Comparative study on the durability of heat-treated White Birch (*Betula papyrifera)* subjected to the attack of brown and white rot fungi.

LEKOUNOUGOU, S., KOCAEFE, D.*

Department of Applied Sciences, University of Quebec at Chicoutimi,

555 Blvd. de l'Université, Chicoutimi, G7H2B1, QC, Canada.

* Corresponding author: Kocaefe D**:** duygu_kocaefe@uqac.ca

Tel: (+1) 418-545 5011 ext 5215 Fax: (+1) 418- 545 5012

Abstract

Effect of heat treatment on decay resistance of white birch was evaluated for different incubation periods ranging from 2 to 12 weeks using three species of brown rot and one species of white rot fungus. The results of weight loss tests showed that the white rot fungus, *Trametes versicolor*, effectively degraded the untreated wood (73.5%). While the degradation of untreated wood by brown rot fungi species *Gloephyllum trabeum* (11.6%) and *Conifora puteana* (6.2%) was considerably less compared to *T. versicolor,* the third brown rot fungi studied, *Poria placenta,* caused an appreciable degradation of the same species (52.4%). The results clearly showed that the heat treatment reduced the effect of fungi attack on white birch. Increasing the heat treatment temperature from 195°C to 215ºC resulted in reduction of weight loss, consequently, reduction in fungal attack. As en example, the weight loss due to *T. versicolor, P. placenta, G. trabeum* and *C. puteana* attack was reduced 62.2%, 71.3%, 89.6% and 100%, respectively, compared to the weight loss of untreated wood when it is heat treated at 215ºC. Thus, these results confirmed that the heat-treatment increased the biological resistance of white birch.

Keywords: *Betula papyrifera,* brown rot fungi, heat-treated wood**,** white rot fungus**,** White birch, Wood decay

1. Introduction

The heat treatment of wood is an environment friendly method for improving the resistance against decay (Kamdem et al. 2002; Mburu et al. 2007). Many organisms can deteriorate wood, but the greatest damage is caused by fungi. Wood can be colonized and biodegraded by a variety of fungi including brown rot, white rot and soft rot fungi. The degradation caused by fungi is a complex process and depends on the fungi involved, and the kind of wood used. During wood decay, compounds such as cellulose, hemicelluloses and lignin are depolymerised in order to provide energy and metabolites for fungal growth (Fengel and Wegener 1984).

One of the effects of heat treatment is the reduction of the hygroscopicity which improves the dimensional stability of wood. Another effect is the improvement of the durability of wood by limiting its biodegradation by decay fungi (Tjeerdsma et al. 1998; Weiland and Guyonnet 2003). A number of authors have attempted to explain the improvement of wood durability by heat treament on molecular level (Baechler 1959; Boonstra et al. 2006; Hakkou et al. 2006; Highley 1970; Kamdem et al. 2000; Kamdem et al. 2002; Stamm 1964; Tjeerdsma et al. 1998). According to the literature, the reasons for the improvement in durability of wood by heat-treatment against fungal attack can be grouped under following four categories (Kamdem et al. 2002; Weilland and Guyonnet 2003): (1) enhancement in hydrophobic character of wood, (2) production of extractives, (3) modification of the wood polymers, (4) degradation of hemicelluloses.

Hakkou et al. (2006) have undertaken a study with the aim of understanding the effect of heat treatment on the durability of beech wood. The durability of heat-treated beech wood was tested against *Trametes versicolor*. There was not enough evidence supporting the

hypothesis of improved decay resistance due to generation of fungicidal compounds or due to the increasing hydrophobic character of wood during heat treatment. According to the authors, the most plausible hypothesis which would explain the improvement of wood durability could be its chemical modifications. Indeed, degradation of hemicellulose associated with other chemical modifications appearing during treatment could be the origin of improved durability.

In the literature, there are studies reported on the optimization of wood heat-treatment parameters (Poncsák et al. 2006). Contrarily, data on decay resistance due to heat-treated wood are scarce (Shi et al. 2007). The present study aims to fill this void.

In this study, the white birch wood was heat-treated at different temperatures in the prototype furnace of University of Québec at Chicoutimi. The objective of this work was to evaluate the effect of heat treatment on the biological resistance of this wood species against three species of brown rot fungi and one white rot fungus species. The molecular reasons for the modification of resistance against fungal attack are discussed.

2. Materials and Methods

Untreated and heat-treated Canadian white birch (*Betula papyrifera*) sapwood was used throughout this study. The biological durability tests were carried out and the equilibrium moisture content (EMC) of the wood was also measured. Wood specimens samples were oven dried at 103^{o}C ± 2 until stabilization of their mass (approximatively 48 hours) before determination of their anhydrous weights.

2.1. Heat Treatment

White birch wood boards with dimensions of 0.015 m x 0.045 m x 2.44 m were obtained from a local sawmill in Saguenay-Lac-St-Jean (Quebec, Canada). They were pre-dried in air until the moisture content was reduced to 5-17 %. The heat treatment of white birch was carried out in a prototype furnace of UQAC at Chicoutimi (Quebec, Canada). Heat treatment was carried out at three different maximum temperatures (195°C, 205°C and 215°C). 15 boards were heated to maximum temperature with a heating rate of 15°C/h in a humid and inert gas, and were kept at that temperature for one hour. A detailed description of the thermal modification process is published elsewhere (Poncsak et al., 2006).

The percent of mass loss of wood due to heat-treatment (WL-HT) is determined using the equation (1) given below:

$$\text{WL-HT (\%)} = 100\ (m_o - m_1)/m_o \qquad (1)$$

where m_o and m_1 are the oven dried mass of untreated and heat-treated wood samples, respectively.

2.2. Fungal Durability

Three brown rot fungi, *Poria placenta* (FTK120E), *Conifora puteana* (FTK9B) and *Gloephyllum trabeum* (FTK47D), and a white rot fungus, *Trametes versicolor* (FTK105D) purchased from FPInnovations FORINTEK, Québec, Canada were used in this study. Stock cultures of fungi were maintained on malt-agar slants stored at 4^{o}C.

Three brown rot fungi *G. trabeum*, *C. puteana* and *P. placenta* were chosen because they are the most common brown rot fungi available in the area and are well known for wood

degradation in the Nordic conditions (Borrega et al 2009). Among the white rot fungi, *T. versicolor* and *Phanerochaete chrysosporium* are very common in Quebec area. However, it was difficult to culture *Phanerochaete chrysosporium* with the conditions of study, and the results of degradation of wood were not reproducible. Therefore *T. versicolor* was chosen as the only white rot fungus for this study.

In this study, the methodology used to perform solid state cultures on wood has been adapted from EN-113 (1986) standard. 864 wood samples with dimensions of 0.015 m x 0.005 m x 0.035 m in radial, tangential and longitudinal directions were prepared. The degradation of the wood samples was studied based on EN 113 (1986) standard. The only difference was that small sized samples were used following the works of Lekounougou et al (2009), Bami et al (2011). In this study sample size (0.015m x 0.005m x 0.035m) and test duration (12 weeks) were maintained in accordance with Lekounougou et al (2009). Untreated birch wood was used as a reference for biological durability.

20 ml of sterile medium was prepared by dissolving 40g malt and 30g agar in 1 liter of distilled water. Petri dishes of 9 cm in diameter were filled with this medium, inoculated with fungus, incubated for 2 weeks at the temperature of 22^{o}C ± 1^{o}C, and the relative humidity of 70% ± 4% so that the mycelium can colonize.

Three sets of each wood sample, both heat-treated and untreated, were placed in different petri dishes. Each experiment was carried out three times to ensure the reproducibility of the results. Incubation was carried out under controlled temperature and humidity (22^{o}C ± 1^{o}C, 70% ± 4% relative humidity) in climatic chamber (Conviron). At the end of each test

period, mycelia were removed and the samples were dried at 103ºC ± 2ºC and the weight loss caused by the fungal decay (WL-FD) was determined. This was expressed as a percentage of the initial oven dried weight of the wood sample as follows:

$$WL\text{-}FD\ (\%) = 100\ ((m_0 - m_2)/m_1) \quad (2)$$

$$WL\text{-}FD\ (\%) = 100\ ((m_1 - m_3)/m_1) \quad (3)$$

Where m_0 and m_2 are the mass of the untreated wood samples before and after exposure fungal attack whereas m_1 and m_3 are the mass of the heat-treated wood samples before and after exposure fungal attack, respectively.

2.3. Equilibrium Moisture Content (EMC)

In this work the moisture content was actually measured by monitoring the weight loss of the clean sample before and after heating at 103ºC for 48 hours.

3. Results

The weight loss data of untreated wood exposed to three brown rot fungi, *P. placenta*, *G. trabeum* and *C. puteana,* and one white rot fungus, *T. versicolor,* for periods varying from 2 to 12 weeks are presented in Figure 1. It was observed that the fungal growth was fast, and mycelia covered the untreated wood completely in two weeks. The decay of untreated birch samples used in this study was slow for all fungi in the beginning of the test up to 4 weeks. Starting from the fourth week of exposure, the samples decayed continuously until 12 weeks. The mycelia growth depended on the kind of decay fungi.

Thus, growth was greater for *T. versicolor* and *P. placenta decay* fungi (Fig. 1) compared to decay of the other two fungi. The growth of four decay fungi was considerably different at the end of the exposure period. The weight losses observed for *T. versicolor* and *P. placenta* were considerably higher 73.9% and 52.4 % respectively, confirming the virulence of these two fungi under the conditions studied (Fig. 1). In contrast, *G. trabeum* and *C. puteana* fungi had lower weight losses of 11.6% and 6.2% respectively which showed that they were less effective in the untreated white birch degradation compared to the other two fungi.

The effect of maximum heat treatment temperature on the weight loss of heat-treated white birch exposed to decay fungi is shown in Figure 2. The weight loss of untreated birch due to fungal decay is also shown on the same figure. The evaluations of samples subjected to the fungi degradation indicated that there is a considerable improvement in the decay resistance of wood samples with increasing heat treatment temperature. The weight loss of control (untreated) samples was consistently higher than that of the heat-treated samples, but the degree of improvement depended on the type of fungus used under experimental conditions of this study. The treatment temperature seems to have an effect on the resistance to fungal attack of heat-treated white birch against *T. versicolor*, *P. placenta*, *G. trabeum* and *C. puteana* as can be seen in Figure 2. It was observed that with increasing maximum heat-treatment temperature, within the range of 195ºC to 215ºC studied, weight loss observed due to fungal decay is decreased.

Although heat-treatment improved the resistance of white birch wood against all decay fungi, its effect was lower on *C. puteana* and *G. trabeum* after 12 weeks of exposure (Fig.2) compared to its effect on other fungi studied.

The Figure 3 presents the weight loss of white birch untreated and heat-treated at 215°C and colonized by *T. versicolor*, *P. placenta*, *G. trabeum* and *C. puteana* for 4, 8 and 12 weeks. A slight increase in weight loss was observed after 8 weeks up to 12 weeks of incubation for *T. versicolor*, *P. placenta* and *G. trabeum* fungi. In the beginning of the colonization process, fungal growth takes place probably by using nutrients provided by the surrounding malt agar which might explain the low weight loss in the first weeks of wood colonization. Indeed, in filamentous fungi, majority of genes involved in polymer breakdown are suppressed by the presence of easily available carbon source, such as glucose (Aro et al. 2005). The weight loss of heat-treated birch is less than that of the untreated birch indicating that the heat treatment increases the resistance of this species to fungal degradation.

The results confirmed that increasing the heat-treatment temperature from 195°C to 215ºC considerably reduced the weight loss of samples due to decay by fungi compared to that of untreated birch (Table 1). 9.1 % reduction in weight loss was detected at 195°C compared to that of untreated birch whereas at 215ºC the weight loss was reduced 62.2 % for *T. versicolor*. Similar results were also obtained on *P. placenta* and *G. trabeum* with weight loss reductions of 18.9 % and 71.3% for *P. placenta*, and 29.3 % and 89.6 % for *G. trabeum* (Table1) at 195°C and at 215ºC, respectively. These findings are also in agreement with previous studies with other species (Boonstra et al. 2006; Hakkou et al. 2006; Kamdem et al. 2002; Weilland and Guyonnet 2003).

4. Discussion

This study showed that the weight loss due to decay by all brown rot fungi was lower than that of white-rot fungus *T. versicolor* on the white birch for the same exposure period (Fig. 1). Similar findings were reported by Enoki et al. (1988) who showed that usually white-rot fungi degrade hardwoods more efficiently than softwoods. This can be due to differences in the chemical composition of softwood species which contain fewer hemicelluloses than those of hardwood with mannose as the major constituent whereas the major constituent in hardwood such as white birch is xylose (Fengel and Wegener 1984). The white rot fungus *T. versicolor* is known to degrade simultaneously lignin and polysaccharides while the brown rot fungi preferentially degrade polysaccharides (Machuca and Ferraz 2001). This might explain the higher weight losses of white birch observed after exposure to *T. versicolor* compared to those due to exposure to brown rot fungi.

According to ASTMD-2017 (1994) the class of wood is moderately resistant if the weight loss due to decay varies within the range of 25% to 45% (Kartal and Ayrilmis 2005). Therefore, a weight loss of less than 25% indicates resistance against degradation. Thus, an acceptable range of decay is 0 to 25%. The wood can be used for hazard classes 3 and 4 and can be exposed to outdoor conditions (carpentry, siding) where it is in contact with the ground and humidity.

Of all the brown rot fungi, the highest weight loss was observed for *P. placenta* (52.4%), followed by *G. trabeum* (11.6%) and *C. puteana* which showed the lowest weight loss

(6.2%) (Table1). Based on these results, white birch can be classified as slightly resistant or non-resistant to *T. versicolor* and *P. placenta* decay according to ASTM D-2017 (1994) standard because the weight loss due to decay is more than 45% (Kartal and Ayrilmis 2005). At the same time, this wood can be classified as highly resistant to *G. Trabeum* and *C. puteana* fungal decay according to the same standard. The weight loss due to brown rot fungus *C. puteana* was less than 10% (Fig. 1).

Variations in biological resistance of white birch wood against four fungi observed in this study were also observed by Calenego et al. (2010), Jesus et al. (1998), and Paes et al. (2004). They all showed that different woods frequently presented differences in their resistance to different fungal decay, and the ASTM D-2017 (1994) cited that the same kinds of woods do not necessarily posses the same class of resistance against all decay fungi types.

The improvement in decay resistance due to heat treatment is observed for heat treatment temperatures starting from 195ºC under conditions of this study. It is around this temperature that the chemical changes start to take place in wood due to heat treatment (Fig. 2, Table 1) (Kamdem et al. 2002; Kocaefe et al. 2007; Tjeerdsma et al. 1998). The main polymeric components of the cell wall (cellulose, hemicelluloses and lignin) are linked by covalent and hydrogen intrapolymer bonds (Winandy and Rowell 1984) and this contributes in different degrees to the strength and durability of wood. It is reported in the literature that hemicelluloses are the most thermal- chemically sensitive components of wood (Bourgois and Guyonnet 1988; De groot et al. 1988). Several authors showed that degradation of hemicelluloses and chemical modifications of the wood polymers during heat treatment lead to a decrease in fungal decay, thus,

improvement of resistance of heat-treated wood against decay fungi (Hakkou et al. 2006; Vernois 2001; Weiland and Guyonnet 2003).

Boonstra and co-workers (2007) exposed heat-treated birch wood to the decay fungus *T. versicolor*. They used the Plato process which is carried out in two separate heat treatment stages and a drying stage in between. During the first stage of the heat treatment, the wood is treated in an aqueous environment at superatmospheric pressure (8-10 bars). This stage is called hydro thermolysis treatment which is conducted in the temperature range of 165 to 185°C. Then, wood is dried in an oven. The second stage is called curing treatment during which the wood samples are heat treated under atmospheric pressure and dry environment. The maximum temperature of heat treatment is 180°C and the treatment time is 6 hours. During this stage, superheated steam or nitrogen gas was used as sheltering gas to protect the wood from oxygen. Similar to the present study, their results showed a clear improvement in decay resistance of heat-treated birch wood against white rot fungus *T. versicolor*. Contrarily, the relationship between weight loss and decay resistance for untreated and heat-treated birch wood (*Betula pendula* and/or *Betula pubescens*) against decay fungus *C. puteana* was found to be different than that observed during this study (Fig. 2). The average weight loss of 25-44% was observed and this wood was classified as moderately resistant. These differences can be due to the variations which can be observed among the same kind of woods who do not necessarily posses the same class of resistance across all decay fungi (Paes et al. 2004). As it can be seen from the results of this study, European and North American birch wood behaves differently when exposed to same fungi. Another reason

might be the effect of the type of heat treatment technology, consequently, the treatment parameters (heating rate, holding time and treatment temperature) used on the durability of same wood species.

5. Conclusions

This study showed that thermal treatment of White birch increases durability against decay fungi *T. versicolor* and *P. placenta*. For temperatures between 195º C and 215º C, a considerable reduction in weight loss was detected (9.1-62.2% and 18.9-71.3% respectively). However *G. trabeum* and *C. puteana* had little effect on the decay resistance of White birch due to the fact that they had low weight losses of 11.6% and 6.1% respectively for the untreated control. In other words, White birch has high decay resistance against *G. trabeum* and *C. puteana* even in untreated condition. But there was considerable difference in the activities of *G. trabeum* and *C. puteana*. For example the reduction % was 32.7 for *G. trabeum* for heat treatment at 205ºC whereas for *C. puteana* the value was 100 for the same condition.

Acknowledgements

The authors thank Dr. Yasar Kocaefe, Dr. Noura Oumarou and Ms. Claire Fournier for their help during the heat treatment trials and fungal tests. The financial support of NSERC, UQAC (University of Quebec at Chicoutimi) and FUQAC (Foundation of University of Quebec at Chicoutimi) is greatly appreciated.

References

American Society for testing and Materials-ASTM D-2017 (1994) Standard method of accelerated laboratory test of natural decay resistance of wood. Annual Book of ASTM Standard 0410, pp. 324-328.

Aro, N., Pakula, T., Penttila, M. (2005) Transcriptional regulation of plant cell degradation by filamentous fungi. FEMS Microbiology Reviews, 32, 59-65.

Baechler, R.H. (1959). Improving wood`s durability through chemical modification. Forest Products Journal, 9, 166-171.

Bami, L.K., Mohebby, B. (2011) Bioresistance of Poplar wood compressed by combined hydro-thermo-mechanical wood modification (CHTM): soft rot and brown – rot. International Biodeteration and Biodegradation, 65, 866-870.

Boonstra, M.J., Pizzi, A., Rigolet, S. (2006) Correlation of 13C-NMR analysis with fungal decay tests of polymeric structural wood constituents. I. Basidiomycetes. Journal of Applied Polymer Science, 101, 2639-2649.

Boonstra, M.J., Van Acker, J., Kegel, E. (2007) The effect of two-stage heat treatment process on the mechanical properties of full construction timber. Wood Material Science and Engineering, 2, 138-146.

Borrega, M., Nevalainen, S., Heräjärvi (2009) Resistance of European and hybrid aspen wood against two brown-rot fungi. European Journal of Wood Products, 67, 177-182**.**

Bourgois, J., Guyonnet, R. (1988) Characterization and analysis of torrified wood. Wood Science and Tehnology, 22, 143-155.

Calenego, F.W., Severo, E.T.D., Furtado, E.L. (2010) Decay resistance of thermally-modified Eucalyptus grandis wood at 140 ºC, 160 ºC, 180 ºC, 200 ºC, and 220 ºC. Bioresource Technology, 101, 9391-9394.

De Groot, W.F., Pan, W.P., Rahman, M.D., Richards, G.N. (1988) First chemical events in pyrolysis of wood. Journal of Analytical and Applied Pyrolysis, 13, 221-231.

Enoki, A., Tanaka, H., Fuse, G. (1988) Degradation of lignin-related compounds, pure cellulose, and wood components by white-rot and brown-rot fungi. Holzforschung, 42, 85-93.

EN 113 (1986) Wood preservatives. Determination of toxic values of wood preservatives against wood destroying basidiomycetes cultured on AN agar medium (Norme Francaise NF EN 113 produits de préservation des bois-Détermination du seuil d`efficacité contre les champignons basidiomycetes lignivores cultivés sur milieu gélosé).

Fengel, D., Wegener, G. (1984) Wood-Chemistry, Ultrastructure, Reaction. In Walter De Gruyter (Eds.) (Berlin), pp. 319-344.

Hakkou, M., Petrissans, M., Gérardin, P., Zoulalian, A. (2006) Investigations of the reasons for fungal durability of heat-treated beech wood. Polymer Degradation and Stability, 91, 393-397.

Highley, T.L. (1970) Decay resistance of four woods treated to destroy thiamine. Phytopathology, 60, 1660-1661.

Jesus, M.A., de Morais, J.W., de Abreu, R.L.S., Cardias, M.deF.C. (1998). Natural durability of 46 Amazonian woods species in an in-ground essay in a forest environment. Scientia Forestalis, 54, 81-92.

Kamdem, D.P., Pizzi, A., Jermannaud, A. (2002) Durability of heat-treated wood. Holz als Roh-und Werkstoff, 60, 1-6.

Kamdem, D.P., Pizzi, A., Triboulot, M.C. (2000) Heat-treated timber: potentially toxic byproducts presence and extent of wood cell wall degradation. Holz als Roh-und Werkstoff, 58, 253-257.

Kartal, S.N., Ayrilmis, N. (2005) Blockboard with boron-treated veneers laboratory decay and termite resitance tests. International Biodeteration and Biodegradation, 55, 93-98.

Kocaefe, D., Chaudry, B., Poncsák, S., Bouazara, M., Pichette, A. (2007) Thermogravimetric study of high temperature treatment of aspen: Effect of treatment

parameters on weight loss and mechanical properties. Journal of Materials Science, 42, 854-866.

Lekounougou, S., Pétrissans, M., Jacquot, J.P, Gelhaye, E., Gérardin, P. (2009) Effect of heat treatment on extracellular enzymatic activities involved in beech wood degradation by *Trametes versicolor*. Wood Science and Technology, 43, 331-341.

Machuca, A., Ferraz, A. (2001) Hydrolytic and oxidative enzymes produced by white and brown-rot fungi during Eucalyptus grandis decay in solid medium. Enzyme and Microbial Technology, 29, 386-391.

Mburu, F., Dumarcay, S., Hubert, F., Petrissans, M., Gerardin, P. (2007) Evaluation of thermally modified Grevillea robusta heartwood as an alternatuve to shortage of wood resource in Kenya: Characterisation of physicochemical properties and improvement of bio-resistance. Bioresource Technology, 98, 3478-3486.

Paes, J.B., Morais, V.deM., de Lima, C.R. (2004) Natural resistance of nine woods of brasilian semi-arid region to wood-destroying fungi under laboratory conditions. Revista Ávore, 28, 275-282.

Poncsák, S., Kocaefe, D., Bouazara, M., Pichette, A. (2006) Effect of high temperature treatment on the mechanical properties of birch (*Betula papyrifera*). Wood Science and Technology, 40, 647-663.

Shi, J.L., Kocaefe, D., Amburgey, T., Zhang, J. (2007) A comparative study on brown-rot fungus decay and subterranean termite resistance of thermally-modified and ACQ-C-treated wood. Holz als Roh-und Werkstoff, 65, 353-358.

Stamm, A.J., 1964. Dimensional stabilization. In wood and cellulose science, The Ronald press Co (Eds.) (USA), pp. 312-342.

Tjeerdsma, B.F., Boonstra, M., Pizzi, A., Tekely, P., Militz, H. (1998). Characterisation of thermally modified wood: molecular reasons for wood performance improvement. Holz als Roh-und Werkstoff, 56, 149-153.

Vernois, M. (2001) Heat treatment of wood in France: State of the art. In: Rapp, A.O. (Eds.), Review on heat treatments of wood. In: special Seminar: Environmental Optimisation of wood protection (Antibes, France: Cost Action E 22), pp. 39-46.

Weiland, J.J., Guyonnet, R. (2003) Study of chemical modifications and fungi degradation of thermally modified wood using DRIFT spectroscopy. Holz als Roh-und Werkstoff, 61, 216-220.

Winandy, J.E., Rowell, R.M. (1984) The chemistry of wood strength. In: The chemistry of solid wood. Rowell American Chemical Society (Eds.) (Washington), pp. 211-256.

Table.

Table 1: Effect of heat treatment temperature on the decay resistance of white birch wood to the four decay fungi after 12 weeks of colonization.

Fungal species	Heat treatment temperature (°C)	MC* (%)	Weight loss (%)	Reduction in weight loss due to heat treatment (%)
T. versicolor	Untreated	161.1 ±1	73.9	-
	195°C	75.4 ±1	67.2	9.1
	205°C	40.7 ±1	33.9	54.1
	215°C	100.5 ±1	27.9	62.2
P. placenta	Untreated	135.8 ±1	52.4	-
	195°C	127.1 ±1	42.5	18.9
	205°C	95.7 ±1	27.6	47.3
	215°C	61.9 ±1	15.1	71.3
G. trabeum	Untreated	114.5 ±1	11.6	-
	195°C	115.8 ±1	8.2	29.3
	205°C	80.5 ±1	7.8	32.7
	215°C	69.7 ±1	1.2	89.6
C. puteana	Untreated	50.1 ±1	6.2	-
	195°C	114.8 ±1	2.5	59.7
	205°C	26.4 ±1	0	100
	215°C	21.6 ±1	0	100

* MC: moisture content

Figure Captions

Fig.1. Degradation of untreated white birch wood by *T. versicolor, P. placenta, G. trabeum* and *C. puteana* after 12 weeks of incubation.

■**:** *Trametes versicolor* (TV); ▲**:** *Poria placenta* (PP); ●: *Gloephyllum trabeum* (GT); x**:** *Conifora puteana* (CP).

Fig.2. Effect of maximum heat treatment temperature on the weight loss of white birch after 12 weeks of exposure to *T. versicolor, P. placenta, G. trabeum and C. puteana.*

□**:** Control samples; heat-treated wood to: ■**:** 195°C; ■: 205ºC; ■**:** 215°C.

Fig.3. Weight loss of untreated and heat-treated (215°C) white birch due to degradation by *T. versicolor, P. placenta, G. trabeum* and *C. puteana* for 4, 8 and 12 weeks.

■**:** *Conifora puteana*; □**:** *Gloephyllum trobaum*; ■: *Poria placenta*; ⊟**:** *Trametes versicolor*.

Figures

Fig. 1

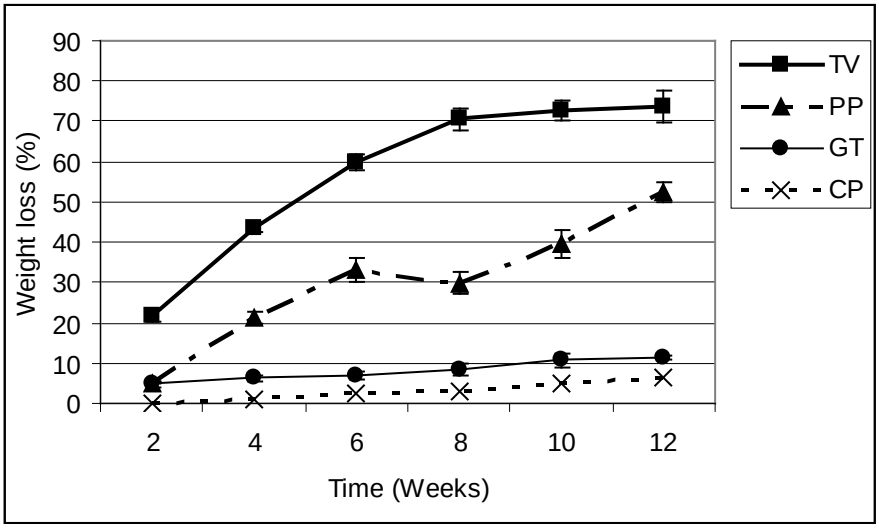


Fig. 2

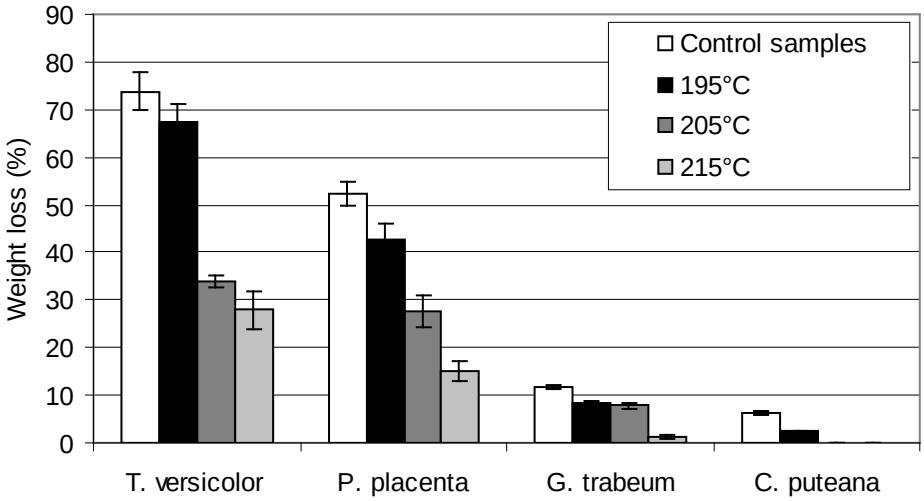
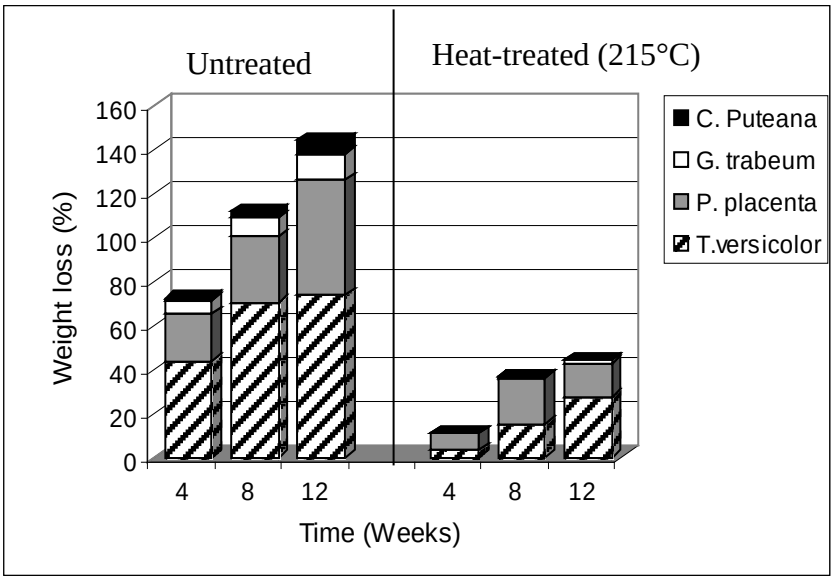

90
80
70
60
50
40
30
20
10
0
Weight loss (%)
Control samples
195°C
205°C
215°C
T. versicolor
P. placenta
G. trabeum
C. puteana

Fig. 3


Untreated
Heat-treated (215°C)
Weight loss (%)
160
140
120
100
80
60
40
20
0
4
8
12
4
8
12
Time (Weeks)
C. Puteana
G. trabeum
P. placenta
T.versicolor