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ORIGINAL ARTICLE

Physical-mechanical properties and biological resistance of thermally modified juvenile *Handroanthus chrysotrichus* wood

Propriedades físico-mecânicas e resistência biológica da madeira de Handroanthus chrysotrichus jovem termicamente modificada

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RESUMO: Wood in its natural state is susceptible to the attack of xylophagous organisms, often requiring the use of products and techniques that enhance resistance to biological deterioration and increase the service life of the material. In this context, thermal modification is an environmentally sustainable alternative compared to others that use chemical preservatives. Thus, the objective of this study was to determine the physical-mechanical properties and biological resistance of thermally modified juvenile *Handroanthus chrysotrichus* wood. For this purpose, specimens were manufactured for the determination of physical and mechanical properties and biological resistance. Besides control samples without thermal modification, four groups of treated specimens were analyzed, submitted to thermal modification during four hours in an oven at temperatures of 120, 150, 180, and 210 ºC. The results showed the effectiveness of the thermal modification for wood preservation. Biodeterioration was lower with rising temperature; and improved dimensional stability and increased wood density were observed, although mechanical resistance decreased in the samples treated at 210 ºC. In general, the treatment at 180ºC is better suited when considering the interaction of the studied properties.

KEYWORDS
Ipe wood
Technological properties
Heat-treatment
Biodegradation

ABSTRACT: *A madeira no seu estado natural é susceptível ao ataque de organismos xilófagos, sendo muitas vezes necessário o uso de produtos e técnicas que acrescentem resistência à deterioração biológica e vida útil ao material. Neste contexto, a modificação térmica surge como uma alternativa ambientalmente sustentável quando comparado a outras, que utilizam conservantes químicos. Assim, o objetivo deste estudo foi determinar as propriedades físico-mecânicas e resistência biológica da madeira de Handroanthus chrysotrichus jovem termicamente modificada. Para este fim, foram fabricados corpos de prova para a determinação das propriedades físicas, mecânicas e biológicas. Além da amostra de controle (sem modificação térmica), foram aplicadas as temperaturas de 120, 150, 180 e 210ºC durante 4 horas em estufa. Os resultados indicaram a eficácia da modificação térmica como conservante de madeira onde a biodeterioração foi menor com o aumento da temperatura; ocorreram várias alterações nas propriedades físicas do material e observou-se uma tendência de diminuição da resistência mecânica à temperatura de 210ºC. Em geral, o tratamento a 180ºC é mais adequado quando se relaciona a interação das propriedades estudadas.*

PALAVRAS-CHAVE
Madeira de ipê
Propriedades tecnológicas
Tratamento de calor
Biodegradação

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1 Introduction

Due to the myriad uses of wood, knowledge of its physical and mechanical properties, as well as durability when exposed to severe weather and biological organisms, is relevant to select the best species to use in different situations. Therefore, the characterization of the technological properties of wood, *in natura* or after the treatments that add value to the material, is crucial to assign quality ratings and choose among multiple usages, from exotic and native species, in the latter case where information is still lacking.

The study of native species is particularly important when talking about species having economic, environmental and ecological relevance such as the *Handroanthus chrysotrichus* Mart ex DC. Popularly known as Ipê-amarelo in Brazil (Zimmermann et al., 2014), it has a high natural occurrence in countries such as Argentina and Brazil, with a slow growth rate and high natural durability, and is frequently used for urban afforestation (Carvalho, 2003). However, even for species with good durability in the natural state, wood is susceptible to the attack of xylophagous organisms, and when the wood will be exposed to severe weather conditions, it is recommended to use methods or practices, such as application of chemical preservatives, to increase the material's resistance to deterioration (Araújo et al., 2016). In this context, this process is an environmentally sustainable alternative compared with others that use chemical elements that can damage the environment (Freitas et al., 2017). This situation has prompted increasing interest in developing wood treatments that do not involve use of chemicals (Salman et al., 2017).

Referring to the same species, a study conducted by Brancalion et al. (2018) found widespread fraud in the declared species of wood harvested in the Brazilian Amazon, being the wood of the genus of this study, wood of the genus *Handroanthus* spp. is the most illegally exploited, probably due to the high international market demand and consequent prices, for uses replacing the big-leaf mahogany (*Swietenia macrophylla*). That way, studies are necessary to characterize wood from *Handroanthus* spp. regarding physical, mechanical and biological properties and the treatments that can be applied to improve these properties, to enable a better understanding of the exploitation of this wood, mainly because most of the exploited material is imported into Europe, where different treatments, such as heat, for example, are widely applied.

This treatment is widely used by the wood industry, particularly in Europe (Zhang et al., 2013), because it does not use toxic chemical formulations that can damage health or the environment. This method consists of submitting wood to temperatures between 120 and 200 ºC to modify cellulose, hemicellulose and lignin, with the objective of obtaining a material that is less hygroscopic, more stable and with fewer problems caused by shrinkage and swelling (De Paula, 2016; Almeida et al., 2018). The resulting modifications occur primarily to polymers, which represent from 18 to 35% of the wood's weight, depending on species (Molinski et al., 2016).

Therefore, the process of thermal modification makes the material more resistant to the attack of biological deterioration agents (Modes et al., 2017a). It also alters the material's intrinsic characteristics and color, which can be favorable for some forest species (Freitas et al., 2017), adding value. However, even though the combination of different times and temperatures applied in the process of thermal modification results in generally positive alterations, there are reports that in certain situations this action induces a decrease in mechanical resistance (Carvalho et al., 2017; Huller et al., 2017).

In Brazil, thermal modification is not yet widespread. Its application is particularly limited by the huge range of species that grow naturally in the country (De Paula, 2016) and the variety of climate and soil characteristics. The resulting variability of the technological properties makes it more complicated to ascertain the best treatment times and temperatures to be applied (Delucis et al., 2014; Fontoura et al., 2015). Therefore, the objective of this study was to determine the physical-mechanical properties and biological resistance of thermally modified juvenile *Handroanthus chrysotrichus* wood.

2 Material and Methods

The material used originated from vegetation suppression along the margin of Highway BR 158/386, in accordance to Forest Permit number 33/2014 from the Frederico Westphalen municipal government. Four *Handroanthus chrysotrichus* (Ipê-amarelo) trees with 11 years of age were selected based on the diameter at breast height (DBH), by means of a pre-defined diametric class of 9-14 cm. The logs were then cut into specimens, containing parts of the core and albumin, which are quite distinct for the species in question, as depicted in Figure 1.

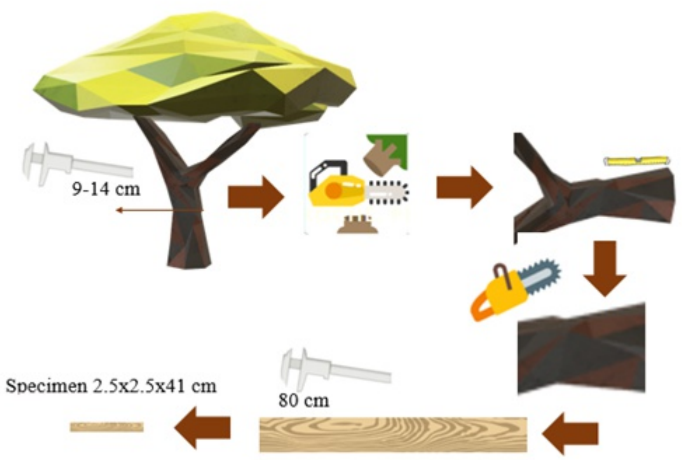

Figure 1. Representative scheme for obtaining the specimens of Ipe wood for the tests.

Figura 1. Esquema representativo para a obtenção dos corpos de prova de madeira de Ipê para os ensaios.

Subsequently, 80 specimens were produced with dimensions of 2.5 x 2.5 x 41.0 cm (thickness, width and length, respectively, Figure 1), taken from the center boards, in accordance with the D-143 (ASTM, 2014). The specimens remained in ambient conditions until reaching moisture content between 14 and 15%. After reaching the desired conditions, they were separated into 16 samples for thermal modification in a Marconi MA035 oven with temperature control, with renovation and forced air circulation during four hours, at temperatures of 120, 150, 180 and 210 ºC, according to the scheme represented in Figure 2, along with a control sample without thermal modification, being one treatment at a time. After thermal modification, the specimens were weighed, measured and allowed to cool to ambient temperature (approximately 25 Cº). Then static bending strength tests were performed to determine the modulus of elasticity (MOE), modulus of rupture (MOR) and proportional limit (PL) using an EMIC model ML 2000 universal testing machine (ASTM, 2014).

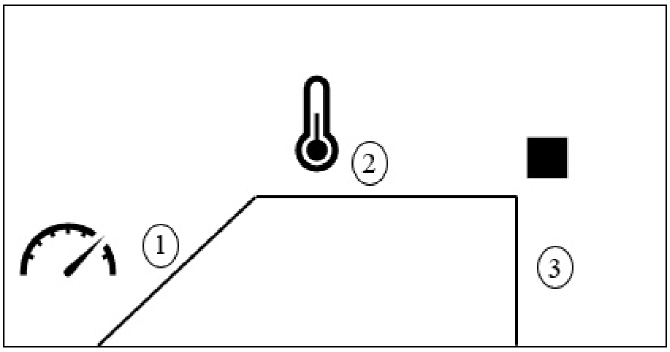

Figure 2. Representative scheme of application of thermal modification in the different treatments: 1 = time to reach the desired temperature (20 minutes for 120 ºC; 30 minutes for 150 ºC; 40 minutes for 180 ºC; 80 minutes for 210 ºC); 2 = constant temperature application period, 4 hours for all treatments; 3 = ending of treatment, removal of specimens from the oven and allocated in a desiccator to stabilize at ambient temperature, of approximately 20ºC.

Figura 2. Esquema representativo da aplicação da modificação térmica nos diferentes tratamentos: 1 = tempo para atingir a temperatura desejada (20 minutos para 120 ºC; 30 minutos para 150 ºC; 40 minutos para 180ºC; 80 minutos para 210ºC); 2 = período de aplicação de temperatura constante, 4 horas para todos os tratamentos; 3 = fim do tratamento, remoção de espécies da estufa e inserção no dessecador para estabilizar à temperatura ambiente, de aproximadamente 20ºC.

To determine the physical properties, samples from the mechanical testing were selected, without damage, which were scaled in 6 samples with dimensions of 2.5 x 2.5 x 5.0 cm (thickness, width and length, respectively), as shown in Figure 3, taken from the sites where no break in the mechanical assay occurred, all possible samples were taken in each treatment, and then 6 were selected for actual use.. These specimens were exposed to ambient conditions of relative humidity and temperature for a period of 15 days and afterwards were measured at three points marked beforehand, in the radial, tangential and longitudinal anatomical directions, using the method suggested by the D-143, with adaptation of the size of the specimens according to the material available for the tests (ASTM, 2014).

Figure 3. Image of the specimens after the mechanical testing, highlighted by the black ruler icons where the material was removed for the physical tests.

Figura 3. Imagem das amostras após o teste mecânico, destacada pelos ícones da régua preta o material que foi removido para os testes físicos.

A caliper gauge with precision of 0.01 mm and analytical scale with precision of 0.01 g were used to determine the specimens' dimensions and weight in the conditions air-dried, saturated and oven-dried, enabling the determination of shrinkage and swelling. The anisotropic coefficient was calculated for both shrinkage and swelling by the ratio between the tangential and radial directions. The basic, apparent (air-dried) and saturated specific mass, just as the moisture content, were obtained in accordance with D-143 (ASTM, 2014).

The biological property of mass loss was determined through the accelerated decay test, conducted in accordance with D-2017 (ASTM, 2005). Five specimens from each thermal modification were produced, plus the control sample, with dimensions of 2.5 x 2.5 x 0.9 cm (thickness, width and length, respectively), originating from reuse of material submitted to the mechanical testing in which the initial weight had been obtained.

The white-rot fungus *Trametes versicolor* was inoculated into plates of Pinus sp. for growth of fungal colonies, and after mycelial development, the culture material was inserted into flasks, which were placed in a Bod chamber for 16 weeks. After that the specimen were submitted to analyses of mass loss to obtain the final weight.

The statistical analyses involving the physical, mechanical and biological properties were conducted after the confirmation of the mathematical models' assumptions. Therefore, when there was a need to transform the original data, power transformation (Box & Cox, 1964) was applied. Due to the data transformation, only the results of the means of the dependent variable are described in their original form.

Thus, the values obtained for mass loss (ML), apparent air-dried specific mass (ρapp) and basic specific mass (ρbas) were transformed by applying equations 1 to 3.

$$ML' = 1 + \frac{(ML\^{}0.379\text{-}1)}{(0.379*12.6044\^{}\text{-}0.621)} \qquad (1)$$

$$\rho app' = 1 + \frac{(\rho app\^{}4.729\text{-}1)}{(4.729*0.876298\^{}3.729)} \qquad (2)$$

$$\rho bas = 1 + (1.477*0.690488\^{}0.477) \qquad (3)$$

Where: ML' = transformed mass loss; ML = observed mass loss; ρapp' = transformed apparent air-dried specific mass; ρapp = observed apparent air-dried specific mass; ρbas' = transformed basic specific mass; and ρbas = observed basic specific mass.

The data on the physical, mechanical and biological properties according to the thermal modification used were obtained in a completely randomized experimental design and were submitted to analysis of variance (ANOVA). In case of rejection of the hypothesis of equal means, the LSD t-test (least significant difference, α = 5%) was used.

3 Results and Discussion

Specific mass and moisture content of the wood of *Handroanthus chrysotrichus* presented differences according to the temperatures used in the thermal modification (Table 1). An increase in the basic specific mass occurred with increased temperature (180 ºC and 210 ºC), but the results of the milder treatments (120 ºC and 150 ºC) did not differ significantly from those of the control. For apparent saturated specific mass and apparent air-dried specific mass, the results were similar among the treatments, suggesting that temperature did not influence these variables for the species under study. With regard to the moisture contents, a tendency to decrease was observed with rising temperature.

Table 1. Mean of basic and apparent (saturated and air-dried) specific mass and moisture content of the juvenile *Handroanthus chrysotrichus* wood by treatment.

Tabela 1. Médias para a massa específica básica e aparente (saturada e seca ao ar) e o teor de umidade da madeira juvenil de *Handroanthus chrysotrichus* por tratamento.

Treatment	Specific mass (g cm $^{-3}$)			Moisture content (%)	
	Basic	Saturated	Air-dried	Saturated	Air-dried
Control	0.684bc (±0.02)	1.157a (±0.05)	0.913a (±0.03)	55.23a (±6.06)	15.62a (±0.41)
120°C	0.654c (±0.05)	1.164a (±0.02)	0.862a (±0.06)	54.73a (±5.37)	14.42b (±0.65)
150°C	0.645c (±0.06)	1.130a (±0.04)	0.829a (±0.07)	46.33b (±10.06)	11.84c (±0.71)
180°C	0.739a (±0.02)	1.171a (±0.03)	0.929a (±0.03)	54.41ab (±5.61)	9.48d (±0.29)
210°C	0.724ab (±0.05)	1.129a (±0.01)	0.860a (±0.08)	37.45c (±5.89)	7.02e (±0.63)
MSE	0.002154	0.001261	0.003707	46.6529	0.320198
Fval	4.74	1.82	2.43	7.70	198.94
Prob>F	0.0055**	0.1575^{ns}	0.0744^{ns}	0.0003**	0.0001**

MSE = Mean squared error; Fval = calculated value of F; Prob>F = error probability level; ** significant at an error probability level of 1%; ns not significant at an error probability level of 5%. Means followed by different letters in the column differ statistically by the test LSD t-test (least significant difference, α = 5%). Standard deviations in parentheses.

Similar results for basic specific mass were reported by Araújo et al. (2016) analyzing the species *Aspidosperma populifolium*, who found increasing values of this characteristic according to the thermal modification used. Carvalho et al. (2017) also observed an increase of this variable when thermally treating the wood of *Eucalyptus uhophylla*. Conversely, Delucis et al. (2014) reported a decrease of basic specific mass with an increase in temperature for the Eucalyptus spp. This same increase in specific gravity at a temperature of 180 ºC was observed by Melo et al. (2019), where the authors stated that the thermal modification occurs in different ways in the treatment phase, that is, according to the applied temperatures. In general, wide variation in this wood property was observed in the literature, which may be due to the heterogeneity of wood, since the analyzed variable is complex and affected by a number of factors, such as different cell diameter, wall thickness and length, as well as varying contents of extractives (Jesus & Silva, 2020).

For the saturated specific mass, the results were similar to those obtained by Soares et al. (2015) for the same genus, who found results close to 1.000 g cm^{-3}, although without thermal modification. For the apparent air-dried specific mass, the results were similar to those observed by Huller et al. (2017), where they ascertained 0.850 g cm^{-3} for thermally modified wood of *Eucalyptus cloeziana*, and on this basis, a decrease of this variable induced by thermal modification.

The decrease in air-dried moisture content was similar to the finding of Ferreira et al. (2019) for the thermal modification *Hymenolobium petraeum* species, where the authors pointed out that this pattern might be explained by the decrease of the wood hygroscopicity because of the increase in temperature. Moisture content is an important question, since its reduction due to methods that alter the material, such as thermal modification, can broaden its final use options (Bal, 2015). This decrease of the moisture content of wood as the temperature increases is a consequence of deterioration of the free hydroxyl groups (OH) which are present in the material subjected to thermal modification (Almeida et al., 2018).

These alterations in the physical properties also derive from the lignin modification, which above 55 ºC is molecularly changed, where the cellulose microfibrils are linked more strongly due to the increased number of crosslinks. Thus causing chemical and physical changes in the material subjected to high temperatures (Almeida et al., 2018).

The results for shrinkage and swelling in the tangential, radial and longitudinal anatomical directions, as well as for the anisotropic coefficient (Table 2), were greater in the control sample and presented a tendency to decrease with increase in temperature. The anisotropic coefficient values did not differ among each other, indicating that the treatments did not alter this property.

They were close to 1, classifying the wood as excellent for use in situations that involve changes in moisture of the material.

Table 2. Mean dimensional stability of the juvenile *Handroanthus chrysotrichus* wood by treatment.
Tabela 2. Médias de estabilidade dimensional da madeira juvenil de *Handroanthus chrysotrichus* por tratamento.

Treatment	Shrinkage - β (%)			Swelling - α (%)			Anisotropic coefficient	
	βt	βr	βl	αt	αr	αl	β	α
Control	9.46a (±1.28)	8.51a (±0.89)	0.74ab (±0.12)	6.53b (±0.61)	5.63a (±0.97)	0.66a (±0.22)	1.15a (±0.18)	1.21a (±0.31)
120°C	8.22ab (±0.72)	7.43ab (±1.60)	1.00a (±0.30)	6.50b (±0.73)	5.44a (±1.38)	0.64a (±0.35)	1.12a (±0.23)	1.07a (±0.64)
150°C	7.32bc (±1.05)	5.94b (±1.69)	0.75ab (±0.22)	6.29b (±0.31)	5.26a (±1.08)	0.77a (±0.28)	1.23a (±0.16)	1.32a (±0.30)
180°C	9.14a (±0.89)	7.00ab (±0.86)	0.52b (±0.18)	7.93a (±1.05)	5.22a (±0.86)	0.50a (±0.19)	1.36a (±0.17)	1.42a (±0.18)
210°C	6.56c (±1.78)	3.87c (±1.54)	0.69b (±0.19)	4.08c (±1.12)	3.81a (±1.32)	0.66a (±0.42)	1.24a (±0.26)	1.13a (±0.34)
MSE	1.379	1.874	0.048	0.719	1.311	0.093	0.041	0.151
Fval	5.98	9.91	3.45	15.96	2.40	0.59	1.22	0.80
Prob>F	0.002**	0.001**	0.025*	0.001**	0.077^{ns}	0.670^{ns}	0.328^{ns}	0.536^{ns}

t = tangential, r = radial and l = longitudinal direction; MSE = Mean squared error; Fval = calculated value of F; Prob>F = error probability level; ** significant at an error probability level of 1%; *significant at an error probability level of 5%; ns not significant at an error probability level of 5%. Means followed by different letters in the column differ statistically by the LSD t-test (least significant difference, α = 5%). Standard deviations in parentheses.

The decrease of shrinkage and swelling with the increase of temperature was also observed by Paneque et al. (2019) for *Eucalyptus grandis*, and by De Paula (2016), who studying the physical properties of thermally modified *Dinizia excelsa* wood in all anatomical directions, also found less pronounced shrinkage with lower temperatures applied to the material. Bal (2015) also observed smaller values of shrinkage and swelling at higher temperatures. The decrease of anisotropy with thermal modification is a positive result, since wood after being subjected to this process becomes more resistant to tensions, especially when exposed to adverse weather conditions (Almeida et al., 2009).

Several factors explain the alteration of dimensional stability of the material after the thermal modification, such as loss of hygroscopic hemicellulose polymers, leading to a decrease of the hydroxyl groups, and consequently reduction of hygroscopicity (Kocaefe et al., 2015). Among the anatomical planes of wood, the longitudinal is considered the most dimensionally stable. The radial and tangential have less dimensional stability because with an increase of temperature, the structural changes of links are bigger, decreasing the volume of the material due to the increase of shrinkage (Freitas et al., 2017). This difference between the values of shrinkage in the radial and tangential planes can be explained by the structure of the material in those directions, which affect the capacity of shrinkage of the wood cell walls (Kocaefe et al., 2015).

The static bending strength results are reported in Table 3, containing the mean values of the modulus of elasticity (MOE), modulus of rupture (MOR) and proportional limit (PL). These tests indicated a distinct pattern according to the different temperatures applied, where the lowest values of MOE and PL were observed in the control sample.

Table 3. Mean of static bending strength of the juvenile *Handroanthus chrysotrichus* wood by treatment.
Tabela 3. Médias de resistência à flexão estática da madeira juvenil de *Handroanthus chrysotrichus* por tratamento.

Treatment	Modulus of elasticity (MPa)	Modulus of rupture (MPa)	Proportion Limit (MPa)
Control	8,010.8c (±1525.3)	94.5b (±21.60)	33.8c (±11.56)
120°C	9,966.5ab (±1044.3)	127.2a (±33.46)	75.7ab (±14.16)
150°C	9,322.2b (±967.8)	108.7ab (±38.09)	67.2b (±9.90)
180°C	10,394.4a (±1508.5)	126.7a (±22.63)	79.13a (±13.01)
210°C	9,489.5ab (±1523.8)	73.6c (±20.07)	69.9ab (±16.35)
MSE	1.796	790.4	173.79
Fval	7.25	10.45	30.25
Prob>F	0.001**	0.001**	0.001**

MSE = Mean squared error; Fval = calculated value of F; Prob>F = error probability level; ** significant at an error probability level of 1%; Means followed by different letters in the column differ statistically by the LSD t-test (least significant difference, α = 5%). Standard deviations in parentheses.

The MOE results showed that the treatment at 180 ºC was associated with a 22.9% higher value than the control. For MOR, the temperature of 210 ºC was associated with 28.3% lower value than the control. Thus, a decrease of the mechanical resistance of the material was observed, which may have occurred because of the deterioration of the carbohydrates present in the wood, reducing its strength (Melo et al., 2019). The proportional limit value was lower in the untreated wood, by 51.6% at highest temperature. In that respect, Modes et al. (2017b) evaluating the influence of thermal modification of *Eucalyptus grandis* wood at the same temperatures as the present study, observed tendencies of increased MOE and decreased MOR compared to wood that was not thermally modified.

The MOE values were similar to those found by De Paula (2016) for *Dinizia excelsa* wood, where treatment at 180 ºC also caused the largest difference. The average MOR and MOE values obtained for the control samples corroborate the results found by Ribeiro et al. (2016) for *Erisma uncinatum* wood.

With regard to the proportional limit, the treatment at 180ºC presented the highest mean, which was also observed by Fontoura et al. (2015), who applied thermal modification under the same conditions of the present study and found 74.4 MPa at temperature of 180 ºC for *Hovenia dulcis* wood.

The evaluation of the mechanical properties showed lower values than those observed by Teles (2005) for the air-dried wood of *Tabebuia serratifolia* (same family), where the author observed values of 169.3 and 12851.1 MPa for MOR and MOE, respectively. Those results together with ours indicate that thermal modification at high temperatures can reduce the mechanical resistance of wood, due to the oxidation and carbonization of the material followed by dimensional alterations. However, this effect can be reduced by vacuum treatment according to Kocaefe et al. (2015). After the analyses of static bending strength, the thermal modification at 180 ºC appeared to be the most attractive for enhancement of the mechanical properties, because they showed smaller decreases.

The mechanical property results are in accordance with the observation of Molinski et al. (2016), who analyzed the literature published in the last few years and reported that after being subjected to thermal modification, wood can present greater resistance to compression and static bending, as well as greater modulus of elasticity and hardness.

With regard to the biological resistance of *Handroathus chrysotrichus* wood, we observed that, for the most part, thermal modification can be an alternative to preserve wood, since smallest mass losses of the material were obtained with treatments at higher temperatures compared to the control sample (Figure 1). Despite this, the data obtained did not show statistical differences between treatments.

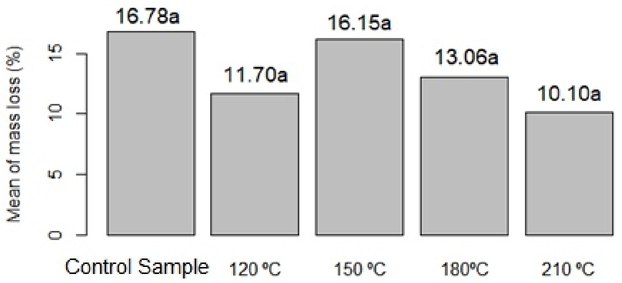

Figure 4. Mean of mass loss after the accelerated decay test of the juvenile *Handroathus chrysotrichus* wood, according to treatment.
Figura 4. Médias de perda de massa do ensaio de apodrecimento acelerado da madeira juvenil de *Handroanthus chrysotrichus* por tratamento.

The behavior observed for the biological properties is commonly found in the literature, where there is a consensus that thermal modification results increases wood's resistance to the attack of xylophagous organisms, as reported by Araújo et al. (2016) and and Zhang et al. (2013). The greater value found for the treatment at 150 ºC may have occurred because of the stages of the thermal modification process, which, by subjecting the wood to high temperatures causes intrinsic alterations, releasing sugar with low molecular weight by degrading the hemicellulose, increasing the food supply available to xylophagous fungi (Modes et al., 2017a).

With regard to wood resistance to the attack of xylophagous organisms, in accordance with the D-2017 (ASTM, 2005), the thermal modifications until 180 ºC enabled the classification of the material as resistant. This was expected because of the high natural durability of the species under study. The wood subjected to a temperature of 210 º C presented the lowest average mass loss, and so was classified as very resistant, as proposed in the literature for thermal modifications at high temperatures. After heat treatment, the polymers in wood, on the whole, do not undergo significant alterations until the temperature of 180 ºC (Batista et al., 2016), the point where the deterioration of cellulose rises from medium to high. Therefore, the lowest mass loss in the treatment at 210 ºC can be attributed to cellulose deterioration, and the lack of food supply for wood-decomposing organisms.

4 Conclusion

The thermal modification reduced the moisture content and the shrinkage of the *Handroathus chrysotrichus* wood, and increased the basic specific mass. The highest temperature reduced the wood's mechanical resistance.

In the biological properties, the thermal modification was positive at high temperatures, reducing the mass loss caused by wood deterioration.

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