Scientia Agraria Paranaensis – Sci. Agrar. Parana.
ISSN: 1983-1471 – Online

CHARACTERIZATION OF PROPERTIES AND DETERIORATION BY TERMITES IN THE *Pinus elliottii* ENGELM. WOOD

Ezequiel Gallio[1*], Henrique Weber Dalla Costa[2], Laíse Guerreiro[1], Nidria Dias Cruz[1], Rafael Beltrame[1], Darci Alberto Gatto[1]

SAP 23682 Received: 27/11/2020 Accepted: 27/04/2020
Sci. Agrar. Parana., Marechal Cândido Rondon, v. 19, n. 3, jul./sep., p. 252-257, 2020

ABSTRACT - The technological properties of wood are constituted by parameters, which after being analyzed, make it possible to define an appropriate use for this material. However, the deterioration of the wood due to the attack of termites, which find their food source in the chemical components, ends up altering these original technological characteristics, reducing their useful life and compromising their use. Thus, this study aimed to determine some technological properties of *Pinus elliottii*, as well as to evaluate the influence of deterioration caused by *Nasutitermes* termites in this wood. Specimens with dimensions of 20 x 20 x 150 mm (tangential x radial x longitudinal) were used as specimens. The physical properties evaluated were the basic density and linear shrinkage (tangential and radial contractions, and anisotropy coefficient), while the mechanical properties were represented through the Janka hardness test and compression parallel to the fibers. After 40 days of the biodeterioration test with *Nasutitermes* termites, changes in the equilibrium moisture content, retractability, water absorption rate and mechanical properties were evaluated. While the physical and mechanical properties evaluated showed values similar to those found in the literature, the deterioration caused by termites caused a reduction in hardness and parameters related to compression, increasing the dimensional instability of the wood, represented by the variation in the anisotropy coefficient. This made it possible to conclude that the biodeterioration resulting from the attack of termites directly affected the technological parameters of the wood, and consequently, its quality for the use in the purpose it could initially be destined.
Keywords: biodeterioration, coniferous, *Nasutitermes*.

CARACTERIZAÇÃO DE PROPRIEDADES E DETERIORAÇÃO POR TÉRMITAS NA MADEIRA DE Pinus elliottii Engelm.

RESUMO - As propriedades tecnológicas da madeira são constituídas por parâmetros, os quais após analisados, possibilitam definir um uso adequado para esse material. Entretanto, a deterioração da madeira em função do ataque de térmitas, os quais encontram nos componentes químicos sua fonte de alimento, acabam alterando essas características tecnológicas originais, reduzindo sua vida útil e comprometendo sua utilização. Diante do exposto, objetivou-se com o presente trabalho determinar algumas propriedades tecnológicas do *Pinus elliottii*, bem como avaliar a influência de deterioração provocada por térmitas *Nasutitermes* nessa madeira. Para tanto, utilizaram-se corpos de prova com dimensões de 20 x 20 x 150 mm (tangencial x radial x longitudinal). As propriedades físicas avaliadas foram a massa específica básica e a retratibilidade linear (contrações tangencial e radial, e coeficiente de anisotropia), enquanto as propriedades mecânicas foram representadas por meio do ensaio de dureza Janka e compressão paralela as fibras. Passados 40 dias do ensaio de biodeterioração com térmitas *Nasutitermes*, avaliaram-se modificações no teor de umidade de equilíbrio, retratibilidade, taxa de absorção de água, e propriedades mecânicas. Enquanto as propriedades físicas e mecânicas avaliadas apresentaram valores semelhantes aos encontrados na literatura, a deterioração causada por térmitas ocasionou redução na dureza e parâmetros relacionados à compressão, aumentando a instabilidade dimensional da madeira, representada pela variação no coeficiente de anisotropia. Isso possibilitou concluir que a biodeterioração proveniente do ataque de cupins afetou diretamente os parâmetros tecnológicos da madeira, e consequentemente, sua qualidade e o uso na finalidade a qual inicialmente poderia ser destinada.
Palavras-chave: biodeterioração, conífera, *Nasutitermes*.

INTRODUÇÃO

Regarding the exotic wood species used in the southern region of Brazil, varieties belonging to the *Pinus* genus stand out on the market due to the quality of their wood, allowing the application in several purposes. Among the species of this genus, *Pinus elliottii* stands out when compared to the others. This is mainly due to the adaptation of this species to the climate in the southern region and because of its rapid development cycle, providing a quality raw material for resin (obtaining rosin and turpentine), employment in civil construlction,

[1]Universidade Federal de Pelotas (UFPel), Pelotas, Rio Grande do Sul, Brasil. E-mail: egeng.florestal@gmail.com, *Autor correspondente.
[2]Universidade Federal de Santa Maria (UFSM), Santa Maria, Rio Grande do Sul, Brasil.

furniture, cellulose industry and paper (MISSIO et al., 2015; PERTUZZATTI et al., 2016)

However, even though it is a versatile material because of the variety of uses due to its quality, the wood of *P. elliottii* has an organic origin, a characteristic that makes it susceptible to attack by xylophagous agents, such as termites. These agents find in the cell walls of this material the source of energy for their development, since they have enzymes capable of metabolizing the compounds in smaller fractions, making them available for use (BRITO et al., 2019).

The termites cause significant economic damage to wood due to the severity of their attack, with the *Nasutitermes* genus being one of the most important, presenting a high spectrum of geographic distribution and species diversity (STALLBAUN et al., 2017). As a consequence of the deterioration caused by the attack of these xylophages, there is a decrease in the parameters related to the quality of this material, compromising the use for its initial purpose, generating maintenance costs and replacement of damaged parts (GHALY; EDWARDS, 2011). The main changes occur in the chemical components of the wood due to their removal because of the attack by termites. This became evident after the study by Gallio et al. (2020), who observed that the deterioration caused after exposure to termites of the genus *Nasutitermes* resulted in changes in the chemical and thermal characteristics of *Eucalyptus grandis* wood due to the variation in the contents of cellulose, hemicellulose, lignin and extracts.

However, information about changes in the properties of wood damaged by termites is still scarce. In this context, studies such as those developed by Motta et al. (2013) and Corassa et al. (2014), which addressed with greater emphasis parameters such as natural resistance, food preference, wear and loss of mass resulting from the attack of termites in the analyzed specimens.

Given this scenario, and assuming that the quality of the wood is associated with its technological parameters (physical, mechanical, chemical properties and natural durability), which direct the wood to its appropriate use (ARAÚJO et al., 2016), knowledge about the deterioration in the variables that characterize this material caused by termites becomes fundamental. This study aimed to determine some technological properties of the *Pinus elliottii* species, as well as to evaluate the influence that the deterioration caused by *Nasutitermes* termites had on its properties.

MATERIALS AND METHODS

Selection of material and obtaining the specimens

Boards of *Pinus elliottii* Engelm., from a log taken of a tree approximately 15 years old, were used. From these, 30 samples of sapwood were made, with dimensions of 2.0 x 2.0 x 15.0 cm (tangential x radial x longitudinal), divided into 10 for the control treatment and 20 for the biodeterioration test (these divided into 10 for physical properties and 10 for mechanical properties).

The specimens were placed in an air-conditioned room with a temperature adjusted to 20 ° C and 65% relative humidity until they reached constant mass, making it possible to obtain the variables in the condition of hygroscopic balance (12% humidity).

Physical and mechanical properties of wood

The specific gravity (ρb) and the equilibrium moisture content (EMC) were determined by adapting the standard described by the *American Society For Testing and Materials* (ASTM D 2395, 2017). Retractability was evaluated by means of the maximum linear contraction in the tangential (β_T) and radial (β_R) planes, and by the contraction anisotropy (CA_β) coefficient, both obtained according to the recommendations of ASTM D 143 (ASTM, 2014).

The masses were obtained in their respective ambient conditions from the use of an analytical scale (± 0.01g). The dimensions were measured with a digital pachymeter (± 0.001mm). For the determination of dry masses and dimensions at approximately 0% humidity, the specimens were kept in an oven, at a temperature of 103 ° C, until they reached a constant mass.

The relationship between deterioration caused by termites of the genus *Nasutitermes* sp. and the mechanical properties of the *Pinus elliottii* wood was verified by the Janka hardness test, and the modulus of elasticity (E_C) and compressive strength (f_C) obtained through the compression test parallel to the fibers. Therefore, the specimens were resized to the dimensions of 2.0 x 2.0 x 10.0 cm (tangential x radial x longitudinal). Both tests were performed according to the adaptation of the ASTM D 143 (ASTM, 2014) standard on a universal EMIC testing machine, with a 300kN load capacity cell. The parameters were obtained directly by the TESC software installed on the equipment.

Biodeterioration by termites

For the deterioration test, a colony of termites of the genus *Nasutitermes* was used, which was placed in a water tank (2000 liters capacity) containing a 15 cm layer of sand regularly moistened with water, avoiding the formation of water blades on the sand surface. The biodeterioration test was conducted according to the adaptation of the ASTM D 3345 (ASTM, 2008) standard and studies carried out by Motta et al. (2013). The specimens were systematically distributed in four lines (five specimens per line), with a spacing of 10 cm in the lines and between the lines, considering a test duration of 40 days.

The changes occurred by the deterioration caused by the *Nasutitermes* genus were analyzed by the variations in the humidity equilibrium, in the linear retractability, in the Janka hardness and in the parameters related to the compression test parallel to the fibers. By adapting the methodology used by Pertuzzatti et al. (2016), water absorption and water absorption rate (Equations 1 and 2, respectively) were determined until the curve stabilized, obtained after three successive measurements.

$$WA = \frac{M_U - M_0}{M_0} * 100 \quad \text{(Equation 1)}$$

$$WAR = \frac{M_U - M_0}{\Delta t} \quad \text{(Equation 2)}$$

Where:

WA = water absorption (%),
WAR = water absorption rate (g/h),
M_U = mass of the sample saturated in water at time (g),
M_0 = mass of the sample dried in an oven at 0% (g) and
Δt = variation of the immersion time of the specimens (h).

Statistical analysis

The data from the control and deteriorated samples were subjected to tests for homogeneity of variances and normality of residues by the Levene and Kolmogorov-Smirnov tests, respectively. And then, considering that the preliminary tests showed satisfactory results, the analysis of the simple variance (ANOVA) was carried out, and the existence of significant differences between the treatments (healthy and deteriorated) was verified by means of the F test, which compares the variances of two treatments. All statistical analyzes were performed with a 5% probability of error using the software Statgraphics.

Also, for each treatment, regression models were described in order to correlate water absorption with the period of immersion. The best fit for the analyzed data, considering the adjusted determination coefficient (r²) and the value obtained from the F test, was with the Equation 3 model:

$$y = \sqrt{\left[a \pm \left(b * \sqrt{x}\right)\right]} \quad \text{(Equation 3)}$$

Where:
y = water absorption (WA),
a e b = model constants and
x = imersion time.

RESULTS AND DISCUSSION

Technological characterization of *Pinus elliottii* Engelm. wood

The specific gravity (ρb) obtained for *Pinus elliottii* wood with approximately 15 years of age was 0.414 g cm^{-3}. The specific gravity (ρb) found in the present study is similar to that obtained by Mattos et al. (2011) for wood of the same species, with 13 years old (0.410 g cm^{-3}). Besides the species and age, the percentage of initial and late wood and the marrow-bark direction are factors that directly influence ρb.

The tangential plane (β_T) and the radial plane (β_R) contracted 5.71% and 3.98%, respectively, making it possible to verify that this species presented a contraction anisotropy (CA_β) of 1.43. Considering the retractability, it is observed that the percentage of contraction is superior on the tangential plane when compared to the radial plane, being this a recurring pattern in forest species (BATISTA et al., 2010). The difference in dimensional variations on the anatomical planes is associated with the arrangement and dimensions of anatomical elements, such as the rays and the supporting elements (OLIVEIRA et al., 2010). Other factors can be considered, such as age, early or late wood, adult or juvenile wood, the latter mainly due to the thickness of their respective cell walls.

For *Pinus merkusii* wood (aged 26 years), Bortoletto Júnior (2008) found a 7.4% contraction in the tangential anatomical plane, while in the radial the referred dimensional variation was 4.0% (anisotropy coefficient of approximately 1.8). When considering *Pinus elliottii* wood, from a 13 year old stand, Santini et al. (2000) found different contractions in the tangential and radial planes (respectively 5.8% and 3.9%), making it possible to determine an anisotropy coefficient of approximately 1.5, similar to that found in this study.

Regarding dimensional stability, woods that have an anisotropy coefficient below 1.5 are considered excellent (CHRISTOFORO et al., 2016). Therefore, considering that woods with these characteristics are dimensionally stable, an appropriate purpose may be employment in the furniture industry, since they don’t tend to bend.

As for the parameters related to the mechanical properties, the wood of *P. elliottii* presented Janka hardness of 27.13 MPa and 26.75 MPa for the tangential and radial planes, respectively, with a compressive strength (fc) of 32.60 MPa and modulus of elasticity (E_C) of 6,728.6 MPa. Santini et al. (2000) in their studies observed that the hardness in the radial plane was 23.5% lower when compared to the tangential, and in the present study, the same trend was observed, however with a lower percentage (1.40%).

In addition to the structural heterogeneity of this material, the anatomical plane in which the semisphere penetrates the wood causes variations in resistance, because when the direction of load is applied perpendicular or parallel to the growth rings, it finds a continuous layer of late wood (thicker walls) or juvenile wood (thinner walls), respectively. The f_C value was higher than that found by Santini et al. (2000), which obtained a compressive strength module of 28.6 MPa, and lower than that obtained by Bortoletto Júnior (2008), for *P. elliottii* var. *elliottii* (40 MPa).

The E_C obtained in the present study was lower than those observed, respectively, by Santini et al. (2000) and Trianoski et al. (2014), who cited E_C values of 7,213.4 MPa and 12,436.2 MPa, for the woods of *P. elliottii* and *P. taeda*, aged approximately 15 years old. In this context, according to the classification proposed by Carvalho (1996) for coniferous woods, the *P. elliottii* used in this study falls into the class of light woods (ρb located in the range of 0.40 to 0.49 g cm^{-3}), with little retractability (β_T and β_R below 7 and 4%, respectively), low anisotropy (CA_β below 1.5), medium hardness (between 19.6 to

29.4 MPa) and moderate f_C (34.3 to 45.1 MPa). Therefore, this makes it possible to verify that the physical and mechanical parameters varied between the same species, as well as between different species, in addition to issues such as age and other anatomical characteristics mentioned above, corroborating the influence of these factors on the technological properties of wood.

Influence of deterioration on technological properties

As for the deterioration by termites of the *Nasutitermes* genus, in percentage, there were reductions in the EMC (0.73%), in the β_T (16.99%) and β_R (47.49%). The relation between the contraction of the tangential plane in relation to the radial plane (represented here by CA_β) increased by 58.74% (Table 1). The non-significant reduction in the EMC indicates that there was a non-selective deterioration of the primary components of the wood (cellulose and hemicellulose, mainly). This is corroborated by the fact that holocellulose contains a large number of hydroxyl groups (O–H), which have an affinity for water. If both components are deteriorated, there is a possibility that there are no significant changes in the humidity content, which is what was observed in this study.

The reduction in the percentage values of β_T and β_R due to the attack by the *Nasutitermes* termites is associated with greater removal of the spring wood (larger lumens and thinner cell walls) compared to the autumn. Thus, the increase in anisotropy may cause wood to be more susceptible to having defects due to dimensional variations resulting from humidity adsorption or desorption (OLIVEIRA et al., 2010), thus interfering in its quality and later use.

TABLE 1 - Summary of analysis of the variance and average values of the physical properties of *P. elliottii* wood deteriorated by termites of the genus *Nasutitermes*.

Treatment	EMC (%)	β_T (%)	β_R (%)	AC_β
Control	12.38 $^{(0.95)}$ a	5.71 $^{(0.67)}$ a	3.98 $^{(2.14)}$ a	1.43
Deteriorated	12.29 $^{(0.15)}$ a	4.74 $^{(0.78)}$ a	2.09 $^{(0.87)}$ a	2.27
CV (%)	4.81	16.55	60.18	-
F	0.04 ns	3.88 ns	3.33 ns	-

CV = coefficient of variation, values in parentheses and superscripts = standard deviation. *Means followed by the same letter in the columns do not differ by the F test, with a 5% probability of error ($p \leq 0.05$), ns = not significant at 5% probability of error ($p > 0.05$).

In addition to the preferential removal of spring wood, the increase in wood instability (CA_β) is correlated with the deterioration of the structural components and crystalline areas of the wood, resulting in a disorder of the crystalline arrangement, to the detriment of amorphous zones. Structural changes present in the wood due to the amorphous and crystalline arrangement can cause an increase in porosity in the cell wall, thus generating dimensional instability (LYND et al., 2002).

A significant reduction of 19.48% in Janka hardness was also noted in the radial plane, while in the tangential it was 6.23% (Table 2). As for the compressive strength (f_C) and the modulus of elasticity (E_C) obtained by the compression test parallel to the fibers, there is an absence of significant variations. While the f_C parameter showed a 25.95% reduction, the E_C showed an increase of approximately 10.01% after the period of the biodeterioration test.

TABLE 2 - Summary of analysis of the variance and average values of the mechanical properties of *P. elliottii* wood deteriorated by termites of the genus *Nasutitermes*.

Janka hardness (MPa)				
Anatomical Plan	Control	Deteriorated	CV (%)	F
Tangential	27.13 $^{(2.84)}$ a	25.44 $^{(1.30)}$ a	8.35	2.27 ns
Radial	26.75 $^{(2.87)}$ a	21.54 $^{(2.81)}$ b	16.07	11.58 *
Compression Parallel to Grain (MPa)				
Parameter	Control	Deteriorated	CV (%)	F
f_C (kgf/cm²)	32.60 $^{(1.75)}$ a	24.14 $^{(6.38)}$ a	22.02	4.90 ns
E_C (kgf/cm²)	6,728.6 $^{(2.096.8)}$ a	7,402.3 $^{(2.114.8)}$ a	27.16	0.15 ns

CV = coefficient of variation, values in parentheses and superscripts = standard deviation. *Means followed by the same letter in the row do not differ by the F test, with a 5% probability of error ($p \leq 0.05$), ns = not significant at 5% probability of error ($p > 0.05$).

The differences in technological parameters related to mechanical tests are associated with the deterioration mechanism used by termites, which use their jaws to disrupt the cell wall (ARCHER & LEBOW, 2006), as well as the structural and anatomical heterogeneity characteristic of wood. The deteriorations caused in the wood structure resulting from the attack of termites cause a decrease in mechanical strength (CORASSA et al., 2014). This reduction is associated with the degradation of the primary constituents, cellulose and hemicellulose mainly, which together with lignin provide mechanical resistance to the wood. The lignin undergoes scarification during this process.

Through the analysis of the water absorption (WA) and water absorption rate (WAR) curves of *Pinus elliottii* woods healthy and deteriorated by *Nasutitermes* termites (Figure 1), it appears that the highest absorption rate of water is after 1 h, being the largest amount of water absorbed by the deteriorated samples.

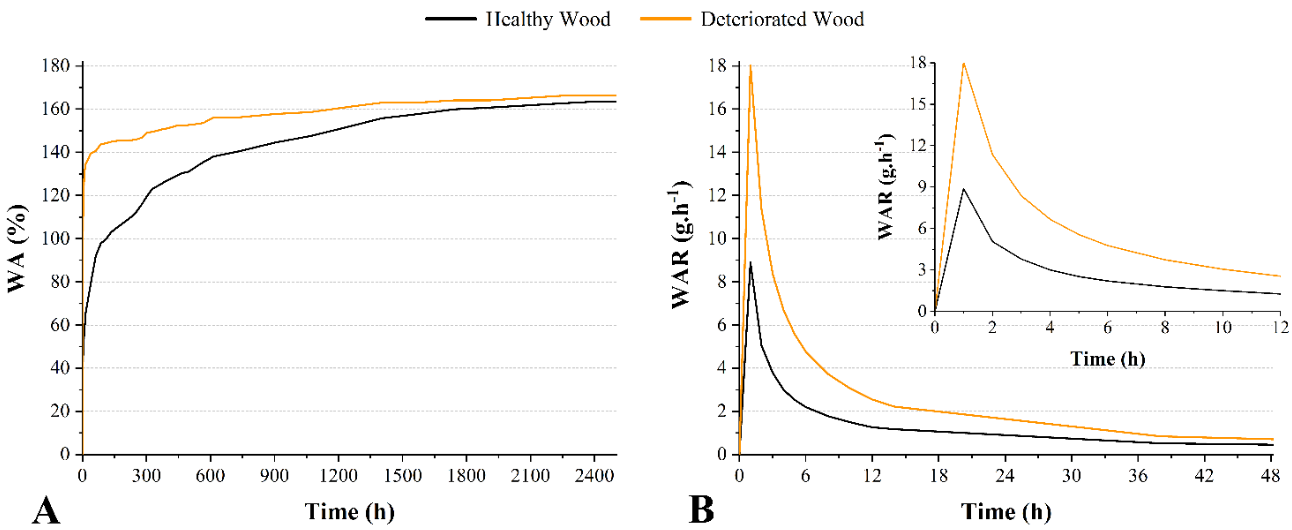

FIGURE 1 - Curves of water absorption – WA (A) and water absorption rate – WAR (B) in samples of *P. elliottii* wood healthy and deteriorated by *Nasutitermes* termites.

Considering WA and WAR, in the case of deteriorated samples, the highest values are due to the opening of galleries in the wood, increasing its porosity, causing a higher flow of water inside it in the first moments of immersion. Regarding the use of adjusting a model in order to correlate water absorption as a function of time, significant adjustments are observed in both treatments (Table 3). However, the greatest correlation was found for healthy woods, caused mainly by a more uniform WA (as seen in Figure 1) in relation to the deteriorated ones, mainly due to lower porosity.

TABLE 3 - Summary of analysis of the variance for the adjusted models related to water absorption of *P. elliottii* wood healthy and deteriorated by *Nasutitermes* termites.

Treatment	Adjusted Model	r^2 Adjusted	F
Control	$WA = \sqrt{[3,292.17 + (549.258 * \sqrt{T})]}$	0.9492	879.14*
Deteriorated	$WA = \sqrt{[14,607.10 + (335.471 * \sqrt{T})]}$	0.6722	95.31*

WA = water absortion (%), T = time (hours), * = significant difference at 5% error, by the F test ($p \leq 0.05$).

Therefore, studies that relate the changes that termites cause in the technological properties of the wood become of fundamental importance. When analyzing the behavior of properties that have been modified, it is possible to recommend an appropriate use for wood, considering possible limiting factors depending on its final use.

CONCLUSIONS

The values related to the properties of basic specific mass and retractability of the *Pinus elliottii* Engelm wood were similar to those of the literature, determined by other authors.

The attack of the termites *Nasutitermes* sp. caused the degradation of the chemical constituents and opening of galleries inside the wood, reducing the parameters related to the mechanical properties, mainly hardness and resistance to compression.

The removal of primary constituents, mainly cellulose and hemicelluloses, generated an increase in the dimensional instability of the wood, observed by the increase in the anisotropy coefficient. The galleries made it possible to increase the flow of water inside the wood.

As a result of the properties analyzed, it is concluded that the attack of termites altered the original technological properties of wood, reducing its quality and compromising its use for the purpose of which it could initially be used.

REFERENCES

ARAÚJO, B.H.P.; SOUSA, M.A.R.; NASCIMENTO, H.E.M.; ZANUNCIO, A.J.V.; RODRIGUES, D.M.S.; GUEDES, M.C. Propriedades físicas da madeira de *Calycophyllum spruceanum* Benth. em função do diâmetro e da posição (base e topo) no fuste. **Scientia Forestalis**, v.44, n.111, p.759-768, 2016.

ARCHER, K.; LEBOW, S. Wood preservation. In: WALKER, J.C.F. **Primary wood processing:** principles and practice. 2a. ed. Dordrecht: Springer, 2006. Cap. 9, p.297-338.

ASTM. AMERICAN SOCIETY FOR TESTING AND MATERIALS. **ASTM D2395-17.** Standard test methods for density and specific gravity (relative density) of wood and wood-based materials. ASTM International, West Conshohocken, PA, 2017. 13p.

ASTM. AMERICAN SOCIETY FOR TESTING AND MATERIALS. **ASTM D143-94.** Standard test methods for small clear specimens of timber. ASTM International, West Conshohocken, PA, 2014. 31p.

ASTM. AMERICAN SOCIETY FOR TESTING AND MATERIALS. **ASTM D3345-74.** Standard test method for laboratory evaluation of wood and other cellulosic materials for resistance to termites. ASTM International, West Conshohocken, PA, 2008. 3p.

BATISTA, D.C.; KLITZKE, R.J.; SANTOS, C.V.T. Densidade básica e retratibilidade da madeira de clones de três espécies de *Eucalyptus*. **Ciência Florestal**, v.20, n.4, p.665-674, 2010.

BORTOLETTO JÚNIOR, G. Estudo de algumas propriedades físicas e mecânicas da madeira de *Pinus merkusii*. **Scientia Forestalis**, v.36, n.79, p.237-243, 2008.

BRITO, J.O.; DIAS JÚNIOR, A.F.; LANA, A.Q.; ANDRADE, C.R.; BERNARDES, F.F. Biological resistance of heat-treated wood of *Pinus caribaea* and *Eucalyptus saligna*. **Maderas. Ciencia y Tecnologia**, v.21, n.2, p.223-230, 2019.

CARVALHO, A. **Madeiras portuguesas, estrutura anatômica, propriedades utilizações.** Direcção-geral das Florestas, 1996. v.1, 340p.

CHRISTOFORO, A.L.; ALMEIDA, T.H.; ALMEIDA, D.H.; SANTOS, J.C.; PANZERA, T.H.; LAHR, F.A.R. Shrinkage for some wood species estimated by density. **International Journal of Materials Engineering**, v.6, n.2, p.23-27, 2016.

CORASSA, J.N.; PIRES, E.M.; ANDRADE NETO, V.R.; TARIGA, T.C. Térmitas associados à degradação de cinco espécies florestais em campo de apodrecimento. **Floresta e Ambiente**, v.21, n.1, p.78-84, 2014.

GALLIO, E.; SCHULZ, H.R.; GUERREIRO, L.; CRUZ, N.D.; ZANATTA, P.; SILVA JÚNIOR, M.A.P.; GATTO, D.A. Thermochemical behavior of *Eucalyptus grandis* wood exposed to termite attack. **Maderas. Ciencia y Tecnología**, v.22, n.2, p.157-166, 2020.

GHALY, A.; EDWARDS, S. Termite damage to buildings: nature of attacks and preventive construction methods. **American Journal of Engineering and Applied Sciences**, v.4, n.2, p.187-200, 2011.

LYND, L.R. ; WEIMER, P.J.; VAN ZYL, W.H.; PRETORIUS, I.S. Microbial cellulose utilization: fundamentals and biotechnology. **Microbiology and Molecular Biology Reviews**, v.66, n.3, p.506-577, 2002.

MATTOS, B.D.; GATTO, D.A.; STANGERLIN, D.M.; CALEGARI, L.; MELO, R.R.; SANTINI, E.J. Variação axial da densidade básica da madeira de três espécies de gimnospermas. **Revista Brasileira de Ciências Agrárias**, v.6, n.1, p.121-126, 2011.

MISSIO, A.L.; CADEMARTORI, P.H.G.; MATTOS, B.D.; WEILER, M.; GATTO, D.A. Propriedades mecânicas da madeira resinada de *Pinus elliottii*. **Ciência Rural**, v.45, n.8, p.1432-1438, 2015.

MOTTA, J.P.; OLIVEIRA, J.T.S.; PAES, J.B.; ALVES, R.C.; DAMBROZ, G.B.V. Resistência natural da madeira de *Tectona grandis* em ensaio de laboratório. **Ciência Rural**, v.43, n.8, p.1393-1398, 2013.

OLIVEIRA, J.T.S; TOMAZELLO FILHO, M.; FIEDLER, N.C. Avaliação da retratibilidade da madeira de sete espécies de *Eucalyptus*. **Revista Árvore**, v.34, n.5, p.929-936, 2010.

PERTUZZATTI, A.; MISSIO, A.L.; CONTE, B.; SOUZA, S.C.; SANTINI, E.J.; HASELEIN, C.R. Propriedades físicas da madeira de *Pinus elliottii* var. *elliottii* termorretificada sob diferentes atmosferas. **Ciência da Madeira**, v.7, n.1, p.7-15, 2016.

SANTINI, E.J.; HASELEIN, C.R.; GATTO, D.A. Análise comparativa das propriedades físicas e mecânicas da madeira de três coníferas de florestas plantadas. **Ciência Florestal**, v.10, n.1, p.85-93, 2000.

STALLBAUN, P.H.; BARAUNA, E.E.P.; PAES, J.B.; RIBEIRO, N.C.; MONTEIRO, T.C.; ARANTES, M.D.C. Resistência natural da madeira de *Sclerolobium paniculatum* Vogel a cupins em condições de laboratório. **Floresta e Ambiente**, v.24, e20160013, 2017.

TRIANOSKI, R.; MATOS, J.L.M.; SETSUO IWAKIRI, S.; PRATA, J.G. Avaliação das propriedades mecânicas da madeira de espécies de *Pinus* tropicais. **Scientia Forestalis**, v.42, n.101, p.21-28, 2014.