

APPLICABILITY EVALUATION OF *Cupressus lusitanica* FOR PULP PRODUCTION

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ABSTRACT

This paper aimed to study *Cupressus lusitanica* wood tracheids biometrics along radial direction and chemical analysis in order to encourage the use of new forest species for pulp production in southern Brazil. Axial tracheids anatomical analysis was held in 3 positions, in the pith-periphery direction. Total length, total diameter and lumen diameter were analyzed, and wall thickness, flexibility coefficient, wall fraction, felting index and Runkel's ratio were calculated based on these variables. Chemical analysis determined total extractives, sodium hydroxide attack degree, ash, lignin and holocellulose content. For anatomical variables, a statistically significant increase in the pith-periphery direction was observed for total length ($L = 5,85\text{mm}$), for total diameter ($D = 47,18 \mu\text{m}$), lumen diameter ($d = 32,92\mu\text{m}$) and wall thickness ($e = 14,26\mu\text{m}$) was observed stabilization from intermediate section. The species was characterized as with high rigidity tracheids ($WF = 61,73\%$), although being considered "good" for wood pulp production ($RI = 0,93$). The chemical composition showed high lignin content ($L = 36,21\%$) and low holocellulose content ($H = 59,19\%$). *Cupressus lusitanica* wood showed appropriate anatomical characteristics to be part of the pulp industry raw material supply. However, chemical properties may compromise the species use due to high lignin content.

Keywords: Cypress, felting index, fiber length, Runkel index, tracheids.

INTRODUCTION

Brazil was the 5th largest world pulp producer (softwood and hardwood) in 2000, surpassed by the United States, Canada, Japan and Finland (ABRAF 2013). However, in the last decade, industry investment and national economic development exerted great impact on pulp production (BRACELPA 2013). It provided an increase of 87,7% in pulp domestic production and 190,4% in exports. Brazil's market share in the international pulp market went from 9,6% to significant 21% (ABRAF 2013).

According to IBÁ (2015), in 2014, Brazilian pulp production increase 8,8% when compared to 2013. During that year 16,46 million pulp tons were produced, evidencing Brazil as the 4th largest world Pulp producer, only surpassed by United States, China and Canada.

The expected pulp domestic industry growth will require large forest areas planting, in addition to cold-resistant species studies, as southern Brazil states planting will be of great importance for the

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Received: 28.05.2015 Accepted: 30.07.2016

sector (Alves *et al.* 2011). Mostly because the majority of Brazilian companies producing pulp and/or paper are located in the South and Southeast regions of the country (IBÁ 2015).

The Brazil's southern region is very heterogenic, to the east, near the coast, there are important mountain chains formed by the Serra do Mar and Serra Geral mountains that constitute the highest elevations in southern Brazil. Heavy fogs frequently occur in these localities as well as snap freezes and frequent snowfalls, principally in the Serra Catarinense and Serra Gaúcha regions. Land elevation gradually diminishes westward, where the climate becomes warmer and drier (Higuchi *et al.* 2012).

Frost occurrence is very normal in the Brazil's southern region during fall and winter and produces severe damages to many *Eucalyptus* species (Soares *et al.* 2002). Thus, pine species use is essential. However, it is necessary to diversify the raw material through the study of alternative species to commonly used *Pinus* genus.

Among species with potential for southern Brazil soil and climatic conditions adaptation, *Cupressus lusitanica* (Okino *et al.* 2008) stands out. According to Shimizu *et al.* (1995), the species is suitable for plantation at elevations of 1500 m, with mean annual rainfall between 1000 mm and 1600 mm, and mean annual temperature of up to 17 °C.

This species does not have large plantation areas in Brazil, and areas are mostly directed for research or experiments. The species adapts well, with rapid growth and high annual increase, which ranges from 20 to 35 m³/ha.year, with the species being also capable of surpassing *Pinus elliottii* growth (Foelkel and Zvinakevicius 1978, Pereira and Higa 2003).

Thus, if new species that stand out for good adaptation and rapid growth are available, it is necessary to assess their country's exploitation potential and quality.

Likewise, Panches (2004) described that there is a need to study wood characteristics, since they are directly related to specific application and, depending on the final use, these properties are critical factors and must be taken into account in selecting the most suitable materials for industrial use.

Clarke and Wessels (1995) stated that for the pulp and paper industry, the quality assessment process is not limited to the product analysis. In order to increase the process efficiency, all aspects that may influence the final product quality are analyzed, and a significant part lies in raw material improvement. However, there are still little available information about *C. lusitanica* wood pulp and paper properties, and little information touch on this species in the question of its features.

In wood pulping process studies, Gomide and Colodette (2007) referred to wood quality as the main parameter, since it is directly related to the wood anatomical and chemical structures. In the pulp and paper industry, the most popular species used as raw material for pulp production, has some contributing factors which include, excellent silvicultural characteristics for commercial planting and high yield rates. Besides wood quality, which is related to fiber dimensions as length and lumen diameter, wood specific gravity between 400 - 550 kg/m³ and chemical compounds determination, highlighting cellulose and lignin (Panches 2004, Sansígolo and Ramos 2011).

Thus, this work had as objective the study of biometrics of tracheid along the radial direction and chemical analysis of the species of *C. lusitanica* in order to direct the use of the species for the production of cellulose and aiming at the determination of the ideal point for harvest.

MATERIAL AND METHODS

The wood used to carry out the study came from a 19 years old *Cupressus lusitanica* MILL., experimental stand belonging to Florestal Gateados company, located in the municipality of Campo Belo do Sul, Santa Catarina state.

Sampling

42 logs with an average diameter ranging from 20 to 40 cm were obtained, and 5 trees out of them were selected according to COPANT 458 (1972) methodology, where the raw material used to carry out the chemical analysis was obtained from the first log. For *C. lusitanica* wood tracheid analyzes, the used material was derived from an approximately 5 cm thick disc located at the 5 selected trees BHD (1,30m) height.

Anatomical analysis of *C. lusitanica* wood aimed to obtain axial tracheids in the wood radial direction with 3 positions along the discs pith-periphery gradient. Samples were obtained in the pith, intermediate and periphery positions, which correspond to pith- periphery distance intervals of 0% (A1), 50% (A2) and 100% (A3), respectively, as shown in Figure 1.

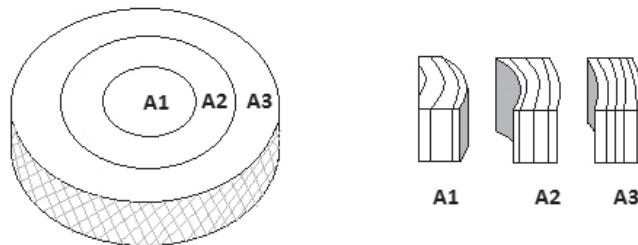


Figure 1. Specimen withdrawal position scheme for tracheids biometrics variation study.

Axial tracheids Analysis

The *C. lusitanica* small wooden fillets were obtained 40 samples for maceration technique application, following the methodology described by Franklin (1945).

Macerate samples were measured through the following variables; total length (L), total diameter (D) and lumen diameter (d) and wall thickness (e), in EUROMEX microscope, measured with the aid of lens with microns (μm) graduated reticule. According to the variables, important pulp and paper production anatomical parameters were assessed, such as: flexibility coefficient (FC), wall fraction (WF), felting index (FI) and Runkel's index (RI).

Samples chemical analysis

Analyses were performed using *C. lusitanica* 40-60 mesh sawdust (dry basis) following TAPPI standards recommendations - Technical Association of Pulp and Paper Industry (TAPPI) and ABNT-NBR, with these being described in Table 1.

Table 1. Wood chemical analysis and standards list.

Procedures	Standards
Analysis Material Preparation	T264 - cm 07*
Holocellulose Content	Through difference
Lignin Content	T222 - om 02*
Total Extractives Content	NBR 14660:2004**
Inorganic Material Content (Ashes)	T211 - om 02*
Sodium Hydroxide Solubility	NBR 7990:2010**

*Technical Association of Pulp and Paper Industry procedures **Brazilian Standards.

Statistical analysis

Data were submitted to the Kolmogorov-Smirnov's test at 5% probability. Studied material chemical variables means, standard deviation and coefficient of variation (CV%) analyses were carried out when data normality was shown. As for tracheid analysis assessment, Tukey's test (TSD) at 5% probability was applied.

RESULTS AND DISCUSSION

Dimensional tracheids analysis

Total length (L), total diameter (D), lumen diameter (d) and wall thickness (e) of wood anatomical characteristics results along radial direction are shown in Table 2.

Table 2. *Cupressus lusitanica*'s pith-periphery direction tracheid dimensions.

Section		L (mm)	D (μm)	d (μm)	e (μm)
Pith	Mean	4,79 c	45,49 b	31,55 b	13,94 b
	Minimum	3,40	27,20	13,60	6,80
	Maximum	6,30	78,20	57,80	23,80
	Standard Deviation	0,62	0,78	0,76	0,31
Intermediate	Mean	5,98 b	48,38 a	34,32 a	14,06 ab
	Minimum	4,39	27,20	13,60	6,80
	Maximum	8,69	81,60	68,00	30,60
	Standard Deviation	0,77	0,86	0,91	0,35
Periphery	Mean	6,85 a	47,67 a	32,87 ab	14,79 a
	Minimum	5,40	30,60	17,00	6,80
	Maximum	8,90	68,00	51,00	23,80
	Standard Deviation	0,82	0,67	0,63	0,30

Means followed by the same minuscule letter in the column do not differ by Tukey's test at 95% probability. (L: tracheid length; D: tracheid total diameter; d: lumen diameter; e: wall thickness).

For the analyzed variables, a statistically significant increase was observed in the pith-periphery direction for tracheid length only, wall thickness has only statistical difference between pith and periphery sections. Total diameter has pith section lower than intermediate and periphery sections. For lumen diameter, tracheids in wood intermediate portion differ from pith section and is statistically equal as periphery region.

The study material showed tracheid mean length of 5,85 mm, the values were higher than obtained for 56 years old *C. lusitanica* (2,9 mm) (Pereira and Higa 2003), 22 years old *Cryptomeria japonica* (2,21 mm) (Pereira et al. 2003), 12 years old *Pinus tecunumanii* (4,56 mm) (Shimoyama and Wiecheteck 1993), *P. caribaea* (4,08 mm), *P. patula* (3,85 mm), *P. oocarpa* (4,00 mm) ranging 28 to 35 year old (Anoop et al. 2014) and 18 years old *P. taeda* (3,03 mm) (Castelo et al. 2008). It was only similar to a 38 years old *A. angustifolia* tracheid length; 5,84 mm, obtained by Mattos et al. (2006).

The 19 years old *C. lusitanica*, wall thickness had a mean value of 14,26 μm . This was a higher result than those observed within the same species; 5,90 μm 56 year old (Pereira and Higa 2003) and 17 year old *C. lusitanica* (4,1 μm), *C. arizonica* (3,8 μm) *C. sempervirens* (4,4 μm) (Santos et al. 2014). As well as other conifers such as *C. japonica*; 5,50 μm (Pereira et al. 2003), and *A. angustifolia*; 7,30 μm (Mattos et al. 2006), *P. caribaea* (5,13 μm), *P. patula* (4,98 μm), *P. oocarpa* (5,50 μm) up to 28 year old (Anoop et al. 2014).

Species that were closer to *C. lusitanica* were *P. tecunumanii*, with 10,00 μm (Shimoyama and Wiecheteck 1993), *P. taeda*, with 9,33 μm (Castelo et al. 2008), and *P. elliottii*, with 8,80 μm (Barrichelo 1984).

Unlike previous variables, total diameter (D) and lumen diameter (d) showed constant values from the intermediate portion, with mean values of 47,18 and 32,92 μm , respectively. The 19 years old *C. lusitanica* showed values higher than *C. lusitanica* (D= 34,3 μm , d= 22,4 μm) (Pereira and Higa 2003), *C. lusitanica* (D = 22,5 μm , d = 19,5 μm), *C. arizonica* (D = 20,2 μm , d = 17,6 μm), *C. sempervirens* (D = 23,2 μm , d = 19,8 μm) (Santos et al. 2014) and *C. japonica* (D = 30,1 μm , d = 19,2 μm) (Pereira et al. 2003) for both variables.

However, values were lower than those observed in *P. tecunumanii* (D = 54,80 μm and d = 34,90 μm) (Shimoyama and Wiecheteck 1993), *P. caribaea* (D = 53,49 μm and d = 43,23 μm), *P. patula* (D = 48,52 μm and d = 34,73 μm), *P. oocarpa* (D = 49,53 μm and d = 39,55 μm) (Anoop et al. 2014), *P. taeda* (D = 53,76 μm and d = 35,11 μm) (Castelo et al. 2008), *P. elliottii* (D = 45,80 μm d = 28,20 μm) (Barrichelo 1984) and *A. angustifolia* (D = 54,95 μm and 47,65 μm) (Mattos et al. 2006).

Thus, due to fiber length and wall thickness high values and reduced total diameter and lumen diameter values, higher paper strength and higher pulp yield may be expected. However, very thick fibers tend to keep their original form, what weaken interfiber bonding, decreasing strength and burst resistance, although it means an increase in tear resistance (Shimoyama and Wiecheteck 1993).

In addition to wood characteristics, anatomical relation indexes are essential for the selection of most suitable species to certain products and uses. Pulp and paper production influential parameters of *C. lusitanica* wood is described in Table 3.

Table 3. Pulp and paper production dimensional relations.

Section		FC (%)	WF (%)	FI	RI
Pith	Mean	68,73 a	62,54 a	115,50 c	0,95 a
	Minimum	40,00	26,67	71,26	0,31
	Maximum	86,67	120,00	182,61	3,00
	Standard Deviation	7,80	15,61	1,93	0,37
Intermediate	Mean	70,12 a	59,74 a	124,10 b	0,90 a
	Minimum	45,45	20,00	85,14	0,22
	Maximum	90,00	109,09	184,46	2,40
	Standard Deviation	8,48	16,95	1,96	0,38
Periphery	Mean	68,54 a	62,92 a	132,73 a	0,95 a
	Minimum	46,15	33,33	88,94	0,40
	Maximum	83,33	107,69	181,86	2,33
	Standard Deviation	6,96	13,92	2,16	0,32

Means followed by the same minuscule letter on the columns do not differ by Tukey's test at 95% probability (FC: flexibility coefficient; WF: wall fraction; FI: felting index; RI: Runkel's index).

C. lusitanica wood tracheids relation indexes variation in pith-periphery direction showed statistical significance for the felting index only.

Among these indexes, the flexibility coefficient relates lumen diameter and fiber length, and the higher its value, the more flexible will be the fiber, with more connections being likely to occur between them, what would increase tension and burst resistance (Shimoyama and Wiecheteck 1993). Thus, *C. lusitanica* wood has a mean FC value (69,13%), being higher than values observed for *P. taeda* (66,71%) (Castelo *et al.* 2008) and *P. tecunumanii* (64,00%) (Shimoyama and Wiecheteck 1993).

Wall fraction is a relation that must be assessed in the reverse of flexibility coefficient. Values below 40% are expected, so that fibers are not too rigid (Nisgoski *et al.* 2011). However, the material under study had a mean value of 61,73%; which is much higher than *P. tecunumanii*, 36 % (Shimoyama and Wiecheteck 1993) and *P. taeda* 33,29% (Castelo *et al.* 2008), meaning that *C. lusitanica* fibers are extremely rigid, inflexible and with interconnection difficulties (Rocha *et al.* 2004).

Regarding, felting index tracheids showed higher quality along the pith-periphery gradient, so that the wood next to the periphery region has higher resistance to tearing and rupture than wood pith and intermediate sections. In order to produce good quality papers, higher than 50 felting index values are necessary (Nisgoski *et al.* 2011), what is reached on *C. lusitanica* wood.

The higher felting index mean obtained in *C. lusitanica* was of 132,75 on periphery section, Nisgoski *et al.* (2011) describes that conifers can reach values higher than 60, as obtained by Castelo *et al.* (2008) in *P. taeda*, 61,85 and Shimoyama and Wiecheteck (1993) in *P. tecunumanii*, 83.

Runkel's index showed no variation along positions, with a mean value of 0,93. The Runkel ratio is the ratio of fiber cell wall thickness to its lumen that determines the suitability of a fibrous material for pulp and paper production. If a wood species has a high Runkel ratio, its fiber will be stiff and less flexible and poor bonding ability. High Runkel ratio fibers produce bulkier paper than fibers with low Runkel ratio (Kiaei *et al.* 2014).

Fiber quality can be considered as "good", Rocha *et al.* (2004) mentions that fiber quality with up to 0,25 index is considered excellent for paper; from 0,25 to 0,50 is very good; from 0,50 to 1 is good; from 1 to 2 is regular, and above 2 may not be used for paper.

The value observed was higher than described by Anoop *et al.* (2014) with maximum values were below 0,60 for *P. caribaea*, *P. patula* and *P. oocarpa* on the same sections evaluated.

Even with high wall thickness and low flexibility coefficient, *C. lusitanica* wood showed suitable characteristics to supply the pulp and paper industry, with better RI values than some commonly used species in industry, such as *P. taeda*, with 0,52 (Castelo *et al.* 2008), *P. tecunumanii*, with 0,57 (Shimoyama and Wiecheteck 1993), and *Eucalyptus grandis*, 0,60 (Rocha *et al.* 2004).

However, contrary to Foelkel and Zvinakevicius (1975) and Pereira and Higa (2003), *C. lusitanica* wood has suitable anatomical characteristics for kraft pulp production, especially higher tear resistance compared to *Pinus sp.* species, which are commonly grown for pulp and paper production in southern Brazil.

The results also demonstrate a stabilization in the morphological parameters from the intermediate section and suggest the anticipation in the harvest of the afforestation, reducing the rotation duration.

Chemical Analysis

Results shown in Figure 2 are related to *C. lusitanica* wood chemical composition values through the following variables: total extractives, ash content, lignin content and holocellulose content.

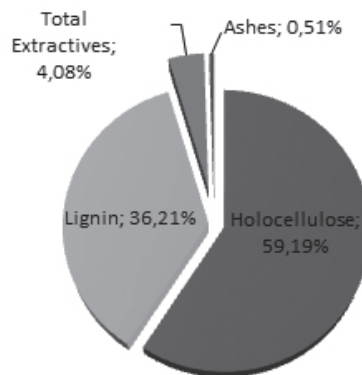


Figure 2. *Cupressus lusitanica* wood constituent levels.

Total extractives content showed values ranging from 3,56 to 4,73%; and the maximum range was of 1,17%. Klock *et al.* (2005) reported that this content usually ranges from 5 to 8% in coniferous woods.

Likewise, Pereira and Higa (2003) found 7,3% total extractives in 56 years old *C. lusitanica* plantations, while Okino *et al.* (2010) found a mean value of 4,1% for total extractives, a very close value to the one obtained in this study. In a study with *C. lusitanica*, *C. arizonica* and *C. sempervirens*, Santos *et al.* (2014) observed total extractives values of 3,87; 2,46 and 3,34% respectively.

When compared to other conifers, *C. lusitanica* total extractive levels are higher than those obtained in *A. angustifolia* 3,8% (Mattos *et al.* 2006), and lower than *C. japonica* 4,9% and *P. elliotii*, 4,98% (Pereira *et al.* 2003), *P. pinaster* (5,05%) and *P. sylvestris* (4,47%) obtained by Santos *et al.* (2014).

Wood extractives influence is of fundamental importance for species establishment, especially for forest-based industry unusual species, with main emphasis in the pulp and paper industry production processes.

Thus, extractives presence negatively affects productive pulping aspects, besides also causing increased reagents consumption, delignification reaction inhibition, equipment corrosion, pulp quality reduction and cooking liquor recovery hindering (Fengel and Wegener 1989, MIMMS 1993, IPT 1988, Sarto 2010). Therefore, species used for pulp and paper production need to have low extractive levels in its constitution, and *C. lusitanica* has acceptable extractive levels compared to already used *Pinus spp.* species.

In sodium hydroxide solubility analysis, mean values were of 18,82% higher values than those obtained by Brand and Muniz (2012) in *P. taeda* (14,24%) and *E. dunnii* (16,49%) biomass studies. However, results were lower than those obtained by Trugilho *et al.* (2005) using *Eucalyptus* clones, in which 21,69% values were shown for sodium hydroxide extractives, what states that *C. lusitanica* wood has lower low molecular weight carbohydrates removal susceptibility (hemicellulose and degraded cellulose) than some *Eucalyptus* clones used for pulp production.

Inorganic material proportion in this study was shown through ash content, which had a mean of 0,51% what is close to commonly found values for conifers. According to Aló *et al.* (2011), *Pinus sp.* wood ash content is of 0,62% while Souza *et al.* (2012) obtained 0,45% content for *P. taeda*.

Lignin results of *C. lusitanica* had mean values of 36,21% which was higher when compared to lignin contents shown to the same specie and similar age by Okino *et al.* (2010) 33,5% and Santos *et al.* (2014) 34,69%. It also corroborate with Foelkel and Zvinakevicius (1975) and Pereira and Higa (2003), who observed lignin values of 33,53% and 29,9% respectively.

The lignin content of *C. lusitanica* wood showed higher values than those observed for *C. sempervirens*, 33,50% (Santos *et al.* 2014), *P. elliottii*, 27,23% (Pereira and Higa 2003), *P. caribaea* (29,54%), *P. patula* (26,20%), *P. oocarpa* (23,80) (Anoop *et al.* 2014), *P. pinaster* (29,12%), *P. sylvestris* (28,48%) (Santos *et al.* 2014), *C. japonica* 32,7% (Pereira *et al.* 2003), *A. angustifolia* 27,8% (Mattos *et al.* 2006), *Eucalyptus sp.*, 27,5% obtained by Gomide *et al.* (2005) and six *E. globulus* genotypes that vary up to 23,8% to 28 % (Aguayo *et al.* 2015). The high lignin proportion in *C. lusitanica* wood affects cellulose-pulping process, where high percentages influence paper yield, brightness and bleachability (Fengel and Wegener 1989, MIMMS 1993, Dueñas 1997).

Holocellulose is the constituent with the highest wood proportion in *C. lusitanica*, totaling 59,19%. However, the holocellulose content obtained was lower than what is expected for the species, and also low when compared to other conifer species. Okino *et al.* (2010) reported that, for the same species and with similar age 71,8% holocellulose values were observed, corroborating with Foelkel and Zvinakevicius (1975), who obtained 71,6% holocellulose and Pereira and Higa (2003), using 56 years old *C. lusitanica* wood obtained 62,6% holocellulose.

Comparative to other species, like *P. elliottii*, 67,78% (Pereira and Higa 2003), *C. japonica* 65,6% (Pereira *et al.* 2003), and *A. angustifolia*, 68,4% (Mattos *et al.* 2006) holocellulose values were lower. In the present study, holocellulose value was superior only to *P. caribaea* (33,54%), *P. patula* (40,32%) and *P. oocarpa* (47,55%) obtained by Anoop *et al.* (2014).

CONCLUSIONS

It was concluded that *C. lusitanica* wood has adequate anatomical characteristics to be part of the pulp and paper industry raw material, such high tracheid length, high felting index and good Runkel's index. The values stabilization from the intermediate section for the majority of the features analyzed can suggest a harvest anticipation, which reduces the crop cycle and increases the economic gain.

However, chemical properties, especially the high lignin content and low holocellulose content, compromised the process yield and also increase the production cost of *C. lusitanica* wood in bleached paper. Thus, the species is more suitable for packaging and industrial bags production.

ACKNOWLEDGEMENTS

The authors thank FAPESC for granting the scholarship and for the financial support. The authors also express their thanks to the Gateados Florestal company for the raw material used in this study donation.

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