ISSN 0104-7760
v.26 n.3 2020

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BEHAVIOR OF THERMALLY MODIFIED WOOD TO BIODETERIORATION BY XYLOPHAGE FUNGI

BELLON, K. R. R.; MONTEIRO, P. H. R.; KLITZKE, R. J.; AUER, C. G.; ANDRADE, A. S. de. Behavior of thermally modified wood to biodeterioration by xylophage fungi. **CERNE,** v. 26, n. 3, p. 331-340, 2020.

HIGHLIGHTS:

The increase in total extractive content is a result of polysaccharide degradation.

There is an increase in lignin content after the thermal modification process.

The chemical changes in wood influence the biodeterioration by fungi.

The thermally modified wood behaved differently to biodeterioration by fungi.

Keywords:
White rot
Brown rot
Rotting fungi
Thermal modification
Wood chemistry

ABSTRACT

Thermally modified wood undergoes chemical, physical, and mechanical modifications, resulting in changes in resistance to wood biodegrading agents. The objective of this study was to evaluate the resistance to biodeterioration of thermally modified wood by the industrial process VAP HolzSysteme® of *Eucalyptus grandis*, *Pinus taeda* and *Tectona grandis*, submitted to the *Lentinula edodes* fungi (brown rot) and *Pleurotus djamor* fungi (white rot), and to analyze the chemical properties, contents of holocellulose, lignin, total extracts, and ash, before and after biodeterioration. Three treatments were considered for each species: Control - wood *in natura*, modified wood at 140 °C and 160 °C. The specimens were made according to ASTM D 1413 (ASTM, 1994), in a total of 108 samples per species, 36 per treatment for each species, with 12 samples submitted to the fungus *L. edodes*, 12 to *P. djamor* and 12 correction blocks. Different behaviors occurred among species under fungal action. For *E. grandis* wood the thermal modification increased the resistance to biodeterioration of the wood under the action of the *L. edodes* fungus, in the opposite way occurred for the species *P. taeda*. There was little variation between treatments in *T. grandis* wood for both fungi. Thermal modification conferred chemical alterations on the wood, influencing their behavior the biodeterioration by the fungal action in *P. taeda* species in a negative way, (increasing the degradation level), and *E. grandis* in a positive way, reducing the biodeterioration. However, in *T. grandis* species no significant differences were identified in the different treatments by the action of different rotting fungi.

Historic:
Received 27/01/2020
Accepted 05/08/2020

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DOI:
10.1590/01047760202026032727

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INTRODUCTION

Brazil has more than 7.84 million hectares (MH) of planted forests. Among the genera planted, the highlights are Eucalyptus (5.67 MH), Pinus (1.58 MH), and Tectona (0.08 MH) (Ibá, 2019). The wood produced by such species is considered an alternative form of raw material, due to its economic and sustainable viability when compared to the use of native woods, as long as they have acceptable physical-mechanical and biological standards.

Resistance or natural durability is a parameter evaluated within the quality standards, which can be translated as the capacity of wood to resist the action of any agents that deteriorate the wood (Silva et al., 2005). Resistance to attacks by biological agents is due to the presence of extractives, which are toxic chemicals or repellents to xylophagous organisms. However, the distribution of extractives is different in each species, between trees and between portions of the wood. In general, the highest concentration of extractives is found in the heartwood and more precisely in the transition region to the sapwood, decreasing towards the medulla and increasing towards the stem base. This characteristic, together with the absence of nutritional material, ensures that the heartwood is the portion of the wood that represents greater natural durability (Silva et al., 2005; Paes et al., 2007).

The natural durability of *Eucalyptus grandis* Hill (ex Maiden) is moderate under the action of rotting fungi (IPT, 2013). The *Pinus* genus also presents a wood of moderate resistance when submitted to biodeterioration by fungi (Clausen, 2010), and the *Tectona grandis* L. f. wood has high natural durability and resistance to action of rotting fungi (IPT, 2013; Motta et al., 2013).

Among the rotting fungi, those ones causing white rot (because they cause characteristic white coloration in the wood) have the ability to degrade the lignin. The responsible ones for brown rot degrade hemicellulose and cellulose (holocellulose), and give the wood a darkened appearance (Gimenes, 2010; Moreschi, 2013).

The main rotting fungi belong to the Ascomycota (ascomycetes) and Basidiomycota (basidiomycetes) Divisions. Among the basidiomycetes, the species *Lentinula edodes* (Berk.) Pegler, edible fungus known worldwide as shiitake, is lignocellulite and classified as brown rot fungus (Santos, 2015). Fungi belonging to the *Pleurotus genus* are responsible for white rot, developing in tree trunks or dead wood, producing a white mycelium and degrading both lignin and cellulose (Menezes et al., 2017).

In order to improve the properties of wood, several techniques and treatments for preservation were developed. One of the procedures is thermal modification, used to change some technological characteristics of wood (physical-mechanical, chemical and biological), mainly dimensional stability, durability (Navi and Sandberg, 2012) and biological degradation resistance (Weiland and Guyonnet, 2003).

The chemical modifications in the cellular walls caused by thermal modification at certain temperatures, generally above 150 °C, are effective in altering the resistance of the wood to the attack of xylophagous agents (Boonstra et al., 2007). The durability of wood changes when thermally modified for two different reasons. The first one is the generation of new extractives during the process, which can act as a fungicide, and the second one is the increase in the hydrophobic characteristic of the wood, which reduces water absorption and hinders the development of fungi (Silva, 2012).

Due to these advantages, the main objective of this work was to evaluate the resistance to biodeterioration of thermally modified wood by the VAP HolzSysteme® process of the species *E. grandis*, *Pinus taeda* L. and *T. grandis* submitted to the *L. edodes* fungi and *Pleurotus djamor* fungi (Rumph. ex Fr.). Boedijn relating them to the fractions of chemical analysis.

MATERIAL AND METHODS

For each species, 60 pieces of 30 x 80 x 700 mm sawn wood were use, previously artificially dried at 10% humidity, divided into three lots containing 20 pieces per species. The first one that didn't receive treatment, maintaining the properties of the wood *in natura* and the two other batches, were treated by the thermal modification process, called VAP HolzSysteme® at final process temperatures of 140 °C and 160 °C. The VAP HolzSysteme® process was carried out according to the methodology of the company TWBrazil, located in Ponta Grossa, Paraná (Batista, 2012).

Six pieces were randomly chosen from each species and modification temperature and, from these, six specimens of 19 x 19 x 19 mm were made according to the ASTM D 1413 standard (ASTM, 1994) in the Machining Laboratory of the Department of Forest Engineering and Technology (DETF) of the Universidade Federal do Paraná, Curitiba, Paraná. One hundred and eight specimens per species, 36 per temperature for each species (Figure 1), were prepared and stored in an incubator with forced air circulation at 103 °C until they reached a constant mass. After stabilization, the initial mass (M_i) was measured.

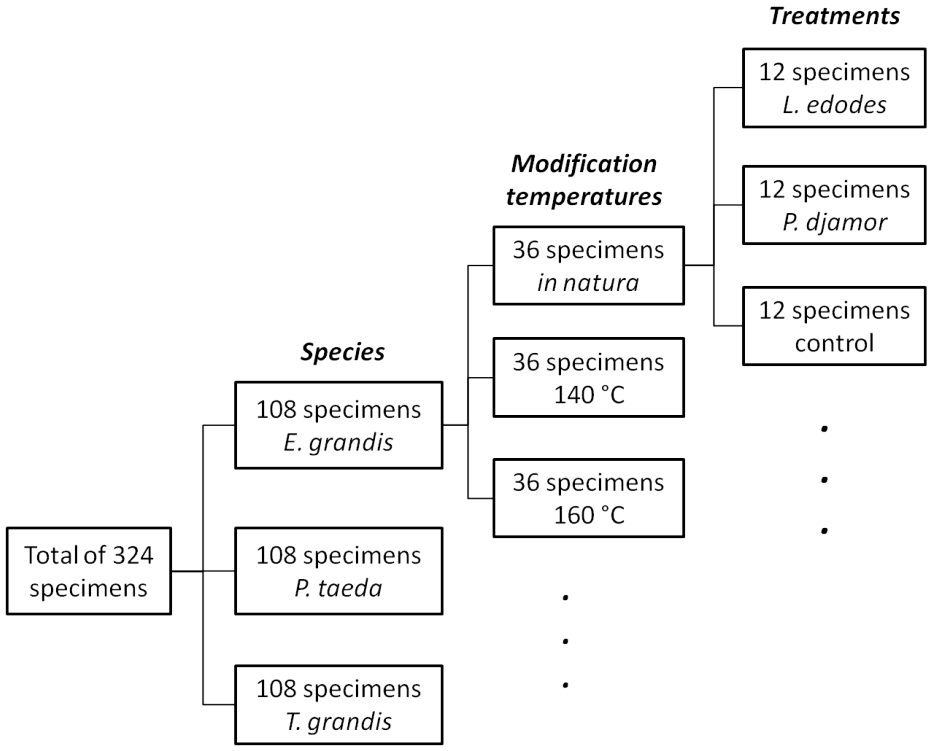

FIGURE 1 Subdivision of specimens for biodeterioration testing.

The prepared parts or specimens were submitted to an accelerated biodeterioration assay carried out at the Forest Pathology Laboratory from Embrapa Florestas, Colombo, Paraná. The specimens were subdivided into three treatments: *Lentinula edodes* and *Pleurotus djamor* fungi, causing brown and white rot, respectively, and control specimens, in each of these treatments 12 specimens were used (Figure 1). The fungi that were used in the biodeterioration test come from the fungi collection of the Non-Wood Products Laboratory from Embrapa Florestas, Colombo, Paraná.

The isolates were pricked from 0.5 cm diameter mycelium-agar discs, which were removed from the preservation vials and placed in disposable Petri dishes containing BDA (potato filter-agar) medium in a laminar flow hood, for growth of pure and active cultures of fungi and subsequent production of inoculum.

For the installation and conduct of the biodeterioration assay, 250 mL clear glass vials with wide mouth, metal screw cap with a 1 cm diameter hole containing 50 mL of BDA medium were used. The vials were sterilized with an autoclave at 121 °C and a pressure atmosphere for 20 minutes. The inoculation in the flasks occurred with the introduction of a 0.5 cm diameter agar-mycelium disk of the fungi *L. edodes* and *P. djamor*, for the respective species and modification temperatures. After the total growth of the fungi on the surface, the specimens of the species *E. grandis*, *P. taeda* and *T. grandis* were arranged in pairs, that is, two specimens for each vial, on the mycelial surface, and later the vials were capped. A cotton wick was placed in the hole of the caps to allow gas exchange. Additionally, six vials were prepared for treatment without inoculation of fungi, to serve as control. This control contained the 12 control specimens for each treatment in order to verify the loss of natural mass of the samples. After installation, the vials were incubated in a BOD chamber with a controlled temperature of 24 ± 2 °C and relative humidity of 70 ± 5 % for a period of eight weeks.

At the end of the incubation period, the specimens were placed in an oven at 103 °C. When reaching constant mass, the specimens were submitted to two stages of evaluation: the first stage to determine the final mass (M_f) and calculate the loss of mass (*PM*) in grams; and the second stage to determine the chemical properties of the wood under analysis. The calculation of mass loss (PM) was performed using Equation 1, where: PM_{cp} - loss of weight of the specimen (%); M_i - initial mass (g); M_f - final mass (g). and Equation 2, where: PM - final mass loss (%); PM_t - total mass loss of the specimen (%); PM_{bc} - average mass loss of specimens without application of fungi (%).

$$PM_{cp} = \frac{M_i - M_f}{M_i} x100 \quad [1]$$

$$PM = PM_t - PM_{bc} \quad [2]$$

The second stage of analysis was performed at the Wood Chemistry Laboratory from Universidade Federal do Paraná, Curitiba, Paraná, where the chemical properties of the wood were evaluated: content of extractives soluble in neutral organic solvents (ethanol:toluene at 1:2) according to TAPPI T204 cm (TAPPI, 1997); content of insoluble lignin according to TAPPI T222 om (TAPPI, 2002); ash content, TAPPI T211 om (TAPPI, 2002). The holocellulose content was obtained by difference according to Equation 3. To meet T257 cm-02 standard (TAPPI, 2002), the specimens were minced and ground in a knife mill and sieved in a set of 60 mesh and 40 mesh granulometry sieves. The particles retained in 40 mesh granulometry were used for chemical analysis. The specimens with fungi were cleaned with a hard bristle brush and a scalpel when necessary, removing the largest amount of mycelium. Six repetitions by factors were performed for non-biodeteriorated samples and three repetitions by factors for the other samples, due to the amount of material available after biodeterioration, using 30 grams of classified and dry sample. Equation 3, where: TLS - soluble lignin content (%); ET - total extractive content (%); C - ash content (%).

$$Holocellulose(\%) = 100 - (TLS + ET + C) \quad [3]$$

The statistical analysis was carried out in a completely randomized design, with a factorial arrangement, where the interactions between the following factors were analyzed: three species (*E. grandis*, *P. taeda* and *T. grandis*), with wood treatments (control - in natura and two heat treatments - 140 and 160 oC) and treatments with and without fungi (*L. edodes* and *P. djamor*). Six repetitions were used for biodegradation evaluations, and, for the chemical properties, three repetitions.

Bartlett's test was used to verify the homogeneity of variances before performing the analysis of variance (ANOVA). The variances were homogeneous, requiring no data transformation. In cases where the null hypothesis was rejected in ANOVA, the Tukey test was used to differentiate the means. The level of significance adopted for all tests was $p > 0.01$.

RESULTS

The thermally modified wood of the tested forest species behaved differently to biodeterioration by fungi (Table 1).

The biodeterioration assay showed a difference in mass loss between the species studied. Figure 2 shows the biodeterioration process, with 30 and 60 days.

TABLE 1 Average loss in mass (%) of thermally modified *Eucalyptus grandis*, *Pinus taeda* and *Tectona grandis* wood, after 8 weeks of colonization by the Lentinula edodes fungi and *Pleurotus djamor* fungi.

FOREST SPECIES	MASS LOSS (%)					
	Lentinula edodes			Pleurotus djamor		
	Control	140 °C	160 °C	Control	140 °C	160 °C
E. grandis	10.58 aA	6.93 aB	5.55 bC	4.67 aA	2.65 aB	5.37 bA
P. taeda	2.60 bC	3.91 bB	9.20 aA	2.86 bB	3.16 aB	7.98 aA
T. grandis	1.37 cB	2.31 cA	1.90 cAB	3.08 bA	3.61 aA	3.15 cA
Bartlett's test	7.2774 ns			0.3190 ns		
ANOVA – F-test	123.046 **			32.385 **		

Classification with capital letters for treatments (rows) and with lowercase letters for species (columns) by the Tukey test ($p < 0.05$). ns: not significant ($p > 0.05$). ** significant ($p > 0.01$). Control: wood *in natura*; 140 °C and 160 °C: temperatures of thermal modification of the woods.

The loss in mass of the species *E. grandis* presented a significant difference between the treatments for the *L. edodes* fungus with a tendency to reduce the loss in mass with the increase in temperature of the thermal treatments. There was a 34.5% and 47.5% reduction in biodegradation of the control for temperatures of 140 °C and 160 °C, respectively. Among the thermally modified woods, the reduction was 19.9 %. However, this reduction trend was not observed for the fungus *P. djamor*. A significant difference was observed only for the treatment at 140 °C concerning the other treatments. Thus, treatment at 140 °C can be considered the best treatment concerning the others, with a 43.2% reduction in mass loss when compared to the control.

Pinus taeda wood showed an increase in mass loss of 50.4% and 253.8% at 140 ° C and 160 ° C respectively for the control. For the fungus *P. djamor,* the same behavior occurred, there was an increase in mass loss of 10.5% at 140 °C and 179.0% at 160 °C when compared to the control. The thermally modified wood of *Pinus taeda* proved to be more susceptible to biodegradable fungi.

Tectona grandis wood was the least biodegraded compared to other woods, 672.3 % and 89.9 % less compared to *E. grandis* and *P. taeda* of the wood *in natura*, respectively, submitted to the *L. edodes* fungus. A similar behavior was found for modified woods, at 140 °C, where *Tectona grandis* biodeteriorated 200 % less than *Eucalyptus* and 69.3 % less than *Pinus taeda*, at 160 °C, 192.1 % and 384.2 %, respectively. As for *P. djamor* fungus, there was no significant difference between *Tectona grandis* and *Pinus taeda* in the control treatment. However, among the *Tectona grandis* and

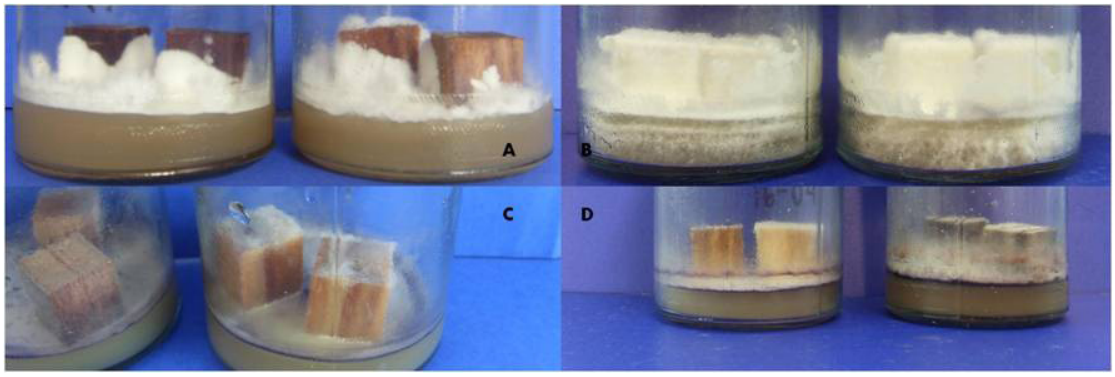

FIGURE 2 Biodeterioration test of thermally modified *Tectona grandis* wood with the fungus *Lentinula edodes* at 30 (a) and 60 days (b), and; *Pinus taeda* wood thermally modified with the fungus *Pleurotus djamor* at 30 (c) and 60 days (d).

Eucalyptus controls, there was a significant difference; the *Eucalyptus* wood was biodegraded 51.6% more than the *Tectona grandis* wood. At 140 °C there was no significant difference in mass loss between species. At 160 °C, *Tectona grandis* wood had the lowest loss in mass, 70.5% less than *Eucalyptus* and 153.3% less than *Pinus*. There was no significant difference between the temperatures of *T. grandis* wood, that is, the thermal modification did not influence the biodeterioration by the fungus *P. djamor*, and for *L. edodes* the thermal modification at 140 °C provided a 68.61% greater degradation than the control, and at 160 °C there was no significant difference in relation to the control.

It was observed that, as the wood modification temperature increased in the VAP HolzSysteme® process, the chemical properties of the wood changed (Tables 2, 3 and 4).

In non-biodegradable wood (without fungi), the holocellulose content in *E. grandis*, from the control sample for modified wood at 140 °C, decreased significantly by 14.2%; this same trend was seen in *Pinus* with a reduction of 23.3%; and, in *Tectona grandis* wood, there was no significant reduction. For all species, there was a significant reduction in the holocellulose content between the control and the thermal modification 160 °C, varying from 31.9%, 27.0%, and 24.0% for the respective species: *E. grandis*, *P. taeda* and *T. grandis*. The same behavior was observed between 140 °C and 160 °C, in *Eucalyptus* it decreased 20.6%, in *Pinus*, 4.8%, and in *Tectona grandis*, 23.4%.

The content of total extracts in non-biodegraded wood showed a significant difference between the control treatments, 140 °C and 160 °C, in all species analyzed, in *E. grandis*, *P. taeda* and *T. grandis*, from the control to 140 °C they increased 186.76%, 219.78% and 14.13%, from the control to 160 °C they increased 893.63%, 228.86% and 158.93% and from 140 °C to 160 °C increased 246.5%, 2.84% and 126.87%, respectively. In *Pinus* wood, there was no significant difference between treatments with thermal modification.

In non-biodeteriorated *Pinus taeda* woods, the lignin content increased significantly. From the control to 140 °C, 9.19 %, from the control to 160 °C, increased 16.52 % and from 140 °C to 160 °C, increased 6.71 %,

TABLE 2 Chemical properties of *Eucalyptus grandis* woods, *in natura* and thermally modified, before and after submission to the accelerated biodeterioration test.

FUNGI	Holocellulose (%)			Lignin (%)			Total Extractives (%)			Ash (%)		
	Cont.	140 °C	160 °C	Cont.	140 °C	160 °C	Cont.	140 °C	160 °C	Cont.	140 °C	160 °C
Without fungus	71.88	61.67	48.94	25.93	32.41	30.59	2.04	5.85	20.27	0.15	0.08	0.20
	aA	aB	bC	bC	aA	cB	bC	abB	aA	bB	bC	cA
L. edodes	62.75	60.75	54.29	31.75	31.91	35.18	5.20	6.98	10.29	0.29	0.37	0.23
	cA	aB	aC	aA	aA	aB	aC	aB	cA	aB	aA	bC
P. djamor	67.61	62.52	54.74	30.68	32.47	32.88	1.47	4.67	12.07	0.25	0.35	0.31
	bA	aB	aC	aB	aAB	bA	bC	bB	bA	aB	aA	aA
Bartlett's test	11.52664 ns			2.366626 ns			11.54858 ns			9.554354 ns		
F-test	167.1 **			42.2 **			250.542 **			72.557 **		

Classification with capital letters for treatments (rows) and with lowercase letters for species (columns) by the Tukey test ($p < 0.05$). ns: not significant ($p > 0.05$). ** significant ($p > 0.01$). Being, Cont.: Control, wood *in natura*; 140 °C: modification at 140 °C; 160 °C: modification at 160 °C.

TABLE 3 Chemical properties of *Pinus taeda* woods, *in natura* and thermally modified, before and after submission to the accelerated biodeterioration test.

FUNGI	Holocellulose (%)			Lignin (%)			Total Extractives (%)			Ash (%)		
	Cont.	140 °C	160 °C	Cont.	140 °C	160 °C	Cont.	140 °C	160 °C	Cont.	140 °C	160 °C
Without fungus	64.80	49.69	47.31	29.48	32.19	34.35	5.51	17.62	18.12	0.21	0.51	0.22
	aA	bB	bC	bC	bB	bA	aB	aA	aA	cB	bA	bB
L. edodes	59.92	58.17	50.84	35.69	33.71	40.09	3.99	7.62	8.59	0.40	0.50	0.47
	bA	aA	aB	aB	abB	aA	bB	bA	bA	bB	bA	aA
P. djamor	60.48	59.38	51.93	34.68	35.53	41.22	4.33	4.49	6.37	0.51	0.59	0.49
	bA	aA	aB	aB	aB	aA	bB	cB	cA	aB	aA	aB
Bartlett's test	3.111604 ns			2.854595 ns			7.374559 ns			10.55543 ns		
F-test	791.1 **			19.02 **			50.227 **			83.78 **		

Classification with capital letters for treatments (rows) and with lowercase letters for species (columns) by the Tukey test ($p < 0.05$). ns: not significant ($p > 0.05$). ** significant ($p > 0.01$). Being, Cont.: Control, wood *in natura*; 140 °C: modification at 140 °C; 160 °C: modification at 160 °C.

TABLE 4 Chemical properties of *Tectona grandis* woods, *in natura* and thermally modified, before and after submission to the accelerated biodeterioration test.

FUNGI	Holocellulose (%)			Lignin (%)			Total Extractives (%)			Ash (%)		
	Cont.	140 °C	160 °C	Cont.	140 °C	160 °C	Cont.	140 °C	160 °C	Cont.	140 °C	160 °C
Without fungus	59.43	58.95	45.16	32.11	31.64	34.35	7.50	8.56	19.42	0.96	0.85	1.07
	aA	aA	aB	bB	bB	cA	aC	aB	aA	aB	aC	aA
L. edodes	57.88	56.11	42.61	35.13	35.71	38.56	6.18	7.49	17.94	0.82	0.69	0.89
	aA	bA	bB	aB	aB	bA	bC	bB	bA	bB	bC	bA
P. djamor	57.80	58.61	42.23	35.91	35.97	42.05	5.44	4.57	14.90	0.85	0.86	0.82
	aA	aA	bB	aB	aB	aA	bB	cC	cA	bA	aA	cA
Bartlett's test	4.955474 ns			3.285851 ns			2.379885 ns			15.21056 ns		
F-test	28.08 **			11.28 **			5.4 **			57.31 **		

Classification with capital letters for treatments (rows) and with lowercase letters for species (columns) by the Tukey test ($p < 0.05$). ns: not significant ($p > 0.05$). ** significant ($p > 0.01$). Being, Cont.: Control, wood *in natura*; 140 °C: modification at 140 °C; 160 °C: modification at 160 °C.

noting a tendency to increase in the content of lignin with the increase in temperature of thermal modification.

T. grandis wood, without fungus, showed no significant difference in the lignin content between *in natura* and 140 °C. However, there was a significant difference between *in natura* and at 160 °C treatments, and 140 °C and 160 °C treatments, which increased the levels of lignin by 6.98% and 8.56%, respectively. For the *E. grandis* wood, there was also a significant difference between the treatments. From wood *in natura* to 140 °C there was an increase of 24.99 %, from wood *in natura* to 160 °C, it increased 17.97 %, and from 140 °C to 160 °C there was a reduction of 5.61 % in lignin content.

The ash content in the non-biodegraded wood had a different behavior between the coniferous ones and the hardwood ones. The ash content in *Pinus* increased by 142.86 % from control to 140 °C, showed no difference between control and 160 °C, and reduced from 140 °C to 160 °C by 56.86%. In the hardwood ones, the behavior was similar, from control to 140 °C reduced 46.66% and 11.46%, *Eucalyptus* and *Tectona grandis*, respectively. From control to 160 °C and from 140 °C to 160°C, the ash content in *Eucalyptus* increased 33.33% and 150%, and in *Tectona grandis* increased by 11.46% and 25.88%, respectively.

Observing the chemical properties of wood submitted to biodeterioration with the *L. edodes* fungi and *P. djamor* fungi in relation to wood without fungus, it was noted that the fungi consumed holocellulose significantly, of *E. grandis* and *P. taeda*.

The chemical analyses of thermally modified woods submitted to both fungi had different behaviors in relation to the control.

The fungi had preference in consuming the chemical compounds present in the total extractives of the thermally modified wood, with the exception of the *E. grandis* wood modified at 140 °C, in which the *L. edodes* fungus consumed holocellulose (1.57 %) and lignin (1.54 %), but this consumption was not significant in relation to the material without fungus. There was significant consumption of holocellulose in wood modified at 140 °C of *T. grandis*, 4.82 % in relation to wood without fungus when submitted to *L. edodes*; and at 160 °C, 6.49 % when submitted to *P. djamor* fungus.

DISCUSSION

The chemical composition of each species results in different responses when subjected to thermal modification and resistance to biodeterioration (Boonstra et al., 2007). The resistance to biodeterioration of any wood is attributed to the presence of certain chemical compounds in the wood, such as tannins and other complex phenolic substances, toxic to biodeterioration agents (Paes, 2002). The natural durability of the wood depends on the degree of ease of access, to the interior of the wood, for the organisms to settle and the chemical composition. Fungal penetration pathways depend on: the structure and anatomical arrangements of the wood; the presence or absence of natural barriers (tyloses, punctuations, gums and resins); and chemical factors (cell wall polymers and extracts) (Eaton and Hale, 1993). The thermal modification altered the chemical composition of the analyzed wood, consequently altering the anatomical structure with respect to the constitution of the cell wall, providing more access routes for the penetration of fungi or not.

The increased susceptibility of *P. taeda* thermally modified wood to fungi attack can be attributed to changes in chemical compounds, certain complex phenolic substances that acted to repel the action of biodeterioration agents (Paes, 2002). It can also be attributed to anatomical (structural) changes suffered by the action of high temperature, providing greater penetration of fungi, reducing the natural durability of the wood. Brito et al. (2019) found similar results for the same type of thermally modified wood.

The thermal modification process provided *E. grandis* wood with greater resistance to biodeterioration by the fungus *L. edodes* at the two test temperatures, and by the fungus *P. djamor*, at 140 °C. The reduction in mass loss of the treated wood probably occurred due to changes in the chemical composition of the wood, producing new compounds that inhibit or repel the development of fungi. The increase in biodegradation by the white rot fungus, of wood modified at 160 °C in relation to thermal modification at 140 ° C, may have been caused by the alteration in the anatomical structure of the wood due to the increase in temperature, facilitating the penetration of the hyphae of the white rot fungus. Calonego et al. (2013), when performing biodeterioration by the brown rot fungus in thermally modified *E. grandis*, also found a reduction in mass loss with increasing temperature. In the field of decomposition, modified wood of the genus *Eucalyptus* showed little loss of mass compared to natural wood (Knapic et al. 2018).

Tectona grandis wood is naturally resistant to the action of xylophagous fungi. However, thermal modification increased the susceptibility of *Tectona grandis* wood, reducing the wood's resistance to the attack of brown rot fungus, probably for the same reasons that increased the degradation in *P. taeda* wood, however to a lesser extent.

The *E. grandis* and *T. grandis* wood, *in natura*, were more deteriorated by the white rot fungus than the *P. taeda* wood. In general, white rot fungi deteriorate the angiosperm wood to a greater degree when compared to gymnosperm wood (Curling et al., 2000). In the present study, the fungus *P. djamor*, behaved in a manner contrary to that described by Curling et al. (2000) against thermally modified wood, deteriorating the wood of *P. taeda* (gymnosperm) to a greater degree. This is probably due to the chemical alteration suffered by the thermally modified wood, making the *P. taeda* wood more susceptible to action by the fungus *P. djamor*. The cleavage of hemicellulose into smaller molecular chains and the formation of new compounds facilitated the work of decomposing and transforming macromolecules into soluble compounds carried out by fungi to be assimilated and digested by them (Mendes and Alves, 1988).

Hemicellulose, a component of holocellulose, starts a strong degradation from a temperature close to 150 °C (Sundqvist, 2004), that is, it is the first chemical component to be affected when the wood undergoes thermal modification processes, followed by cellulose and lignin degradation (Esteves et al., 2008; Brosse et al., 2010; Esteves, et al., 2013), which explains the reduction of the holocellulose content more effectively at the treatment temperature at 160 °C in control. The reduction in holocellulose occurs due to the deacetylation of hemicellulose, attributed to the decomposition of the acetyl and acetoxy groups in xylan (Teejerdsma and Militz, 2005; Esteves et al., 2013). Yalcin and Sahin (2015), Batista et al. (2016), Lengowski et al. (2018), Pratiwi et al. (2019) observed a reduction in the content of holocelluloses after thermal modification in other species.

The increase in lignin content after the thermal modification process was also observed by Kamdem et al. (2002), Tjeerdsma and Militz (2005), Esteves et al. (2008), González-Peña et al. (2009), Brosse et al. (2010), Ding et al. (2011), Esteves et al. (2011), Moura et al. (2012) and Sikora et al. (2018). According to Esteves et al. (2013) and Cademartori et al. (2015), the increase in the percentage of lignin is due to the degradation of carbohydrates (hemicelluloses) and the formation of carbonyl groups in lignin (Li et al., 2002; Lopes et al., 2018).

The increase in total extractive content is due to the formation of new chemical compounds from

the extraction of water and ethanol as a result of the degradation of polysaccharides (Rosa and Pereira, 1994; Esteves et al., 2008). This trend was found by Esteves et al. (2008), Brosse et al. (2010), Lengowski (2018), Batista (2012), Poubel et al. (2013) and Sikora et al. (2018). The new compounds were characterized by an increase in the total extractive content. In the biodeterioration process, the total extractive content of the modified wood was reduced, since the assimilation of the new compounds by the fungi occurred in all species and treatments.

CONCLUSIONS

The thermal modification caused chemical modifications in the wood, influencing the behavior of the species in the biodeterioration by the action of fungi.

The thermal modification at 140 ° C showed: a) the best temperature for the species *Eucalyptus grandis* concerning biodeterioration by fungi; b) the temperature provided in the lower increase in weight loss biodeterioration *Pinus taeda* on wood in nature, and; c) the temperature that gave less changes in the chemical structure of the species.

The process of thermal modification provided *Pinus taeda* wood with greater susceptibility to attack by the tested fungi.

Tectona grandis wood, independent of the thermal modification process, proved to be the most resistant to the attack of rotting fungi.

ACKNOWLEDGEMENTS

The authors thank the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) for their financial support, Embrapa Florestas and UFPR for providing resources and infrastructure, and TWBrazil for the donation of the raw material.

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