Ciência Rural, Santa Maria, v.53:3, e20210467, 2023 http://doi.org/10.1590/0103-8478cr20210467

ISSNe 1678-4596
FORESTRY SCIENCE

Thermal modification influences the mechanical resistance of wood from forestry species

Elder Eloy[1*] Eduarda Bandera[1] Tauana de Souza Mangini[1] Rômulo Trevisan[1] Luana Candaten[1] Laura da Silva Zanchetta[1]

[1]Departamento de Engenharia Florestal, Universidade Federal de Santa Maria (UFSM), 98400-000, Frederico Westphalen, RS, Brasil. E-mail: eloyelder@yahoo.com.br. *Corresponding author.

ABSTRACT: *This study evaluated the effects of thermal modification at different temperatures and for different durations on the mechanical strength of wood of selected species from an agroforestry system. To this end, three 9-year-old (approximate age) individuals, each from four species of forest trees—Parapiptadenia rigida (Benth.) Brenan, Peltophorum dubium (Spreng.) Taub., Eucalyptus grandis × Eucalyptus urophylla hybrid, and Schizolobium parahyba (Vell.) Blake—were evaluated. After obtaining initial measurements, samples from the four species under went heat treatment for 2 h and 4 h and were subsequently subjected to heat using an oven at temperatures 120 °C, 150 °C, 180 °C, and 210 °C; respectively, in addition to the control. For evaluating mechanical strength, the technical standard ASTM D 143-94 was used to obtain the values of the moduli of elasticity and rupture, tension at the proportional limit, and maximum force of the subjects. It was observed that different durations and temperatures altered the mechanical strength of the wood of the four species studied. The 2 h residence time is the most recommended for conducting thermal modification. This procedure modifies the mechanical resistance of wood in a positive manner, with exposure temperatures ranging between 120 ºC and 180 ºC being the most recommended. The thermal treatment carried out for 4 h is not recommended for structural purposes because of the decrease in flexural strength.*
Key words: *static bending, thermal modification, wood quality.*

A modificação térmica influencia na resistência mecânica da madeira de espécies florestais

RESUMO: *O objetivo do presente estudo foi avaliar o efeito da modificação térmica em diferentes tempos e temperaturas na resistência mecânica da madeira de espécies provenientes de um sistema agroflorestal. Para tanto, foram avaliados três indivíduos de Parapiptadenia rigida (Benth.) Brenan, Peltophorum dubium (Spreng.) Taub., Eucalyptus grandis × Eucalyptus urophylla e Schizolobium parahyba (Vell.) Blake, todos com nove anos de idade. Após o dimensionamento, as amostras passaram pelo processo de modificação térmica durante 2h e 4h realizado em estufa nas temperaturas de 120 °C, 150 °C, 180 °C e 210 °C, além da testemunha. Para avaliação da resistência mecânica, seguiu-se a norma técnica ASTM D 143-94, obtendo-se os valores de módulos de elasticidade e ruptura, tensão no limite proporcional e força máxima. Observou-se que os diferentes tempos e temperaturas alteram a resistência mecânica das quatro espécies estudadas. O tempo de 2 h de permanência é o mais recomendado para a realização da modificação térmica. O procedimento modifica a resistência mecânica da madeira de uma forma positiva, sendo que as temperaturas de exposição que variaram entre 120 °C e 180 ºC são as mais recomendadas. A modificação térmica realizada pelo período de 4 h não é recomendada para fins estruturais, pelo fato do decréscimo da resistência à flexão.*
Palavras-chave: *flexão estática, modificada termicamente, qualidade da madeira.*

INTRODUCTION

Over the years, the global demand and consumption of wood has been increasing substantially. The need to meet the demand while preserving the environment remains a top priority in the global sustainability movement. Thus, fast-growing species and new forms of cultivation stand out as alternatives to meet the timber market segment (HULLER et al., 2017).

Given this, agroforestry systems consist of native, exotic, and agricultural cultures in consortia, prioritize soil, water resources, and biodiversity conservation practices, as well as promotethe ecological succession of the environment (CARON et al., 2018). Throughout the years, different methods that improve the behavior and characteristics of wood material have been studied intricately. Among these, thermal modification stands out and is now greatly practiced on a large scale in Europe. The method consists of subjecting the wood to temperatures ranging between 120 °C and 200 °C, to promote chemical changes in the cellulose, hemicellulose, and lignin polymers, thus obtaining a product with

Received 06.15.21 Approved 02.22.22 Returned by the author 06.22.22
CR-2021-0467.R1
Editors: Leandro Souza da Silva João Carlos Azevedo

satisfactory hygroscopicity and greater dimensional stability (MODES et al., 2017). Thermal modification leads to the formation of oxidative products and reduction of sorption sites, especially hydroxyls, which interact with water molecules during moisture exchange with the external environment (KOCAEFE et al., 2015).

As a result, heat-treated wood shows improved mechanical strength (KAPLAN et al., 2018) and natural durability (SANTOS & SILVA, 2021) compared to that of untreated material, which can cause an increase in the use of wood (MENEZES et al., 2014). The process consists of mechanical tests, including the static bending test, which determines properties such as the modulus of elasticity (MOE), modulus of rupture (MOR), tension in the proportional limit (TPL), and maximum force (MF), that are fundamental at the time of applicability.

Thus, the importance and potential of thermal modification of wood should be emphasized as it results in both positive and negative parameters, asreported in literature, that determine the quality of the material (SANTOS & SILVA, 2021). Therefore, the present study evaluated the effects of thermal modification for different time durations and at temperatures on the mechanical strength of wood selected from species from an agroforestry system.

MATERIALS AND METHODS

Experiment location

The wood materials used in this study were acquired from an agroforestry system belonging to the Federal University of Santa Maria Campus Frederico Westphalen (UFSM/FW) located at an altitude of 480 m with the geographic coordinates 27°22 'S; 53°25' W. According to the Köppen classification, the predominant climate of the region falls under Cfa (humid subtropical climate), characterized as sub-humid subtemperate, with an average annual temperature of 18.8 °C and an average temperature of the coldest month of 13.3 °C.

The selected forest tree species, *Parapiptadenia rigida* (Benth.) Brenan (Angico vermelho), *Peltophorum dubium* (Spreng.) Taub. (Canafístula), *Eucalyptus grandis* × *Eucalyptus urophylla* (Eucalyptus) hybrid, and *Schizolobium parahyba* (Vell.) Blake (Guapuruvu), were distributed at a planting distance of 12.0 m spacing between rows and 1.5 m between trees in the planting rows.

These species were selected for the installation of the agroforestry system and, later, for the evaluation of this research, as they are the representative of the study region. *E. grandis* × *E. urophylla* hybrid is commercially cultivated and widely used in the residential, commercial, and industrial segments, especially for the processing of forest tree products. The other native species are characterized by their extensive presence in the region, which has a predominance of small rural properties that use wood for various purposes, such as the processing of logs and other forest commodities.

Sampling and evaluation

In the sampling process, the average diameter of the trees was considered for the estimation of the age of the trees. Trees with a rough estimate of 9-year age were chosen. There after, three replications were selected for each tree species. After the selection process, wood extraction was done for each replicate. Diameter at breast height was calculated at 1.30 m above the ground and log segments with 2 m length were excised from it. Subsequently, these logs were transported to the sawmill where central planks were made, which were used in the production of specimens with dimensions of 2.5 cm × 2.5 cm × 41 cm (width × thickness × length). Twenty specimens of each tree were prepared, totaling 60 samples for each species studied. In total, 240 specimens were produced from the four species.

For the preparation of the specimens, they were initially placed in a drying oven at controlled temperature (± 22 ºC) and humidity (± 55%). The moisture loss of the materials under study was monitored for 40 days, obtaining an average 10.9% equilibrium moisture content based on the methodology developed by SIMPSON (1971). After the drying period, the samples were stabilized at equilibrium humidity and were placed in an oven with forced air circulation at 103 °C for drying at 0%.

For the thermal modification of the selected samples, an oven with forced air circulation was used at different temperatures 120 °C, 150 °C, 180 °C, and 210 °C, for a period of 2 h and 4 h, in addition to the control. Subsequently, the specimens were subjected to a static bending test, performed according to ASTM D 143-94 (2000), in a universal testing machine (EMIC) model DL-2000, where the MOE, MOR, MF, and TPL was obtained.

Experimental design and data analysis

For the assembly and statistical analysis of the data, a completely randomized design was used, characterized by a 2×5 factorial arrangement, with two times and five heat treatments and six replications. The data were subjected to statistical analysis using the "Statistical Analysis System" software (SAS, 2003), in which the Shapiro-Wilk analysis of variance assumption tests (F test) was carried out to verify normality, and Bartlett's test was used to verify the heteroscedasticity of the variances. In the case of significant variance analysis, multiple comparisons of means were adopted using Tukey's test at a 5% error probability.

These analyses were conducted to identify the similarities and differences in the static bending properties of wood and to discuss the influence of thermal modification under different times conditions.

RESULTS AND DISCUSSION

From the analysis of variance, it can be observed that the thermal modification performed under the conditions of time and temperature for each species studied showed significant differences for most of the variables analyzed, modifying the mechanical resistance of the wood of the four species studied. With respect to temperature, it was observed that the variables MOR, TPL, and MF showed significant differences among the four species studied. For the MOE variable, this condition was verified only for *P. rigida* (Table 1).

When analyzing residence time periods, it was reported that the MOR variable presented a significant difference for the species *P. rigida*, *P. dubium* and *E. grandis* × *E. urophylla*. For TPL, this condition was observed in *P. dubium*, *E. grandis* × *E. urophylla* and *S. parahyba*. Similarly, for MF, a significant difference was observed only for *P. dubium* (Table 1).

From the analysis of the average test, it was observed that for the MOR variable, in general,

Table 1 - Analysis of variance for the different treatment time and temperatures with respect to the mechanical properties of the wood of the species studied.

Source of variation	DF	------Mean square------			
		MOR	MOE	TPL	MF
------*P. rigida*------					
Time	1	90365.2*	39964417^{ns}	1676.2^{ns}	5426.4^{ns}
Temperature	4	745238.5*	462009327*	29554.5*	60323.9*
Time × Temperature	4	29792.8^{ns}	38887568^{ns}	4272.9^{ns}	2432.2^{ns}
R^2		0.80	0.85	0.82	0.79
CV		12.3	14.6	12.8	13.6
------*P. dubium*------					
Time	1	791650.7*	3586374.9^{ns}	110.7*	2285635.87*
Temperature	4	2911.7*	819.9^{ns}	220.7*	3112418.13*
Time × Temperature	4	411.4^{ns}	791.6^{ns}	95.6^{ns}	363881.47^{ns}
R^2		0.84	0.95	0.72	0.71
CV		15.4	17.4	17.8	18.9
------*E. grandis* × *E. urophylla*------					
Time	1	2048.6*	2227881.7^{ns}	738.5*	973157.7^{ns}
Temperature	4	7027.7*	2229944.5^{ns}	867.9*	6240705.6*
Time × Temperature	4	2074.4^{ns}	7552372.9^{ns}	666.7^{ns}	1043962.8^{ns}
R^2		0.75	0.71	0.70	0.88
CV		19.2	18.1	16.6	12.1
------*S. parahyba*------					
Time	1	7724.8^{ns}	16055957^{ns}	3964.1*	668.7^{ns}
Temperature	4	136267.4*	86678236^{ns}	23976.9*	10955.7*
Time × Temperature	4	8960.5^{ns}	59644407^{ns}	7534.0^{ns}	881.6^{ns}
R^2		0.88	0.79	0.81	0.78
CV		11.2	14.3	14.1	16.4

GL = degree of freedom, MOE = modulus of elasticity (MPa), MOR = modulus of rupture (MPa), TPL = tension of the proportional limit (MPa), MF = maximum force (N), R^2 = coefficient of determination, CV = coefficient of variation (%), * = significant at 5% error probability, ^{ns} = not significant at 5% error probability.

the values varied increasingly until the temperature reached 150 °C, with a subsequent reduction for all the analyzed species until the temperature reached 210 °C (Figure 1). Regarding the influence of exposure time, the treatment with 2h at the initial temperature of 120 °C did not influence the MOR; however, the greatest differences between time periods were evidenced primarily when the temperatures were higher (180 °C and 210 °C).

Similar results were observed by FONTOURA et al. (2015) for the wood of *Hovenia dulcis* where temperatures of 100 °C, 120 °C, and 140 ºC applied for a period of 2 h resulted in average values of 114.8, 111.1, and 61.6 MPa, respectively, and those applied for 4 h resulted in average valueof 109.7, 99.5, and 51.0 MPa, respectively.

This increase in MOR indicates that the changes that contributed to the wood's strength

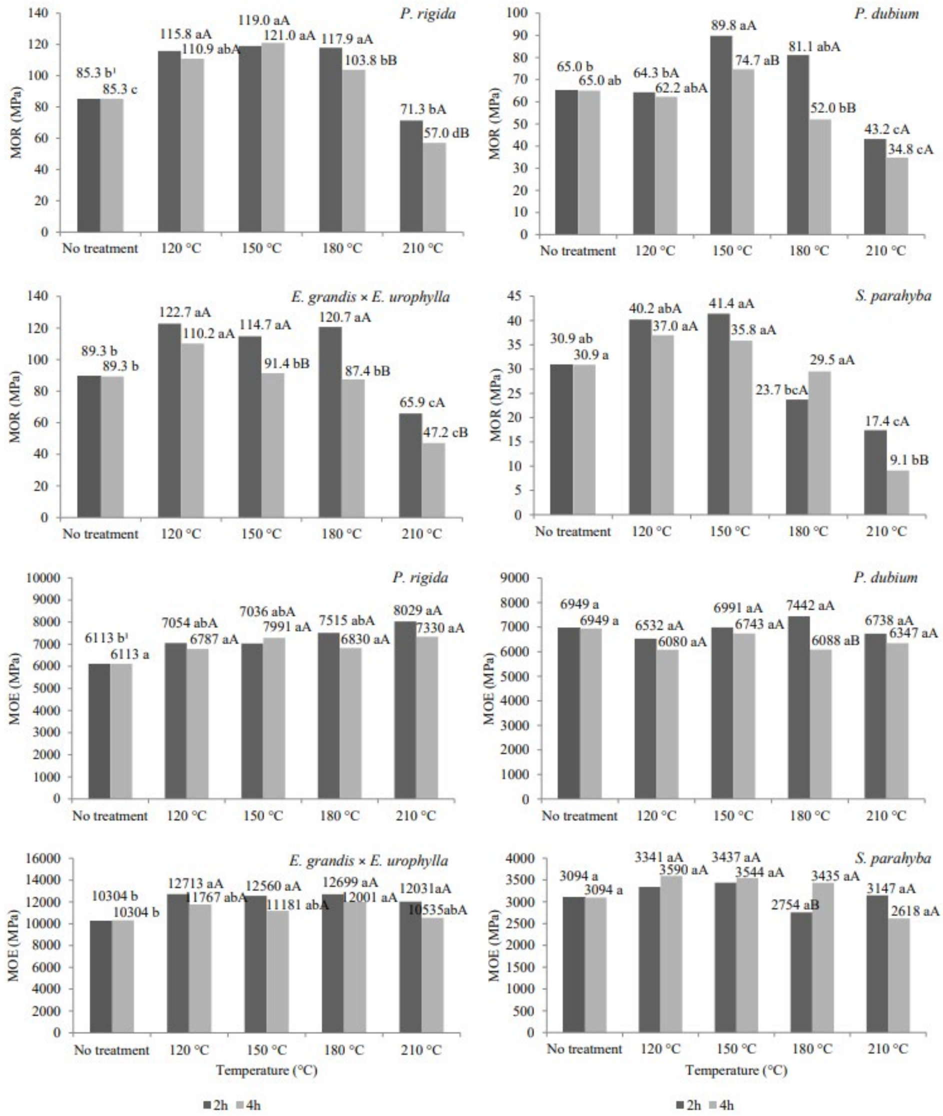

Figure 1 - Test of means for modulus of rupture (MOR) and modulus of elasticity (MOE) of the four forest species for the five temperature treatments with the two-time treatments. [1]Averages followed by lowercase letters compare temperature treatments within each time, and means followed by uppercase letters compare time treatments within each temperature, according to Tukey's test at 5% probability of error.

also increased up to 150 °C, which did not occur at temperatures higher than the aforementioned (180 °C and 210 °C), thus resulting in friable wood. In addition, when the exposure times were compared, there was a tendency for the MOR to decrease both for 2 h and 4 h. This can be explained by the relationship with the amount of hemicellulose, as an increase in time leads to a more accentuated reduction of this polymer, which directly changes the strength (MODES et al., 2017; ARAÚJO et al., 2012).

A result similar to that for *P. rigida* heat-treated at 150 ºC was reported by CHRISTOFORO et al. (2020), who obtained a MOR value of 120.3 MPa when studying the wood of *Piptadenia macrocarpa* and *E. grandis* × *E. urophylla* exposed to 120 °C, 150 °C, and 180 ºC for 2 h; similar results were found in the literature as well when NOGUEIRA et al. (2020) evaluated the wood of *E. tereticornis* and found a value of 131.0 MPa for the same property.

For MOE, there were significant differences in time only at a temperature of 180 °C for *P. dubium* and *S. parahyba*, with the highest values found in wood exposed for 2 h and 4 h, respectively (Figure 1). For the other species, there were no statistically significant differences when exposure times were compared.

Regarding the influence of temperature on the MOE, it was observed that for *P. dubium, P. rigida*, and *S. parahyba*, there were no significant differences at 4 h. However; differences were verified for *E. grandis* × *E. urophylla* during the two evaluated durations.

A result similar to that found for the species *P. dubium* and *S. parahyba* was reported by FERREIRA et al. (2019), who studied the wood of *Hymenoloblum petraeum* and stated that there was no significant difference in MOE values when comparing the conditions of 2 h and 4 h. This corroborates the research carried out by GUNDUZ et al. (2009), who explained that MOE is the property least affected by thermal modification and that the variation of values concerning this characteristic is highly dependent on the species, their anatomical orientation, and the heat treatment program.

Furthermore; although, this significant difference was not observed, an increase in the MOE value was observed in the first treatments used for all analyzed species, except for *P. dubium*. This initial increase maybe because of the condensation of lignin and cellulose, forming new chemical bonds, which increases this property (MODES et al., 2017).

Regarding TPL, it was reported that only for *P. rigida* there was no statistically significant difference in treatment time. For the other species, except *S. parahyba*, this significant difference was observed for temperatures at 180 °C and 210 °C, highlighting the 2 h treatment, which presented the highest values (Figure 2).

When analyzing the influence of different temperatures on the TPL, it appears that there was a gradual increase in the values for *P. rigida*. In contrast, for the other species, there was an oscillation without a stabilization trend, as verified by CANDATEN et al. (2020), and FONTOURA et al. (2015) when studying the wood of *Handroanthus chrysotrichus* and *Hovenia dulcis*, respectively.

For MF, no significant differences were observed between the residence times of *E. grandis* × *E. urophylla*. Concerning the other species, this behavior was observed at 180 °C for *P. rigida*, 150 °C and 180 °C for *P. dubium*, and 210 °C for *S. parahyba* (Figure 2). Regarding the influence of different temperatures, a decreasing variation was observed with an increasing heating, primarily after 150 °C, and at 210 °C; the lowest values were reported for all species.

Thus, it was verified that as the treatment temperature increased, there was a reduction in MF values after treatment at 120 °C for *P. rigida* and *P. dubium*, and after treatment at 150 °C for *E. grandis* × *E. urophylla* and *S. parahyba*. This showed that this property is affected by drying and that its decrease is inversely proportional to the increase in temperature and exposure time of the treated wood (KORKUT & BUDAKÇI, 2009). A similar result was obtained by CADEMARTORI et al. (2012) for *E. grandis* × *E. urophylla*, who verified a gradual decrease in the values of this variable when using temperatures of 180 °C, 200 °C, 220 °C, and 240 °C and the control.

CONCLUSION

Different durations and temperatures altered the mechanical properties of the four species studied. The residence time of 2 h was the most recommended for carrying out thermal modification. Thermal modification carried out for 4 h is not recommended for structural purposes because of the decrease in flexural strength.

The procedure positively influences the mechanical strength of the wood, and the exposure temperatures that most affect the measurement vary between 120 °C and 180 °C.

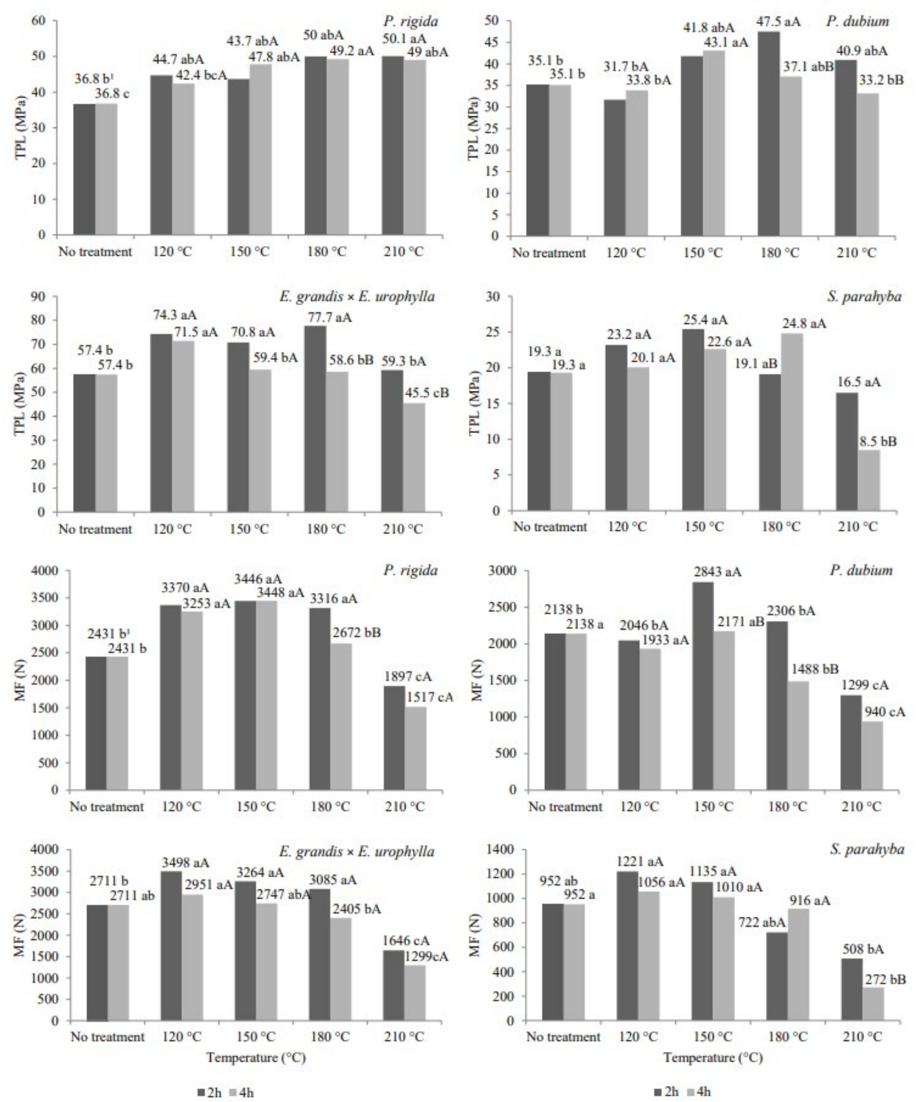

Figure 2 - Test of means for tension of the proportional limit (TPL) and maximum force (MF) of the four forest species relating the five temperature treatments with the two-time treatments. [1]Averages followed by lowercase letters compare temperature treatments within each time, and means followed by uppercase letters compare time treatments within each temperature, according to Tukey's test at 5% probability of error.

ACKNOWLEDGMENTS

This study was funded by the Programas de Iniciação Científica e Tecnológica (PIBIC), Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) and also the Fundo de Incentivo a Pesquisa"(FIPE) of the Universidade Federal de Santa Maria (UFSM); and was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), Brasil –Financecode 001.

DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHORS' CONTRIBUTION

All authors contributed equally to the collection, analysis, and interpretation of data, writing of the manuscript, and making the decision to publish the results. All authors have critically reviewed and approved the final version of the manuscript.

REFERENCES

AMERICAN SOCIETY. **For testing and materials**. Standard methods of testing small clear specimens of timber: ASTM D 143-94. Philadelphia, 2000.

ARAÚJO, S. O. et al. Properties of thermorectificated Wood of *Eucalyptus grandis* and Eucalyptus. **Scientia Forestalis**, v.40, n.95, p.327-336, 2012. Available from: <https://www.ipef.br/publicacoes/scientia/nr95/cap03.pdf>. Accessed: Dec. 20, 2020.

CADEMARTORI, P. H. G. et al. Modification of static bending strength properties of *Eucalyptus grandis* heat-treated wood. **Pesquisa de Materiais**, v.15, n.6, p.922-927, 2012. Available from: <https://www.scielo.br/scielo.php?script=sci_arttext&pid=S1516-14392012000600014>. Accessed: Jan. 11, 2020. doi: 10.1590/S1516-14392012005000136.

CANDATEN, L. et al. Physical-mechanical properties and biological resistance of thermally modified juvenile *Handroanthus chrysotrichus* wood. **Revista de Ciências Agrárias Amazonian Journal of Agricultural and Environmental Sciences**, v.63, p.1-8, 2020. Availablefrom:<http://btcc.ufra.edu.br/index.php/ajaes/article/view/3258>. Accessed: May, 11, 2021.

CARON, B. O. et al. Growth of tree species and sugarcane production in agroforestry systems. **Anais da Academia Brasileira de Ciências**, v.90, n.2, p.2425-2436, 2018. Available from: <https://www.scielo.br/scielo.php?script=sci_arttext&pid=S0001-37652018000502425>. Accessed: Jan. 31, 2021. doi: 10.1590/0001-3765201820170313.

CHRISTOFORO, A. L. et al. Estimation of wood toughness in brazilian tropical tree species. **Engenharia Agrícola**, v.40, n.2, p.232-237, 2020. Available from: <https://www.scielo.br/scielo.php?pid=S0100-69162020000200232&script=sci_arttext>. Accessed: May, 11, 2021. doi: 10.1590/1809-4430-Eng.Agric.v40n2p232-237/2020.

FERREIRA, M. S. et al. Effect of heat treatment on physical and mechanical properties of *Hymenolobium petraeum* wood. **Tecnologia em Metalúrgica, Materiais e Mineração**. v.16, n.1, p.3-7, 2019. Available from: <https://tecnologiammm.com.br/article/10.4322/2176-1523.20191297/pdf/tmm-16-1-3.pdf>. Accessed: Nov. 08, 2020. doi: 10.4322/2176-1523.20191297.

FONTOURA, M. R. et al. Mechanical and chemical properties of heat treated *Hovenia dulcis* Thunberg wood. **Ciência da Madeira**, v.6, n.3, p.166-175, 2015. Available from: <https://periodicos.ufpel.edu.br/ojs2/index.php/cienciadamadeira/article/view/7138/4949>. Accessed: Feb. 22, 2021. doi: 10.15210/cmad.v6i3.7138.

GUNDUZ, G. et al. The density, compression strength and surface hardness of heat treated hornbeam (*Caroinus betulus*) wood. **Maderas: Ciencia y Tecnologia**, v.11, n.1, p.61-70, 2009. Available from: <https://scielo.conicyt.cl/scielo.php?script=sci_abstract&pid=S0718-221X2009000100005&lng=pt&nrm=iso>. Accessed: Dec. 05, 2020. doi: 10.4067/S0718-221X2009000100005.

HULLER, L.A.S. et al. Thermal modification and technological characteristics of Wood of *Eucalyptus cloeziana*. **Pesquisa Florestal Brasileira**, v.37, n.90, p.183-188, 2017. Available from: <https://pfb.cnpf.embrapa.br/pfb/index.php/pfb/article/view/1288/572>. Accessed: Jan. 27, 2021. doi: 10.4336/2017.pfb.37.90.1288.

KAPLAN, L. Effect of the interaction between thermal modification temperature and cutting parameters on the quality of oak wood. **Bio Resources**, v.13, n.1, p.1251-1264, 2018. Available from: <https://bioresources.cnr.ncsu.edu/wp-content/uploads/2018/01/BioRes_13_1_1251_Kaplan_KS_Effect_Thermal_Mod_Temperat_Cutting_Param_Oak_Wood_13043.pdf>. Accessed: Feb. 18, 2021.doi: 10.15376/biores.13.1.1251-1264.

KOCAEFE, D. et al. Dimensional Stabilization of Wood. **Current Forestry Reports**. v.1, p.151 -161, 2015. Available from: <https://link.springer.com/content/pdf/10.1007/s40725-015-0017-5.pdf>. Accessed: Aug. 08, 2021. doi: 10.1007/s40725-015-0017-5.

KORKUT S.; BUDAKÇI M. Effect of high-temperature treatment on the mechanical properties of rowan (*Sorbus aucuparia* L.) wood. **Drying Technology**. v.27, n.11, p.1240-1247, 2009. Available from: <https://www.tandfonline.com/doi/abs/10.1080/07373930903267161>. Accessed: Aug. 08, 2021. doi: 10.1080/07373930903267161.

MENEZES, W. M. de. et al. Thermal modification on the physical properties of wood. **Ciência Rural**, v.44, n.6, p.1019-1024, 2014. Available from: <https://www.scielo.br/scielo.php?pid=S0103-84782014000600011&script=sci_abstract&tlng=pt>. Accessed: Jan. 11, 2021. doi: 10.1590/S0103-84782014000600011.

MODES, K. S. Effect of heat treatment on mechanical properties of *Pinus taeda* and *Eucalyptus grandis* woods. **Ciência Florestal**, v.27, n.1, p.291-302, 2017. Available from: <http://scielo.br/scielo.php?pid=S1980-50982017000100291&script=sci_abstract&tlng=pt>. Accessed: Jan. 14, 2021. doi: 10.5902/1980509826467.

NOGUEIRA, M. C. J. A. et al. Sixteen properties of *Eucalyptus tereticornis* wood for structural uses. **Bioscience Journal**, v.36, n.2, 2020. Available from: <http://www.seer.ufu.br/index.php/biosciencejournal/article/view/45169>. Accessed: May, 11, 2021. doi: 10.14393/BJ-v36n2a2020-45169.

SANTOS, V. B.; SILVA, G. C. Effect of thermalmodification on the physical properties of *Pinus caribaea* var. Hondurensis Barrett & Golfariwood. **Caderno de Ciências Agrárias**, v.13, p.1-7, 2021. Available from: <https://periodicos.ufmg.br/index.php/ccaufmg/article/view/26590>. Accessed: Mar. 28, 2021. doi: 10.35699/2447-6218.2021.26590.

SAS LEARNING EDITION. Getting started with the SAS Learning Edition.2003.

SIMPSON, W. T. Equilibrium moisture content prediction for wood. **Forest Products Journal**, La Grange, v.21, n.5, p.48-49, 1971. Available from: <https://www.fpl.fs.fed.us/documnts/pdf1971/simps71a.pdf>. Accessed: Aug. 08, 2021.