

WOOD QUALITY OF *Pinus patula* Schltl & Cham FOR THE PULP PRODUCTION

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ABSTRACT – The softwood pulp industry is based on the supply of *Pinus taeda* and *P. elliottii* woods, and competes for this raw material with other timber sectors. The study aimed to evaluate the wood quality of *Pinus patula* for pulp and paper production. Trees aged 14 years were obtained from a plantation located in Ponte Alta do Norte, State of Santa Catarina/Brazil. Discs were collected along the commercial height for determining the weighted basic density and its longitudinal variation in the trees, and the chemical composition. For the anatomical characterization, a disc was extracted from the base of each tree to determine the radial variation of tracheids morphological characteristics, and their quality indexes for the production of kraft pulp. The weighted basic density (365 kg.m^{-3}) of the wood was low when compared with other species of the same genus. Regarding the tracheids morphology, a mean length of 2.37 mm; wall thickness of 5.49 μm ; width of 40.32 μm and a lumen diameter of 29.09 μm were observed. The chemical composition of the species showed low contents of lignin (25.06%) and ashes (0.27%), compatible content of holocellulose (70.76%), and high content of extractives (6.24%) compared with conifers of traditional use. In general, *P. patula* species shows characteristics compatible with those traditionally used for the pulp and paper production, and it should be considered in more advanced studies with this species in this segment.

Keywords: Tracheids; Basic density; Chemical composition.

QUALIDADE DA MADEIRA DE *Pinus patula* Schltl & Cham PARA PRODUÇÃO DE CELULOSE

RESUMO – O setor de polpa celulósica de fibra longa tem como base de suprimento as madeiras de *Pinus taeda* e *P. elliottii* e compete por essa matéria-prima com outros setores madeireiros. O estudo objetivou avaliar a qualidade da madeira de *Pinus patula* para a produção de polpa e papel. Árvores com 14 anos foram obtidas de um plantio localizado em Ponte Alta do Norte/SC. Foram coletados discos ao longo da altura comercial para determinação da densidade básica ponderada e sua variação longitudinal nas árvores e da composição química. Para caracterização anatômica extraiu-se um disco da base de cada árvore para determinação da variação radial das características morfológicas de traqueídeos, e os índices de qualidade dos mesmos para produção de polpa celulósica. A densidade básica ponderada da madeira (365 kg.m^{-3}) foi baixa quando comparada com outras espécies de mesmo gênero. Quanto à morfologia dos traqueídeos, observou-se comprimento médio de 2,37 mm; espessura da parede de 5,49 μm ; largura de 40,32 μm e diâmetro do lume de 29,09 μm . A composição química da espécie mostrou baixos teores de lignina (25,06%) e cinzas (0,27%), compatível teor de holocelulose (70,76%), e alto teor de extrativos (6,24%) em relação as coníferas de uso tradicional. De maneira geral a espécie *P. patula* demonstra características compatíveis com as tradicionalmente empregadas para produção de polpa e papel e que devem ser levadas em consideração nos estudos mais avançados com esta espécie nesse segmento.

Palavras-Chave: Traqueídeos; Densidade básica; Composição química.



1. INTRODUCTION

Among the different genres of wood-producing tree species of economic interest globally, *Pinus* genus is among the most successful in view of the rapid growth and diversity of species, being the main source of raw material for the forestry-based industry (Juízo et al., 2015). The State of Santa Catarina has the second largest area with *Pinus* plantations in Brazil, representing 34% of the total of 1.6 million hectares, according to the data from the Brazilian Industry of Trees (2017), and the major representatives of the genus in the State are *P. taeda* L. species, followed by the *P. elliottii* Engelm.

According to Bassa et al. (2007) the wood of species of *Pinus* genus is known for its long fibers (tracheids measure between 3 and 6 mm in length) and, consequently, results in papers with high physical-mechanical resistances. According to the data of the Brazilian Industry of Trees (2017) in 2006 Brazil occupied the 2nd position among the world's largest producers of pulp with a total of 18.8 million tons, and from which, 2.1 million were represented by the softwood pulp sector. Regarding the paper production, in which the country occupies the 8th position among the largest producers, this production was 10.3 million tons, which includes the production volumes of cardboard, packaging and newsprint, which use the conifers wood as raw material.

Despite the *Pinus patula* Schltldl. & Cham species belonging to the second most cultivated genus in Brazil, it is noticed that there is little information on the technological potentialities of its wood growing in the State of Santa Catarina.

According to Gillespie (1992), *Pinus patula* species has its natural occurrence in some States of Mexico, and may be spread in a range between latitudes 13° and 24°N and longitudes 85° 100°W.

According to Gillespie (1992), the species is probably one of those with the greatest growth among the tropical of the genus. In Brazil, the species has higher productivity than *Pinus taeda* L. in higher locations, such as Serra da Mantiqueira, the Southeast of Minas Gerais, Northeast of São Paulo and West of Santa Catarina, in addition to the mountain region of Rio Grande do Sul (Pinusletter, 2009).

As a result of the climatic conditions favorable to the planting of species of *Pinus* genus in the State of

Santa Catarina, it is important to conduct studies that check the quality of the wood that has been produced from species of non-traditional uses, aiming to diversify the forest base of the State.

In addition, the comparison of the wood quality of *P. patula* intended to the production of pulp and paper with that registered for other conifers of the same genus with consolidated knowledge in terms of density, morphology, and chemical composition of its wood, will allow inferring on the suitability of this raw material for use in this segment given the influence of the referred parameters in the process of obtaining the pulp itself, and in the characteristics of the produced paper.

This study aimed to evaluate the wood quality of *Pinus patula* Schltldl. & Cham for pulp and paper production.

2. MATERIAL AND METHODS

For this study, three trees of *P. patula*, 14 years old, of good forest form were randomly selected from a planting in the city of Ponte Alta do Norte, Santa Catarina. After the cut, was determined the diameter at breast height (DBH) and total and commercial heights with measuring tape, resulting in mean values of 25.5 cm, 21.4 m and 17.6 m, respectively. For measuring the commercial height, the trunk position corresponding to the diameter at the thin end of 8.0 cm was considered.

For determining the weighted basic density, discs with 3.0 cm of thickness were sampled in the positions corresponding to the base, 25, 50, 75 and 100% of the commercial height, and one additional disc in the DBH position (1.30 m). From each disc two wedges were extracted for the procedures for determining the discs basic density.

2.1. Weighted basic density

For determining the basic density the produced wedges remained immersed in water for approximately 30 days in order to ensure the full saturation of the material. Subsequently, the barks were removed and the saturated volume was determined. Later they were placed to dry in a forced air circulation oven at a temperature of 103°C±2°C until a constant mass for determining the dry mass.

The basic density of each disc was determined from the basic density average of the two wedges. These values were weighted in function of the volume of logs generated by the extraction of discs, according to Vital (1984).

2.2. Anatomical characterization

For this procedure, a disc from the base of each tree was sampled and from them a radial baguette was made, going through the pith, for the extraction of fragments in the positions referring to 0%, 25%, 50%, 75% and 100% of the radius length of the discs for maceration.

The fragments of each position were placed inside test tubes and subjected to the individualization procedure of tracheids with solution containing nitric acid, acetic acid, and water (5:2:1) in a water bath at approximately 100°C for 1 hour.

After the maceration process were made laminas with samples of each radial position. For obtaining the images the ToupView software was used with a magnifier and the LAS EZ software was used with microscope with a coupled digital camera. For each tree and in each position of the radius length of the discs the parameters of length (mm), width (μm) and diameter of the lumen (μm) of tracheids were measured based on the standards of IAWA (Iawa Committee, 1989), using a specific software for measurement.

After determining these parameters was calculated: cell wall thickness, wall fraction, flexibility coefficient and Runkel Index, for each tracheid.

2.3. Chemical characterization

For determining the wood chemical composition discs from the same sampling positions of the basic density were extracted (base, DBH, 25, 50, 75 and 100% of the trees commercial height). From each disc a wedge was made and these were transformed into chips and then into sawdust using the Willey-type mill. The sawdust resulting from the wedges extracted in each longitudinal position was mixed, generating a composite sample of each tree. After this process, the samples were classified in 40 and 60 mesh sieves, and used the material retained in the 60 mesh sieve.

Triplicates were made for determining the contents of ash, total extractives, Klason lignin, and holocellulose for each tree, following the standards

provided by the Technical Association of the Pulp and Paper Industry – TAPPI (2007).

The procedure for determining the ash content was conducted according to the TAPPI standard (T211 cm – 93). The determination of the total extractives content followed TAPPI standard (T264 cm – 97). For the analysis of Klason lignin the TAPPI methodology (T222 cm – 98) was followed. The determination of the holocellulose content was calculated from the difference of the wood total components, subtracting the previously calculated components (ashes, extractives and lignin).

2.4. Statistical analysis

For the analysis of the longitudinal variation data of the basic density and radial variation of the wood morphological parameters the variance analysis (ANOVA) was conducted, and the differentiation between the averages was made by the Tukey test at 95% of reliability, using the SPSS “Statistical Package for Social Science” software (version 15.0 for Windows). The chemical composition comprised a descriptive statistical analysis.

3. RESULTS

The mean value found for the weighted basic density of the commercial volume of the evaluated *P. patula* trees was $365 \text{ kg}\cdot\text{m}^{-3}$ (CV=8.614%). Regarding the longitudinal variation of the basic density (Figure 1) a reduction trend of basal position of the trees towards the top was observed.

The mean test indicated a difference between the basic density values of the extreme positions of the species stalk (0% and 100% positions of the trees), which did not differ statistically from the intermediate positions.

In Table 1 the values referring to the anatomical characterization of the tracheids of the *P. patula* wood can be observed.

Figure 2 describes the radial behavior of the morphological parameters of the evaluated wood of *P. patula*.

Regarding the tracheids length (Figure 2), an increase of means in the radial direction is observed, without a stabilization trend, as it can be seen with the mean tests.

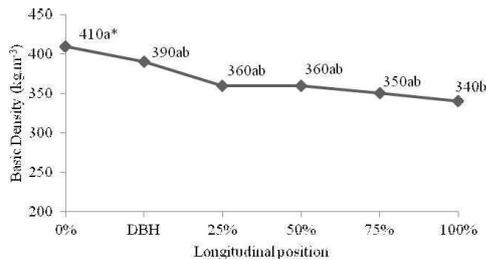


Figure 1 – Basic density of *P. patula* wood along the commercial length of the stalk. * Means followed by the same letter do not differ statistically according to the Tukey test at 95% probability.

Figura 1 – Densidade básica da madeira de *P. patula* ao longo do comprimento comercial do fuste da espécie. *Médias seguidas pela mesma letra não diferem estatisticamente de acordo com o teste de Tukey a 95% de probabilidade.

The means found for the fibers width (μm), lumen diameter (μm) and wall thickness (μm), did not differ statistically between the radial positions.

Table 2 contains the mean of quality indicative coefficients of the *P. patula* wood for the pulp and paper production.

For the evaluated species an ash content of 0.27%, 6.24% of extractives, 25.06% of lignin, and 70.76% of holocellulose were found.

4. DISCUSSION

4.1. Weighted basic density

The value found for the basic density of the commercial wood volume of the species of *P. patula* (365 kg.m^{-3}) was lower than those recorded by Xavier (2009) (384 kg.m^{-3}) and Mattos et al. (2011) (413 kg.m^{-3}) in the wood of *P. taeda* at 16 and 13 years, respectively, and also compared with the *P. elliottii* wood evaluated by Rigatto et al. (2004) (383 kg.m^{-3})

and Pereira and Tomaselli (2004) (490 kg.m^{-3}) at 12 years.

Regarding the already verified for the *P. patula* wood the value is very close to that of Juizo et al. (2015) at 38 years, from Mozambique (370 kg.m^{-3}), lower than the recorded by Moura et al. (1991) (409 kg.m^{-3}), in 12-year-old trees and higher than the recorded by Tavares (2017) (320 kg.m^{-3}) and Rios et al. (2018) (307 kg.m^{-3}) for this species at 12 and 9 years, respectively.

The climatic and edaphic conditions of the growth site and their interaction with the genetics of the species are factors that may influence in the variation of the basic density among individuals of the same species, which can justify the observed differences.

According to Nisgoski (2005) species of *P. taeda* planted in Brazil show faster growth, producing a lower density wood compared to species cultivated in the south of the United States, which elucidates the influence of the genetic and environmental factor interaction in this characteristic.

Regarding the longitudinal variation of the basic density Suardi Junior (2016) and Melo et al. (2013) verified the same behavior of density decreasing in the longitudinal direction in species of *P. taeda* at 6.5 years and *P. elliottii* at 14 years, respectively.

The behavior of the mean test is the same recorded by Trianoski et al. (2013) with the *P. caribaea* var. *hondurensis* and *P. oocarpa* species with ages between 17 and 18 years. This factor is probably due to the presence of compression wood, greater amount of adult wood at the base of the trees and lower at the top (Siqueira, 2004).

Table 1 – Minimum, maximum and mean dimensions for length, wall thickness, width and lumen diameter of tracheids of *P. patula* wood.
Tabela 1 – Dimensões mínima, máxima e média para comprimento, espessura de parede, largura e diâmetro de lume dos traqueídeos da madeira de *P. patula*.

| | Dimensions | | | |
|---------|-------------|----------------------------------|-------------------------|----------------------------------|
| | Length (mm) | Wall thickness (μm) | Width (μm) | Lumen diameter (μm) |
| Minimum | 1.31 | 3.50 | 33.12 | 19.04 |
| Maximum | 3.74 | 10.03 | 46.89 | 35.21 |
| Mean | 2.37 | 5.49 | 40.32 | 29.09 |
| SD | 0.79 | 1.89 | 4.43 | 4.60 |
| CV (%) | 33.33 | 34.43 | 10.99 | 15.81 |

SD= standard deviation; CV= Coefficient of variation.
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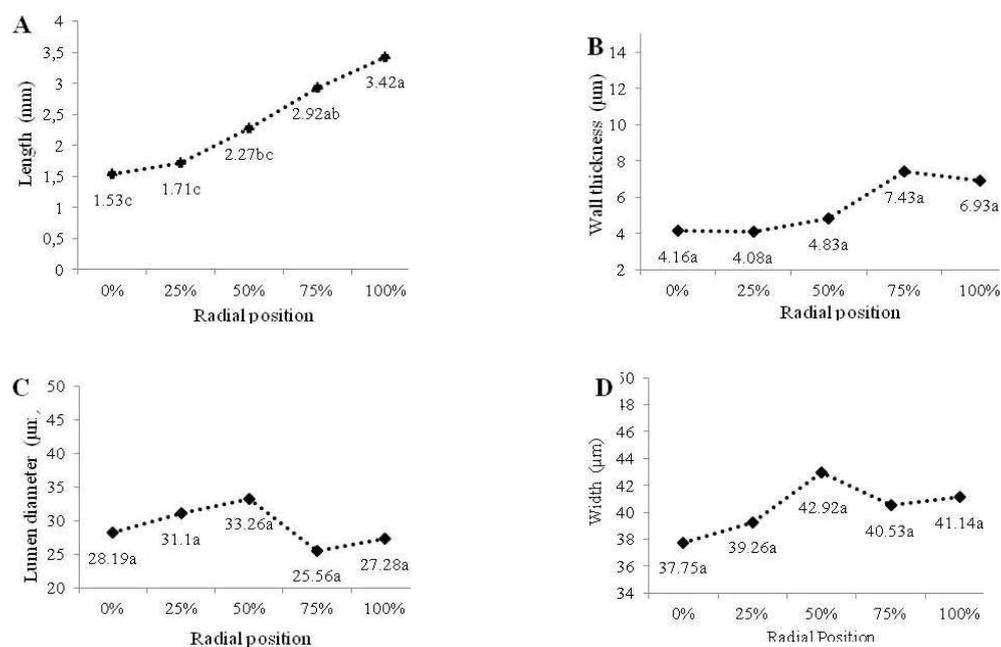


Figure 2 – Radial variation of the length (mm), thickness (µm), width (µm) and lumen diameter of tracheids (µm) of *P. patula* wood at 14 years.

Figura 2 – Variação radial do comprimento (mm), espessura (µm), largura (µm) e diâmetro de lume de traqueídeos (µm) da madeira de *P. patula* aos 14 anos.

Table 2 – Indicative coefficients of quality of tracheids from *P. patula* wood of at age 14 as a function of radial position.
Tabela 2 – Coeficientes indicativos de qualidade dos traqueídeos de *P. patula* aos 14 anos em função da posição radial.

| | Radial position (%) | | | | | Mean |
|-----------------------------|---------------------|-------|-------|-------|-------|-------|
| | 0 | 25 | 50 | 75 | 100 | |
| Wall fraction (%) | 23.01 | 21.04 | 23.00 | 37.49 | 35.07 | 27.92 |
| Flexibility coefficient (%) | 76.99 | 78.96 | 77.00 | 62.51 | 64.93 | 72.08 |
| Runkel index | 0.30 | 0.27 | 0.32 | 0.66 | 0.60 | 0.43 |

The homogeneity present along the stalk in the specie of *P. patula* is an important characteristic for the wood use, which may be associated with the presence of juvenile wood with relatively lower densities (Vale et al. 2009).

According to Foelkel (2015) Brazilian pulp and paper plants use wood with basic density between 400 and 600 kg.m³, classifying the studied species a little below the minimum margin of this classification. For the same author, woods with lower densities, in general, favor the impregnation of the chips, and require a lower load of alkali at certain temperatures and cooking time. However, regarding the specific consumption of wood (m³/t pulp) Gomide et al. (2010) mention the fact that the use of denser wood implies

lower consumption of wood (m³/t pulp), which favors the pulp production in the digester and the maintenance of the chips stack volume in the industry.

4.2. Tracheids morphology

Regarding the information available in the literature with species of consolidated use in the production of kraft pulp, the mean value recorded for the tracheids length (2.37 mm) is similar to that observed by Andrade (2006) in a study with *P. taeda* (2.41 mm) and to the observed by Pereira and Tomaselli (2004) with *P. elliottii* (2.38 mm), both at 14 years. And regarding other studies with *P. taeda* wood of close age like Nisgoski (2005) at 14 (3.47 mm) and 15 years (3.38 mm), Sousa et al. (2007) at

13 years (3.11 mm) and Rigatto et al. (2004) at 12 years (3.43 mm) the value recorded for the tracheids length was lower, which is a disadvantage in relation to the paper resistance.

Nisgoski (2005) reports that the great variation of tracheids length in the tree and between the trees can be influenced by position of stalk, population density, site, geographic location, and silvicultural practices, which may justify the observed differences.

Regarding the wall thickness, the mean value recorded (5.49 μm) was lower than the study of Sousa et al. (2007) for *P. taeda* at 13 years (8.31 μm) and *P. elliotti* (10.13 μm) (Pereira and Tomaselli, 2004) at 14 years. Regarding the *P. taeda* wood at 15 years evaluated by Nisgoski (2005) (5.90 μm) and Rigatto et al. (2004) (4.51 μm) the value was similar. The reduced wall thickness of the *P. patula* tracheids is a competitive advantage given that for Shimoyama and Wiecheteck (1993) very thick fibers are more rigid and tend to maintain their original shape, not collapsing in the formation of the paper, which can impair the interfibers bonds, decreasing the tensile and bursting resistances, and increasing the tear resistance.

Regarding the tracheids width (40.32 μm), the mean found is close to that observed by Foelkel et al. (1976) with *P. elliottii* (40.62 μm) and Nisgoski (2005) with *P. taeda* (38.94 μm), both with individuals of 14 years and at 42.59 μm by Rigatto et al. (2004) in wood of 12 years. However, compared with the reported by Pereira and Tomaselli (2004) in *P. elliotti* at 14 years (46.5 μm), and mean was lower.

Concerning the lumen diameter of tracheids the mean value of 29.09 μm is higher than that found by Foelkel et al. (1976) in *P. elliottii* (25.4 μm), to the *P. taeda* wood evaluated by Pereira and Tomaselli (2004) (26.26 μm) and Nisgoski (2005) (26.80 μm and 23.36 μm , at 14 and 15 years, respectively). Wider and shorter tracheids, with thinner wall thickness and bigger lumen diameter have a greater permeability power of the liquor when cooking, also facilitating the penetration of chemical reagents in wood (Rigatto et al. 2004), which denotes a comparative advantage of the evaluated *P. patula* wood.

Regarding the radial variation in the tracheids length (Figure 2A) the mean test reveals an absence of stabilization in this parameter. Ballarin and Palma (2003) when evaluating the radial extension of the adult and

juvenile wood in *P. taeda* species, based on the length of axial tracheids, observed that in the mentioned species, of the same genus of the one evaluated in this study, the juvenile wood region occurred from the center of the tree to the 14th growth ring, and the transition wood started to occur between this and the 18th ring. Although it should be considered that the growth conditions influence the characteristics of the wood formed by a particular species, anticipating or extending the formation age of the adult wood, the absence of stabilization of the tracheids length can be attributed to the fact of the positions evaluated for the *P. patula* wood at 14 years of age being supposedly included in the formation range of the juvenile wood, which in the study of Ballarin and Palma (2003) was extended until 14 years.

According to Trianoski (2012) the fibers width is associated with the growth rate of the trees, in which the high growth periods result in wider cell elements and with bigger lumen diameters. Therefore, the peak recorded in the position corresponding to 50% of the radial distance of the pith (Figures 2C and 2D) compared with the mentioned parameters may be attributed to the fact that such sampling position was allocated in a region corresponding to early wood due to the high portion of this type of ring in response to favorable growth conditions.

In the pulp and paper production the tracheids dimensions exert a direct influence in the process variables, especially in the refining degree, paste quality and consequently in the physical-mechanical properties of the paper (Trianoski, 2012).

According to Table 2, it is observed that the calculated Runkel index is between 0.25 – 0.50, placing the *P. patula* wood at 14 years in the group II according to Vasconcelos (2005). Woods belonging to this classification group are defined as very good for the quality in the paper production. Therefore, the tracheids of the studied wood species are subject to a higher degree of collapse, which makes them have a greater contact surface among themselves, promoting a greater tensile and bursting resistance in the paper production, differing from the species of higher Runkel index.

The high mean value of the flexibility coefficient (72.08%) confirms the greater susceptibility to flattening of tracheids in paper production, with gains

in resistance to the obtained product.

The quality of *P. patula* tracheids for the purpose of pulp and paper production is confirmed by the calculated mean value of the wall fraction, given that Foelkel and Barrichelo (1975) mentioned that values above 40% do not produce good quality pulp, because the fibers are extremely rigid and little flexible. According to Watson and Dadswell (1961) the smaller the wall fraction the larger the stretching, resistance to bursting and paper tensile, making the fibers more flexible and facilitation the binding between them, which is an advantage of the *P. patula* wood in the production of papers that demand resistance.

Trianoski (2012) in a study of *P. taeda* wood between 17 and 18 years observed a wall fraction of 36.82%, flexibility coefficient of 63.18% and Runkel index of 0.63, distant from the values found in the study, i.e., all indexes show a lower suitability of this species at this age for application in the paper production. The values found by Nisgoski (2005) for the *P. taeda* species at 14 and 15 years of ages compared to the wall fraction (31.20% and 30.92%), flexibility coefficient (68.80% and 69.08%) and Runkel index (0.45 for both ages) respectively, are close to the values found for the *P. patula* species of this study. In the study of Foelkel et al. (1976) with the *P. elliottii* species of the same age of the species in the study, Runkel index values of 0.62, wall fraction of 38%, and flexibility coefficient of 63% were observed. With that, the *P. patula* wood is within the values reported in the evaluations conducted with the main species of conifers used in the pulp and paper production sector.

4.3. Chemical composition

The holocellulose content observed for *P. patula* (70.76%) is close to that found by Andrade (2006) for the *P. taeda* wood at 14 years (71.90%) and higher than that reported for the same species at 10 years (58.67%) (Picinatto Filho et al., 2015) and at 12 years (68.81%) (Rigatto et al. 2004). According to Vasconcelos (2005) the holocellulose value is related to the process yield, and with this, its value should be high, which evidences a positive characteristic of the evaluated *P. patula* wood.

The registered percentage of 25.06% in lignin is low compared with the species of *P. taeda* (33.43%)

(Picinatto Filho, 2015), 27.36% (Andrade, 2006), 28.14% (Rigatto et al., 2004) and 29.75% (Pereira and Tomaselli, 2004). This is an advantage of the evaluated wood, given that the lignin content negatively affects the yield, since the main objective of the kraft pulping is to separate the cellulose fibers by removing the lignin, but it is pointed out, according to Carvalho et al. (2014) that not only the amount of lignin interferes in the dynamics and efficiency of the pulping, but the lignin type also influences the delignification degree and/or saving of the process.

The extractives content (6.24%) obtained is close to the 6.00% recorded by Picinatto Filho (2015) for *P. taeda* but higher than that already reported in most studies for this species (2.44%) (Andrade, 2006), (2.99%) (Rigatto et al. 2004), and for *P. elliottii* (3.0%) (Balloni, 2009). Taking into account the extractives content observed in other studies also with the *P. patula* wood, such as Shimoyama and Wiecheteck (1993) (4.10%) and Mohareb et al. (2012), (3.7%) it is observed that this constituent tends to be high in this species. This characteristic of the *P. patula* wood can negatively influence the yield, given that there is an intense removal of these constituents during the pulping (Gomide et al., 2010). However, when considering the recovery of by-products during the pulping process (Kraft) the highest content of extractives can be a positive characteristic. Tall oil and turpentine are the components of black liquor that have been extracted for longer and more widely in the conifers kraft plants, and today are burned in the recovery boiler and lime kiln, respectively (Centro Tecnológico em Celulose e Papel, 2016).

The ash content (0.27%) can be considered low and is compatible with that already reported in studies with *P. taeda* (0.27%) (Andrade, 2006) and lower than the 0.35% recorded by Picinatto Filho et al. (2015). This mineral residue can cause problems such as clogging, corrosions and incrustations in industrial equipment, and therefore, the low ash content is expected avoiding problems in the operations (Freddo et al., 1999), and which is met by the evaluated wood.

5. CONCLUSION

The *P. patula* wood has a low basic density for the pulp production, and this fact may be associated with a large presence of juvenile wood.

The basic density in the longitudinal direction of stalk trended a reduction, with only the means of extreme values differing statistically between each other, which shows the homogeneity of this parameter in the evaluated wood.

The chemical composition of the species showed low contents of lignin and ashes, but high content of extractives compared with the main species of the *Pinus* spp. genus used in the kraft pulp and paper production.

The parameters of wood quality indicators for the paper production show a good potential of the *P. patula* wood for this purpose, which is within the values found for the *P. taeda* species traditionally used in this segment.

The *P. patula* wood shows desirable characteristics for the pulp and paper production regarding the calculated quality indicative coefficients. Although the species has the potential to adapt to the climatic conditions of the State of Santa Catarina, its use is scarce in the various segments of the paper industry.

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