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Articles

Comparative study of the chemical components of *Pinus taeda* wood in kraft pulping

Estudo comparativo dos componentes químicos da madeira de *Pinus taeda* na polpação kraft

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ABSTRACT

This study aimed to produce kraft pulps from *Pinus taeda* wood and evaluated the efficiency of the pulping process based on pulp quality, considering the chemical composition of its components. Industrial wood chips of *P. taeda*, approximately 16 years old, from commercial plantations of a pulp and paper company in Santa Catarina, Brazil, were used. The chips were classified manually to eliminate oversized ones with the aid of a sieve, and subsequently eliminate knots and fines. For the chemical analyses of the wood, part of the chips was converted into sawdust using a Willey-type mill. The kraft pulping was carried out in a 20-liter capacity electrically heated rotary laboratory digester (Regmed). The physicochemical analyses of the wood and brown kraft pulp included: moisture, ash, total extractives, lignin, holocellulose, and alpha-cellulose. The contents of chemical components (extractives, Klason lignin, holocellulose, alpha-cellulose, and ash) retained in the pulp and removed from the wood during cooking were determined. *P. taeda* wood presented chemical characteristics favorable for kraft pulp production, notably due to its low contents of total extractives (3.76%) and lignin (27.76%) and its high carbohydrate content (holocellulose de 59.61% e alpha-cellulose de 50.66%). Furthermore, its potential use as raw material for brown kraft pulp production is evident.

Keywords: Chemical components; Cellulose yield; Pulp quality

RESUMO

Este estudo teve como objetivo produzir polpas kraft da madeira de *Pinus taeda* e avaliou a eficiência do processo de polpação a partir da qualidade das polpas com base nos teores de seus componentes químicos. Utilizou-se cavacos industriais da madeira de *P. taeda* com idade aproximada de 16 anos, de plantios comerciais de uma empresa do setor de Celulose e Papel, em Santa Catarina, Brasil. Os cavacos foram classificados manualmente e posterior eliminação de nós e finos. Para as análises químicas da madeira, parte dos cavacos foi transformada em serragem, utilizando-se o moinho tipo Willey. A polpação kraft foi realizada em digestor laboratorial Regmed rotativo, aquecido eletricamente e dotado de uma célula com capacidade de 20 litros. As análises físico-químicas da madeira e da polpa kraft marrom de pinus foram: umidade, cinzas, extrativos totais, lignina, holocelulose e alfa-celulose. As determinações do percentual de componentes químicos (extrativos, lignina Klason, holocelulose, alfa-celulose e cinzas) retidos na polpa celulósica e removidos da madeira durante o cozimento. A madeira de *P. taeda* apresentou características químicas favoráveis para produção de polpa celulósica kraft, destacando-se pelos baixos teores de extrativos totais (3,76%) e lignina (27,76%), e elevado teor de carboidratos (holocelulose de 59,61% e alfa-celulose de 50,66%). Além disso, é possível indicar seu uso potencial como matéria-prima para a produção de polpa kraft marrom.

Palavras-chave: Componentes químicos; Rendimento de celulose; Qualidade da polpa celulósica

1 INTRODUCTION

The industrial processes employed in the conversion of wood into cellulosic pulp normally involve the total or partial removal of lignin, applying a cooking liquor to the wood. Among these processes, kraft pulping is the most widely used chemical method and is characterized using a cooking liquor composed of sodium hydroxide (NaOH) and sodium sulfide (Na_2S), under high temperature and pressure, to individualize the cellulose fibers that constitute the lignocellulosic biomass (Fernandes et al., 2025).

In this context, the quality of the wood and the proportions of its chemical constituents exert a strong effect on the efficiency of the pulping process and on the quality of the cellulosic pulp produced. Among the chemical constituents of wood are carbohydrates, which include cellulose and hemicelluloses, lignin, extractives, and inorganic components.

Cellulose and hemicelluloses are the most desirable polymers, as they are directly related to increased yield and to the physical and mechanical properties of the pulp, whereas lignin and extractives, in turn, represent the main constraints, requiring greater consumption of chemical reagents and affecting brightness and viscosity (Dias; Simonelli, 2013; Ramos et al., 2024). According to Ramos et al. (2024), a high holocellulose content positively influences the yield of pulping processes. Conversely, woods with higher lignin contents show lower yield and higher kappa number, requiring higher alkali charge and more severe cooking conditions. In addition, Dias and Simonelli (2013) state that lignin is the most undesirable compound, as it requires a larger amount of alkali for delignification. Likewise, extractives, although representing a small fraction, consume more cooking and bleaching reagents and reduce pulp brightness, thus being considered undesirable for the process (Ramos et al., 2024).

Therefore, comprehensive knowledge of the cellulose, hemicellulose, lignin, and extractive contents of wood is essential to optimize the parameters of the kraft pulping process, since the efficiency of pulping is directly related to the proportion of the chemical components of the wood and to the alkali charge of the cooking liquor (Mboowa, 2024).

In the production of cellulosic pulps, it is also important to highlight that woods with high lignin content, such as those of the genus Pinus, often require higher alkali charges and longer cooking times to achieve adequate lignin dissolution. Moreover, the structure of lignin, particularly the ratio between syringyl and guaiacyl units (S/G), has a strong effect on the pulping process, such that lignins composed exclusively of guaiacyl units, as those present in pine woods, are more condensed and less susceptible to alkaline attack, requiring higher concentrations of chemical reagents and longer cooking times (Manoel et al., 2024).

Severe pulping conditions, such as high alkali charge and prolonged cooking time, can compromise the quality of cellulose fibers, reducing pulp yield and, consequently, the performance of its derived products (Iglesias et al., 2020). Therefore, it is essential to conduct studies that evaluate cooking conditions for the production of cellulosic pulps with high cellulose contents, especially from woods of the genus Pinus.

The wood of the species *Pinus taeda* has been used as a suitable raw material to produce kraft cellulosic pulp. In Brazil, the planted area of the genus exceeds 1.9 million hectares, corresponding to 19% of the total forest sector, with emphasis on two species, *Pinus taeda* and *Pinus elliottii* (IBÁ, 2024). Known in the pulp and paper industry as long-fiber wood, pine cellulosic pulp is used in the manufacture of various products such as paperboard, corrugated board, and newsprint (Vivian; Modes; Caetano, 2020).

Based on the considerations presented above, the present research produced kraft pulps from *Pinus taeda* wood and evaluated the efficiency of the pulping process based on pulp quality according to the contents of their chemical components.

2 MATERIALS AND METHODS

In this study, industrial wood chips of *Pinus taeda*, approximately 16 years old, were used. They originated from commercial plantations of a pulp and paper company located in the state of Santa Catarina, Brazil. The chips were classified manually to eliminate oversized ones with the aid of a sieve, and subsequently eliminate knots and fines. After air-drying, they were stored in polyethylene bags to ensure uniformity and moisture preservation.

For the chemical analyses of the wood, part of the chips was converted into sawdust using a Willey-type mill. The sawdust, after being classified through 40 and 60 mesh sieves, was air-dried and stored in hermetically sealed glass containers.

The kraft pulping was carried out in a Regmed laboratory rotary digester, electrically heated and equipped with a 20-liter capacity cell. In a preliminary stage, experimental cookings were performed with different alkali charges in order to determine the optimal parameters for obtaining brown pulp with a Kappa number of 30±5. A total of 1,500 g of absolutely dry chips was added, with a liquor-to-wood ratio of 4:1. The brown kraft pulps were produced under the following cooking conditions: temperature of 170 °C, H-factor of 1760, sulfidity of 25%, and active alkali of 17%. The cookings were carried out in duplicate.

After cooking, samples of the residual liquor were collected to determine pH and residual alkali. The softened chips were thoroughly washed with water in a washing box, and the fibers were individualized using a Bauer refiner.

The cellulosic pulps were screened on a 0.2 mm slot screen to separate the cooking rejects and collect the acceptable fibers, which were oven-dried at 105 °C for subsequent weighing. The pulps were then centrifuged and weighed to obtain the debugged yield and stored. The parameters evaluated in the cellulosic pulps and residual liquors are described in Table 1.

Table 1 – Parameters evaluated in kraft cookings and residual liquors

Parameter	Standard/Calculation
Total yield	Gravimetric
Debugged yield	Gravimetric
Waste	Gravimetric
Kappa number	TAPPI T236 – cm 85
Residual alkali	Macdonald e Franklin (1969)
pH of residual liquor	Direct Reading on pH meter

Source: Authors (2025)

In where: The table presents the main parameters used to evaluate yield and quality in the kraft pulping process, as well as the methods and standards employed in determining each variable.

The physicochemical analyses of the wood and the brown kraft pulp of Pinus were: moisture (TAPPI 210 CM), ash (TAPPI 211 OM-93), total extractives (TAPPI T204 CM-85), lignin (TAPPI T222 OM-98), holocellulose (Wise; Maxine; D'addiecoa, 1946), and alpha-cellulose (TAPPI T203 CM-99).

The determinations of the percentage of chemical components (extractives, Klason lignin, holocellulose, alpha-cellulose, and ash) retained in the cellulosic pulp and removed from the wood during cooking were calculated according to equations (1) and (2).

$$\%Ret. = \frac{CP \ x \ 100}{CM} \quad (1)$$

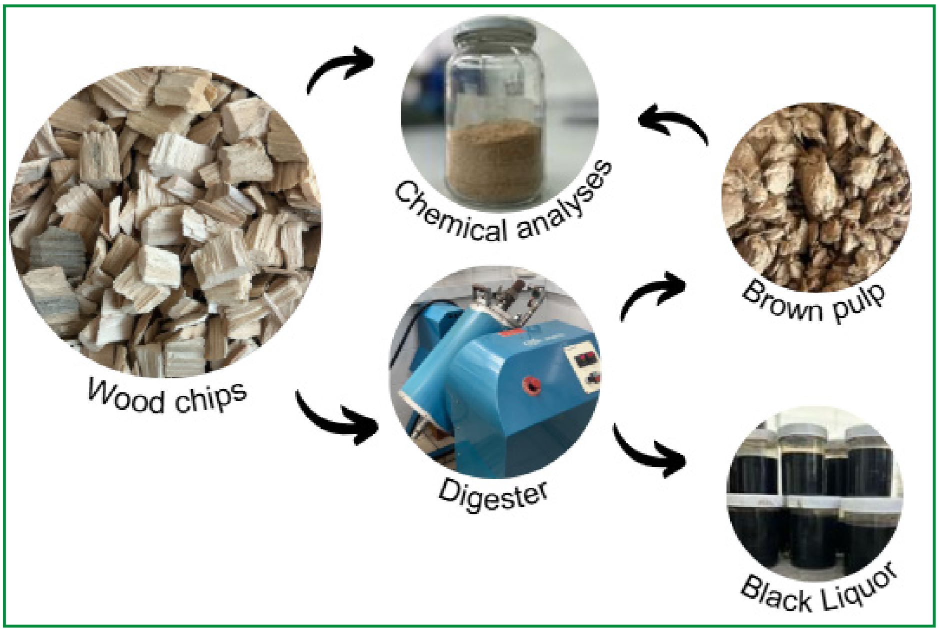
Where: %Ret. = percentage of the chemical component retained in the pulp; CP = chemical component in the pulp (g); CM = chemical component in the wood (g).

$$\%Rem. = 100\% - \%Ret. \quad (1)$$

Where: %Rem. = percentage of the chemical component removed from the pulp; %Ret. = percentage of the chemical component retained in the pulp.

A graphical scheme was produced to illustrate the stages of chemical characterization of *Pinus taeda* wood, kraft pulp production, chemical characterization of pulps and black liquor, which can be observed in Figure 1.

Figure 1 – Graphical summary of the chemical characterization and kraft pulping of *Pinus taeda* wood



Source: Authors (2025)

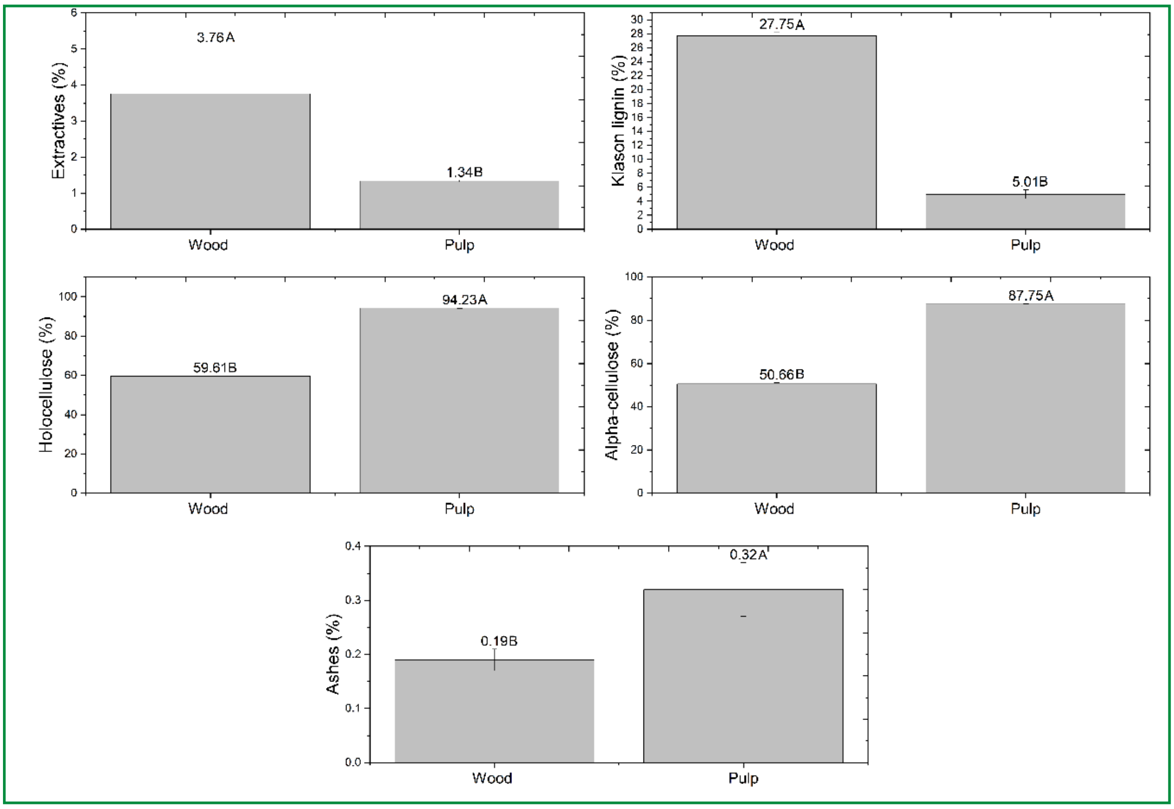
In where: The diagram illustrates the process from wood chips to the production of brown pulp and black liquor, including the digester process and the chemical analyses performed.

The sampling for the chemical analyses of the wood and kraft pulp of *Pinus taeda* was carried out in triplicate, and the results were subjected to analysis of variance (one-way ANOVA, between groups) with Fisher's LSD mean comparison test using the OrangeLab software.

3 RESULTS AND DISCUSSIONS

Figure 2 presents the results of the chemical composition and brown kraft pulp from *Pinus taeda* wood.

Figure 2 – Chemical composition of *Pinus taeda* wood and brown kraft pulp



Source: Authors (2025)

In where: Different uppercase letters (A and B) above the bars indicate statistically significant differences between treatments, according to the applied mean comparison test ($p < 0.05$).

The mean values of the chemical components of *Pinus taeda* wood are within the expected range for pine species previously reported in the literature (Alonso-Esteban et al., 2022; Dias et al., 2020; Vivian; Modes; Caetano, 2020). The average total extractives content observed for *P. taeda* wood in this study was 3.76%, higher than the 2.94% reported by Vidrano et al. (2019) for wood of the same species and harvesting age. The lignin content was 27.75%, lower than the values reported for *P. taeda* (32.56%) (Tuncer et al., 2024), *P. aldarica* (29.10%) (Firouzabadi; Tatari, 2024), and

P. glabra (29.93%) (Vivian; Modes; Caetano, 2020). The lower lignin content found in the present study, compared with values reported in the literature, may be explained by several factors, including silvicultural practices, tree harvesting age, and genetic characteristics.

Considering that high levels of extractives and lignin are undesirable in the pulping process, the low concentrations of these chemical components observed in *Pinus taeda* wood in this study indicate its potential for pulp production. This is because lower levels of extractives and lignin are associated, respectively, with reduced scaling problems in equipment and pitch formation in the pulp, as well as increased pulp yield (Vivian et al., 2022).

Holocellulose corresponds to the carbohydrate fraction of the wood, that is, cellulose and hemicelluloses and is directly related to pulp quality. During kraft pulping of wood with high carbohydrate content, milder cooking conditions are required, preserving the cellulose fibers from excessive degradation and thereby increasing screened yield (Luz et al., 2024).

In this study, the holocellulose and alpha-cellulose contents obtained were 59.61% and 50.66%, respectively. The holocellulose values observed here are higher than those reported for *P. taeda* (51.50%) (Mattos et al., 2016), *P. radiata* (57.00%) (Berrocal et al., 2004), and *P. lambertii (*58.61%) (Vivian et al., 2024).

As shown in Figure 2, the ash content present in *P. taeda* wood remained in the pulp after cooking, indicating that mineral removal during pulping is limited. Since these minerals can cause scaling in industrial equipment and pipelines, their removal during wood cooking is important. However, some minerals may be introduced into the fiber line through wood contamination during harvesting or transportation, or even from the cooking chemicals, which may explain the ash percentage observed in the pulp in this study (Colodette, 2001).

The pulping parameters used for producing *P. taeda* kraft pulp in this study were determined based on experimental cookings aimed at obtaining kraft pulps with a

Kappa number close to 30. The kraft pulp produced presented a kappa number of 31.3 and a total yield of 47.9%. A kappa number between 30 and 35 is typically specified for pulps from pine wood with balanced lignin and carbohydrate contents, intended for subsequent bleaching (Przybysz Buzała et al., 2019; Santos et al., 2021; Tuncer et al., 2024; Vivian et al., 2022).

Severe cooking conditions produce brown kraft pulps with low lignin content; however, they directly affect pulp quality and screened yield. Conversely, mild cooking conditions result in pulps with high residual lignin content, requiring larger amounts of chemicals during the bleaching stage (Luz et al., 2024). The kraft pulping results for *Pinus taeda* wood are presented in Table 2.

Table 2 – Kraft pulping results for *Pinus taeda* wood

Parameters	Results
Residual active alkali (g/l)	13.80
Black liquor pH	12.95
Total yield (%)	47.90
Debugged yield (%)	47.70
Waste (%)	0.40
Kappa number	31.30

Source: Authors (2025)

Coelho et al. (2021), using similar cooking conditions for the same pine species, reported Kappa number, debugged yield, and whaste content values of 27.5, 47.4%, and 0.10%, respectively, results that are consistent with those obtained in this study. The chemical characterization of kraft pulps produced from pine wood is essential to evaluate pulping efficiency and the performance of pulps in different industrial applications. Therefore, the chemical characterization of the pulps was performed (Figure 2).

Regarding extractives and lignin contents, it was observed that 64.36% and 81.96% of these components, respectively, were removed during cooking. Considering that coniferous woods generally contain higher levels of extractives and more complex lignin due to the presence of guaiacyl-lignin (Pedrazzi et al., 2015), it can be inferred that the cooking conditions were effective in removing extractives and lignin from the wood.

According to Figure 2, holocellulose was the main chemical component of *Pinus taeda* kraft pulp, representing 94.23% of the total mass of the cellulosic pulp. The comparison between the quantitative values of the chemical components present in the wood and those found in the kraft pulp allowed the inference that the kraft pulping conditions employed during chip cooking could remove lignin and extractives from the wood while preserving carbohydrates in the pulp. It is noteworthy that the pulping conditions enabled a 73.23% increase in the alpha-cellulose content, which is considered the crystalline, high-molecular-weight fraction of cellulose. Pulps with high alpha-cellulose content are preferred for high-strength printing papers, filters, textiles, and cellulose-derived chemicals. Moreover, due to their characteristics, kraft pulps are widely used in the manufacture of packaging, cardboard, and kraft paper (Sjöström, 1993).

4 CONCLUSIONS

The *Pinus taeda* wood presented chemical characteristics favorable for the production of kraft cellulosic pulp, standing out for its low total extractives and lignin contents, as well as a high carbohydrate content. Furthermore, its potential use as raw material to produce brown kraft pulp can be indicated, however, it is necessary to analyze other wood parameters, such as basic density and fiber dimensions.

The cooking parameters employed in the kraft pulping of *Pinus taeda* wood in this study proved to be efficient in producing pulp with a kappa number of 31.3, promoting the removal of extractives and lignin while preserving part of the carbohydrates in the cellulosic pulp.

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Datasets related to this article will be available upon request to the corresponding author.