

MATERIALS AND METHODS

For the wood material, we used stem sections of *E. nitens* from District VIII in Chile. Six cross sections were obtained. These cross sections were 36.9 cm or 40.9 cm in diameter, with heartwood percentages of 72.6% and 76.7%, respectively.

The sapwood was separated from heartwood, and the two wood samples were chipped by hand. We used TAPPI methods to determine the density and chemical properties for both types of wood.

Kraft pulping was carried out at ratios of heartwood to sapwood of 100:0, 75:25, 50:50, 25:75, and 0:100. Pulping was performed in an M/K System digester with recirculating liquor. The pulping conditions were kept constant at 26% sulfidity, 17% active alkali (as Na_2O), and a liquor–wood ratio of 4.5:1. Starting from 90°C, it took 100 min to reach the maximum temperature of 160°C, where the cook was held for 35 min.

Pulps were evaluated in terms of yield, kappa number, Clark fiber classification, and residual alkali. We also measured the average fiber length, diameter, and cell wall thickness. For each kraft pulp, we measured the Schopper-Riegler drainability. We used TAPPI methods to characterize the pulps in terms of tensile index, burst index, tear index, and bulk. Handsheets were prepared at a basis weight of 60 g/m².

Statistical analyses were performed on the data with a SAS computing program [14]. The variables analyzed were the total yield, the screened yield, the rejects percentage, and the amount of alkali reactives consumed. Values were normalized by numeric transformation [15] for all of these variables except kappa number. When significant differences ($P < 0.05$) were detected between trays, where each tray represents one of the five ratios of hardwood to sapwood, the results were compared using multiple classes.

RESULTS

Morphological and physical properties

Table I lists the fiber properties and chemical properties of the heartwood and sapwood.The two types of wood did not have meaningful differences in density, but they did have significant differences in fiber length and cell wall thickness. Sapwood had fibers that were 12.6% longer than the heartwood fibers, and the cell walls of the heartwood fibers were 11.3% less thick than the cell walls of the sapwood. The difference in fiber diameter did not exceed 1%, which means that any radial variation was negligible.

Chemical properties

Chemical differences between heartwood and sapwood were observed mainly for the compounds of high molecular weight such as lignin, cellulose, and pentosans (hemicelluloses). Heartwood had less cellulose (12.4%) and more lignin (15%) and pentosans (20%). At constant pulping conditions for both materials, the sapwood reached a higher rate of delignification.

Comparing the contents of low-molecular-weight compounds, we see in Table I that the greatest difference was found for the extractives soluble in cool water. These solubles were 43.8% higher in sapwood. The inorganic compounds, or the wood ash, was 50% higher in sapwood.

Kraft pulping process

Pulps were obtained for each of the five different ratios, or chip trays. Each pulp was characterized according to its mean fiber length, Clark fiber classification, and drainage rate (freeness). **Table II** presents these results, along with the kappa number and the percentage of pentosans for each of the five pulps. As the table shows, the pentosan content drops once the percentage of heartwood falls below 25%.

For kappa number, the two curves in **Fig. 1** show differences related to the higher lignin content of heartwood. These curves demonstrate that increasing the ratio of heartwood to softwood in the raw material increases the kappa number and the alkali consumption.

The measurements of freeness demonstrated no linear correlation to the increasing percentage of heartwood. However, morphological differences between heartwood and sapwood give rise to a difference in freeness of 2°SR, as shown in Table II.

The mean fiber length in heartwood pulp was found to be 12.6% shorter than in sapwood pulp. As the percentage of heartwood increased, the mean fiber length decreased consistently, as one would expect.

In terms of fiber classification, an increasing percentage of heartwood coincides with a decrease in fibers retained on the 30-mesh screen. The table also shows an increase in fibers retained on the 50-mesh screen as the heartwood increases.

Fiber properties	Heart-wood	Sap-wood
Basic density, kg/m³	478[1]	486[2]
Length, μm	1038	1169
Diameter, μm	16.39	16.54
Wall thickness, μm	3.52	3.97
Chemical properties		
Ash, %	0.24	0.36
Lignin, %	25.1	21.8
Cellulose, %	46.1	51.9
Pentosan, %	22.0	17.6
Hollocellulose, %	68.4	70.9
Extractives		
Ethanol–toluene, %	2.5	2.3
Cool water, %	1.6	2.3
Hot water, %	2.7	2.9
Total, %	5.6	5.1

[1]Std. dev. = 4.6 kg/m³. Std. dev. = 4.5 kg/m³.

***I. Physical and chemical properties of heartwood and sapwood in* E. nitens.**

As shown in **Fig. 2**, increasing the heartwood percentage to more than 50% leads to a reduction in the screened yield and an increase in the percentage of rejects. As mentioned, the alkali consumption was significantly higher with the increase in heartwood, as a result of the higher lignin content.

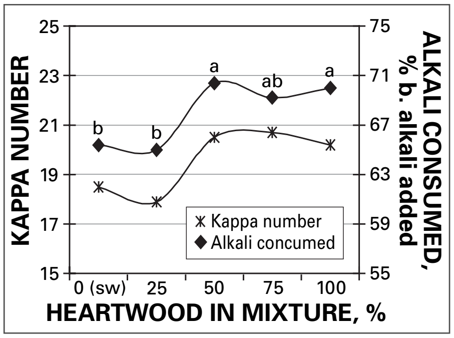
Effects on the mechanical properties of pulp

Higher ratios of heartwood should decrease the tear index of pulp, which is influenced mainly by the fiber length. The average fiber length of sapwood is longer than that of heartwood, and its tear index is 16.3% higher than the tear index of pure heartwood pulp, as **Table III** shows (9.3 mN·m²/g for sapwood vs. 8.0 mN·m²/g for heartwood).

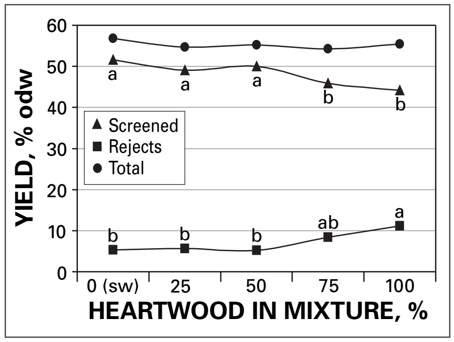
The tensile index increased by about 35% in going from pure sapwood to pure

	Heartwood, %				
	0	25	50	75	100
Kappa number	18.5	17.9	20.5	20.7	20.2
Pentosan, %	16.5	19.9	20.4	19.8	21.1
Fiber length, μm	1169	1130	1135	1116	1038
Fibers retained, %					
Higher than 14	0.75	0.5	0.8	0.3	0.8
Mesh 30	61.9	51.7	50.5	37.6	35.2
Mesh 50	25.8	29.4	30.4	38.5	36.6
Mesh 100	7.7	10.4	10.0	17.0	17.3
Less than 100	3.9	8.0	7.4	6.6	10.1
Freeness, °SR 16	17.5	16	17	18	

II. Properties of* E. nitens *kraft pulps with different heartwood contents.



1. Effects of heartwood content on the properties of kraft pulp.



2. Effects of heartwood content on the pulp yields.

Heart wood, %	Tensile index, Nm/g	Burst index, kPa·m²/g	Tear index, mN·m²/g	Bulk, cm³/g
0	48	2.9	9.3	1.83
25	58.4	4.3	10.0	1.57
50	62	3.9	8.1	1.67
75	55	3.1	8.5	1.76
100	65	4.5	8.0	1.5

III. Physical properties of the handsheets.

heartwood. The heartwood fiber has a lower wall thickness, however, which results in an 18% decrease in bulk, going from 1.83 cm³/g for sapwood to 1.5 cm³/g for heartwood.

On the whole, however, the heartwood percentage did not correlate linearly with the mechanical properties of the pulp.

CONCLUSIONS

A higher percentage of heartwood significantly affects the kraft pulping of *E. nitens.* It promotes less screened yield, a higher rejects percentage, and a higher consumption of alkali. The heartwood fibers are shorter, and their cell walls are not as thick as those of sapwood fibers. The chemical differences between heartwood and sapwood are especially important with high-molecular-weight compounds such as lignin, cellulose, and pentosan.

Increasing the heartwood percentage in the pulp generally tends to increase the tensile index and burst index and decrease the tear index and bulk. However, the correlation was not linear between the heartwood percentage and the physical properties of the pulp. **TJ**

LITERATURE CITED

1. INFOR. Technical Report. No. 163. Ed. Instituto Forestal., Santiago, Chile, 2002, p. 30.
2. Ipinza, R., Gutiérrez, B., Molina, M., and Emhart, V., *Chile Forestal.* 262: 8(1998).
3. Kibblewhite, R., Riddell, M., and Shelbourne, C., *New Zealand J. Forestry Sci.* 30(3): 458(1998).
4. Melo, R., Paz, J., Solís, A., and Carrasco, V., *Celulosa y Papel.* 7(1): 10(1991).
5. Peredo, M., *IX Reunion sobre Investigacion y Desarrollo de Productos Forestales*, Universidad del BioBio y Universidad de Concepción, Chile, 2000, p. 171.
6. Escalona, J., Gonzalez, R., and Millar, H., *Celulosa y Papel.* 16(1): 3(2000).
7. Kibblewhite, R., Johnson, B., and Shelbourne, C. *New Zealand J. Forestry Sci.* 30(3): 447(2000).
8. Muneri, A., and Raymond, C., *Wood Sci. Tech.* 35(1–2): 41(2001).
9. Kibblewhite, R., and Riddell, M., *APPITA J.* 53(3): 237(2000).
10. Molina, S., Forestry Engineer Thesis, Universidad Austral de Chile, 1996.
11. Paz, J., Melo, R., Solís, A., *et al.*, *Procesos de obtención de celulosa a partir de madera de* Eucalyptus globulus *en Chile*, Vol. V., Laboratorio de Productos Forestales, Universidad de Concepcion, 1978, p. 46.
12. Melo, R., Paz, J., Solís, A., *et al.*, OEA Project *Evaluación de recursos fibrosos en la subregión andina, los eucaliptos en Chile*, Vol. 2, Laboratorio de Productos Forestales, Universidad de Concepcion, 1979, p. 74.
13. Mariani, S., and Torres, M., Primer Congreso Chileno de Ciencias Forestales, Universidad de Chile, Chile, 2002, p. 9.
14. SAS. SAS/STAT Guide Version 6, Ed. SAS Institute Inc., 1987, p. 1028.
15. Steel R., Torrie J., *Bioestadistica: Principios y Procedimientos*, Ed. McGraw-Hill, México, 1985, p. 622.

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INSIGHTS FROM THE AUTHORS

In Chile, *Eucalyptus nitens* is becoming an important source of raw material for kraft pulping. Little research has been done on the influence of *E. nitens* heartwood on the quality of kraft pulp. Nevertheless, the *E. nitens* heartwood affects kraft pulping significantly, particularly when the heartwood volume surpasses 50%.

As a result of this research, managers of kraft pulp mills in Chile should be able to estimate the percentage of heartwood in the line production and predict the pulp quality when *E. nitens* is used as the raw material.

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