DECAY RESISTANCE PROPERTIES OF HOT WATER EXTRACTED ORIENTED STRANDBOARD

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Abstract. The use of extracted wood hemicelluloses as a substrate for fermentation and biofuels production has the added benefit of leaving the remaining wood product intact after extraction and being usable in other applications. However, it is still unclear how these extraction procedures might affect susceptibility to fungal attack. Modified oriented strandboards (OSB) were created by hot water extracting red maple strands before adhesive application and pressing of the strands into boards. Treated and untreated boards were tested for decay susceptibility in a modified ASTM soil block jar bioassay using multiple species of white and brown rot fungi. Results showed no significant differences in decay susceptibility between the untreated and extracted boards for all the brown rot fungi tested. The white rot fungi tested were shown to decay the boards made from extracted strands significantly less than the boards made from control strands. These results indicate that modifying OSB panels by removing hemicelluloses for use in ethanol and other alternative fuel production does not increase decay susceptibility to the brown rot fungi tested and appears to confer a degree of decay resistance against the white rot fungi.

Keywords: Oriented strandboard, hemicellulose removal, brown rot, white rot, wood preservation, bioassays.

INTRODUCTION

The goal of reducing oil dependence has led to a surge in feasibility research for deriving ethanol and other products from bio-based resources. The substitution of hemicellulosic sugars for glucose in fermentation applications is currently being investigated. The fact that hemicellulose removal from wood can be accomplished simply with heat and water makes this alternative attractive industrially. Also, wood material with some fraction of the hemicelluloses removed can still be used in many other applications such as the production of oriented strandboard (OSB) (Paredes et al 2008a).

Recent studies done on the mold susceptibility of hemicelluloses-extracted OSB have shown that extracted boards are less susceptible to mold than nonextracted boards (Taylor et al 2008), presumably as a result of the removal of the hemicelluloses as a nutrient source as well as the possible production of toxic compounds during the extraction process and the decrease in water availability. Also, decay tests done on heat-treated wood have shown a decrease in susceptibility to fungal attack, also presumably

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attributable in part to the removal of hemicelluloses (Hill 2006). Nevertheless, multiple studies have shown OSB is one of the wood-based composites most susceptible to decay by brown and white rot fungi (Chung et al 1999; Laks et al 2002). This susceptibility has been attributed to the large surface area and the presence of voids between strands that provide decay fungi with multiple penetration points (Chung et al 1999). Removal of hemicelluloses from OSB strands increases the number of voids and the surface area of the wood (Paredes et al 2008b), which may exacerbate this.

Previous work done in our laboratories has shown that hot water extraction of hemicelluloses from OSB strands significantly decreases decay by the white rot fungus *Pycnoporous sanguineus* and does not appear to effect decay by the brown rot fungus *Meruliporia incrassata* (Howell et al 2008). The purpose of this study was to examine the decay susceptibility of hemicellulose-extracted OSB in other species of brown and white rot fungi to determine if removing hemicellulose sugars for use in alternative energy would inhibit or enhance decay across multiple species.

MATERIALS AND METHODS

Strand Preparation and Oriented Strandboard Production

OSB samples were prepared as previously described (Paredes et al 2008a, 2008b) from butt logs of red maple trees (*Acer rubrum*). Briefly, strands 100 mm long and 0.9 ($\pm$0.05) mm thick were placed inside a high-pressure reactor (digester) filled with fresh tap water to obtain a liquid–solid weight ratio of 4. Extraction conditions were equated to severity factors (SF) through the use of Eqs 1 and 2 (Overend and Chornet 1987; Mosier et al 2002; Paredes et al 2008a).

$$R_0 = \int_0^t \mathrm{Exp}\left[\left(\frac{\mathrm{Tr} - \mathrm{Tb}}{14.75}\right)\right] \mathrm{dt} \qquad (1)$$

where R_0 is reaction ordinate, t is residence time (min), Tr is reaction temperature (°C), and Tb is base temperature at 100°C. The SF is the $\log_{10}$ value of Eq 1. This approach has been used to evaluate the effects of steam-explosion pretreatment on biomass (Jeoh 1998).

$$\mathrm{SF} = \mathrm{Log}_{10}(R_0) \qquad (2)$$

Hemicelluloses (along with small amounts of lignin) were extracted from the strands using a hot water extraction procedure that involved heating from room temperature to 160°C in 50 min (preheating time) followed by constant temperature exposure times of 45 or 90 min to obtain a SF of 3.54 or 3.84, respectively (Jara et al 2006; Paredes et al 2008a).

OSB panels were manufactured using a polymeric diphenylmethane diisocyanate (pMDI) adhesive (Huntsman rubinate 1840) at a target loading of 4% solids content based on the oven-dry strand weight. The actual resin content was determined to be 3.2% based on nitrogen analysis of a sample of resinated strands. Boards with no hemicellulose extraction (nonextracted) were also fabricated for comparison. Blocks measuring 14 $\times$ 14 $\times$ 14 mm were cut from the finished panels for decay tests.

Fungal Cultures

Fungi were maintained at 21°C on 2% (w/v) potato dextrose agar until inoculation. Brown rot fungi used were *Gloeophyllum trabeum* ATCC 11539, *Postia placenta* ATCC Mad 698 R, *Coniophora puteana* ATCC 44393, *Meruliporia incrassata* isolate mfstoner-1, and *Serpula himantoides* ATCC 36335. White rot fungi included *Irpex lacteus* ATCC 60993, *Phanaerochaete chrysosporium* ATCC 24725, *Pycnoporous sanguineus* ATCC 24598, *Ceriporiopsis subvermispora* ATCC 90467, and *Trametes versicolor* Mad 697. All cultures were purchased from the American Type Culture Collection (Manassas, VA) or received from the USDA Forest Products Laboratory (Madison, WI) with the exception of the isolate of *M. incrassata*, which was collected from decaying wood in California in 2002 by Dr. M.F. Stoner.

Modified Soil Block Bioassays

Four 10 × 10 mm pieces of inoculum were taken from the outer edge of mycelium of 3-wk-old fungal colonies and placed into modified AWPA soil block jars (AWPA 2003). Each piece of inoculum was placed at one corner of a set of birch feeder strips on top of approximately 200 mL of a 1:1:1 mixture of potting soil, sphagnum peat moss, and horticultural-grade vermiculite hydrated with deionized water.

One OSB block was placed in the jar after the mycelial mat had covered the birch feeder strips. Blocks were made from either nonextracted (controls) or extracted strands with a SF of 3.54. This SF was chosen deliberately, because boards made with strands treated to the lower SF (as opposed to a higher SF of 3.84) have shown more desirable properties such as improved dimensional stability and flexure (Paredes et al 2008a) and are more likely to be used in commercial applications. The five brown rot fungi were allowed to grow for 12 wk after the addition of the wood block; the five white rot fungi were incubated for 16 wk. After harvesting, blocks were analyzed for percentage weight loss, MC, and wood carbohydrate composition using high-performance liquid chromatography (HPLC). There were five replicates per fungus as well as five noninoculated controls.

Time Series

Bioassays were set up to examine the effect of hemicellulose extraction on decay over time. Fungi tested were brown rots *M. incrassata* and *G. trabeum*, and white rots *P. sanguineus* and *I. lacteus*. *M. incrassata,* and *G. trabeum* were chosen to represent two different methods of brown rot degradation: dry rot and standard brown rot fungi, respectively (Schilling and Jellison 2007). In addition, *P. sanguineus* and *I. lacteus* represent the white rot mechanisms of selective and simultaneous decay, respectively (Luna et al 2004; Martínez et al 2005). Blocks made from nonextracted strands and blocks made with strands treated to a SF of 3.84, each 14 × 14 × 14 mm, were used. The higher SF was chosen for these experiments to maximize potential differences between the extracted and nonextracted samples. Blocks were harvested after 3, 6, 9, and 12 wk of decay and analyzed for MC and weight loss and wood carbohydrate composition using HPLC. The experiment was repeated twice with the fungi *M. incrassata* and *P. sanguineus* to assure repeatability.

Time Series without Adhesive

To determine the effect of adhesive on the growth of the fungi, adhesiveless "blocks" were fashioned from either untreated or extracted strands (SF = 3.84) and bound together with nylon cord. The final adhesiveless block dimensions were approximately 20 × 30 × 10 mm.

Fungi tested were *M. incrassata, G. trabeum, P. sanguineus*, and *I. lacteus*. Blocks were harvested after 3, 6, 9, and 12 wk of decay and analyzed for MC and weight loss. There were four replicates per treatment per fungus as well as four noninoculated controls.

Statistics

Statistical analyses with each block representing an independent measurement were performed using analysis of variance (ANOVA) tests calculated by SySTAT v.11 (Systat Software Inc, San Jose, CA) with protected Fisher's least significant difference post hoc tests.

RESULTS

Effect of Hot Water Extraction on Strand Mass and Hemicellulose Removal

The extraction time was shown to significantly increase the mass loss between SF 3.54 and 3.81 ($p = 0.0011$). The mass lost by the extracted strands was 16.4 ± 0.3% for SF 3.54 and 17.2 ± 0.3% for SF 3.84. HPLC analysis of the extracted liquid revealed hemicellulose and lignin content to be approximately 46.0 and 12.6 mg/g wood, respectively, for SF = 3.54 and 108.2 mg/g hemicelluloses/wood and 28.1 mg/g lignin/wood for SF = 3.84 (Jara et al 2006).

Modified Soil Block Bioassays

Weight loss analysis of blocks decayed by the brown rot fungi by a two-way ANOVA revealed that the removal of hemicelluloses did not significantly affect decay by the isolates tested (p = 0.554). Weight loss values for the five brown rot isolates ranged from a maximum of approximately 50% for *P. placenta* to a minimum of approximately 20% for *C. puteana* (Fig 1).

Analysis of blocks decayed by the white rot fungi produced a nonsignificant interaction term (p = 0.758) indicating that all species responded similarly to the treatment. Average weight loss values for the white rot fungi were significantly lower in blocks made with extracted than nonextracted strands (p = 0.027). Values for the fungi grown on the hemicellulose-extracted blocks ranged from a maximum of 57% for *T. versicolor* to a minimum of approximately 12% for *P. chrysosporium* (Fig 2).

Time Series

Blocks made with extracted strands that were decayed by the brown rot *M. incrassata* showed significantly lower weight loss values relative to the nonextracted controls after 3 wk of decay (p = 0.002) as revealed by a two-factor ANOVA with treatment and time as the factors. However, after 6 wk, weight loss values were statistically similar to the nonextracted controls (p = 0.201) and remained that way through wk 9 and 12 (Fig 3). Over time, there was no significant effect from the extraction treatment on weight loss (p = 0.204). Blocks decayed by *G. trabeum* reflected a similar pattern, but also showed no overall significant effect (p = 0.413).

Blocks made with extracted strands that were decayed by *P. sanguineus*, in contrast, showed no significant differences after 3 wk of decay

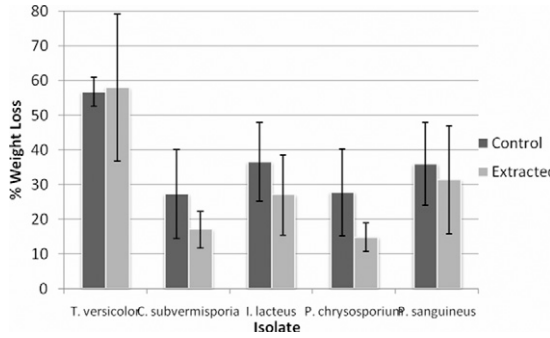

Figure 2. Percent weight loss values for control and extracted (severity factor = 3.54) Red Maple oriented strandboard decayed by white rot fungi. Most of the fungi decayed the extracted material significantly less than the nonextracted control material (p = 0.027). Error bars represent standard deviations.

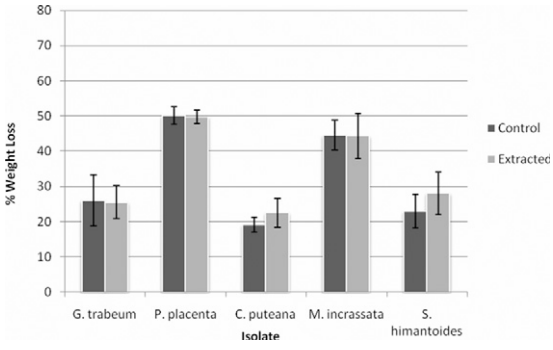

Figure 1. Percent weight loss values for control and extracted (severity factor = 3.54) Red Maple oriented strandboard blocks decayed by brown rot fungi. There were no significant differences for decay of the blocks made from extracted strands vs the nonextracted strands (p = 0.554). Error bars represent standard deviations.

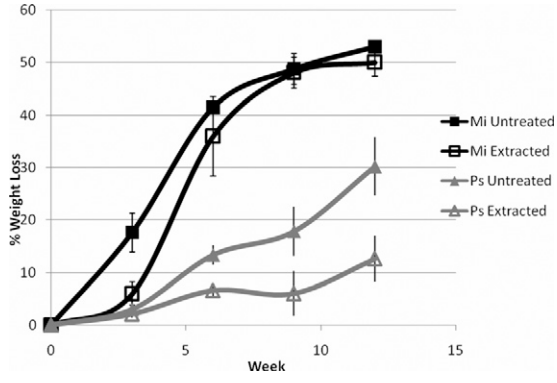

Figure 3. Percent weight loss values over time for *M. incrassata* (Mi, black lines) and *P. sanguineus* (Ps, gray lines) on untreated control oriented strandboards (OSB) (filled symbols) and extracted OSB (open symbols). Error bars represent standard deviations.

(p = 0.336). At 6 wk, however, these samples showed significantly lower weight loss than control blocks (p = 0.001). This difference continued to increase through wk 9 and 12 (p = 0.009 and 0.002, respectively) (Fig 3), resulting in an overall significant effect over time attributed to the extraction procedure (p = 0.001).

Time Series without Adhesive

Weight loss analysis revealed patterns of decay similar to those observed in the standard time study for all tested species (Fig 4). Statistical analysis revealed no significant effects from the extraction treatment over time for *M. incrassata, G. trabeum,* or *I. lacteus* ($p > 0.255$). analysis also revealed that blocks decayed by *P. sanguineus* did show a significant effect from the treatment over time (p = 0.000) (Fig 4).

Comparison of the weight loss values for *M. incrassata* growing on control blocks with and without adhesive revealed no significant effects on weight loss resulting from the presence of the adhesive ($p > 0.490$).

DISCUSSION

Overall, it was found that the hot water extraction of hemicelluloses did not increase decay susceptibility to any of the fungi tested and appeared to decrease decay susceptibility for the five isolates of white rot fungi tested.

In their work on decay susceptibility of various building materials, Chung et al (1999) observed that OSB was more susceptible to decay by fungi and hypothesized that it may be partially the result of the increase in the number of voids in the boards. This would allow the fungi more sites from which to access the wood structure. By this logic, removing the hemicelluloses should increase decay susceptibility, because Paredes et al (2008b) showed that the extraction procedure used significantly increased the number of voids between 0.3 and 0.6 μm. These results may

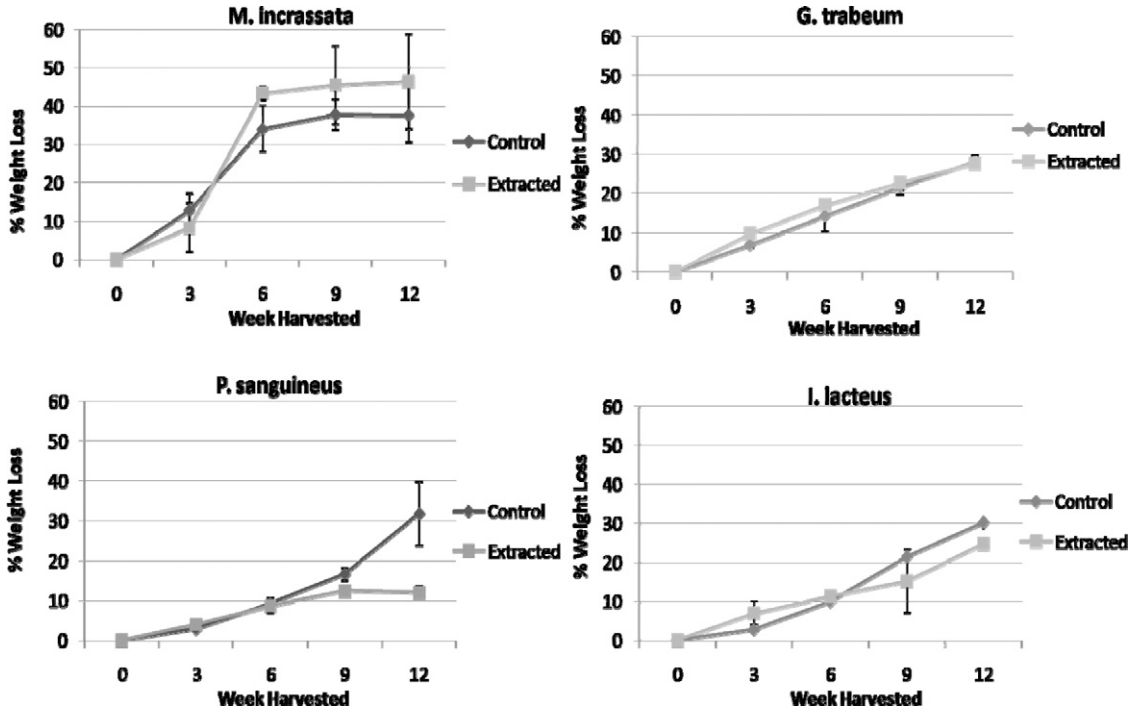

Figure 4. Weight loss values for *M. incrassata, G. trabeum, I. lacteus,* and *P. sanguineus* grown on blocks made from extracted and nonextracted material without adhesive. Error bars represent standard deviations.

indicate that the voids created by hemicellulose extraction are too small for the fungi to take advantage of [the diameter of an individual hypha can range from 0.5 – 20 μm but is generally 2 – 10 μm (Zabel and Morrell 1992)].

One clear potential reason for the decrease in decay of the blocks made from extracted strands by white rot fungi is the removal of the nutrient source offered by the hemicelluloses and small amounts of lignin (Jara et al 2006). This reason has been given for the apparent decay resistance of heat-treated wood (Hill 2006) and for the resistance of hemicellulose-extracted wood to molds (Taylor et al 2008). The different responses of the white and brown rot fungi to the modified OSB may reflect the metabolic differences in the decay mechanisms used by these different fungal groups. White rot fungi are known to decay cellulose, hemicelluloses, and lignin in an erosion-like fashion, whereas brown rot fungi quickly depolymerize cellulose and hemicelluloses using nonenzymatic mechanisms (Zabel and Morrell 1992). Removing a portion of the easily accessible hemicellulose sugars may limit nutrient availability for the white rot fungi, which digest only wood in the immediate vicinity.

Brown rot fungi, on the other hand, are known to make use of nonenzymatic mechanisms in cellulose degradation such as the production of hydroxyl radicals. Because these radicals are produced relatively far away from the hyphae may permit these fungi to gather nutrients from a wider radius (Goodell et al 1997). Also, the extraction process did not significantly inhibit decay by the brown rot fungi; this also might indicate that hemicelluloses do not play as essential a role in brown rot as in white rot decay.

Work done by Taylor et al (2008) showed that mold grew less readily on hemicellulose-extracted OSB than on nonextracted OSB. They suggested that these apparent inhibitory effects from hemicellulose extraction could be from a decrease in water availability or the production of inhibitory compounds in addition to the removal of food sources. These factors may also be playing a role in the apparent effects of hemicellulose extraction on decay by white and brown rot fungi.

Another factor that should be taken into consideration in the interpretation of these data is the removal of hot water extractives. It is expected that most of the water-soluble extractives were removed along with the hemicelluloses during the extraction. Because decay resistance properties of extractives are well known, it is further expected that if the removal of the hot water extractives were to have any effect on the decay susceptibility of this material, it would be to increase it. Because we observed either no significant change (for the brown rot fungi) or a decrease (for the white rot fungi) in the decay susceptibility of the blocks made with extracted strands, we assume that the effect of removing the extractives with this procedure was negligible.

Analysis of weight loss over time for blocks decayed by *P. sanguineus* revealed a reduced rate of degradation (overall) in blocks made from extracted vs nonextracted controls. This may be another indication that this fungus is not able to gather as many nutrients from the extracted material early in the decay process, resulting in a slower rate of growth and, subsequently, a reduced rate of degradation. It is interesting to note, however, that this overall decrease in decay rate did not occur for the other white rot fungus tested in the time series experiments, *I. lacteus,* despite the fact that it showed significantly lower weight loss for extracted vs control boards at 16 wk.

One explanation for this apparent discrepancy may be the differences in the decay mechanisms of these two fungi. *P. sanguineus* is classified as a selective white rot, whereas *I. lacteus* is a simultaneous white rot. Selective white rotters are known to decay only the hemicelluloses and lignin in wood, leaving the cellulose behind, whereas simultaneous white rotters decay all three components simultaneously. Removing the majority of the hemicelluloses would leave a selective white rotter with only lignin as a

nutrient source. Given that lignin is a complex polymer requiring specialized enzymes to be broken down into digestible units, and that the manufacture of such enzymes requires energy and resources, this may explain the more limited growth of *P. sanguineus* on the extracted samples. *I. lacteus*, on the other hand, would be less affected, because it would be able to use both the remaining cellulose and lignin as nutrient sources. If this were the case, we would expect the selective white rotters to show significantly lower overall weight losses relative to the simultaneous white rotters. This difference is not apparent in the data presented here as a result of the full 16-wk incubation period of the other white rot fungi (*C. subvermisporia* is a selective white rot fungus, whereas *T. versicolor* and *P. chrysosporium* are simultaneous white rot fungi); however, further tests over time and with additional species could clarify these findings.

We have previously hypothesized that the increase in resistance of hemicellulose-extracted OSB to attack by *P. sanguineus* could be from the overpenetration of pMDI adhesive into these boards (Howell et al 2008). However, the results presented in the time study without adhesive indicate that the adhesive does not appear to have an effect, because all tested fungi showed the same lack of significant differences (in the cases of *M. incrassata, G. trabeum,* and *I. lacteus*) or a significant difference (in the case of *P. sanguineus)* similar to that observed in the time study with adhesive. In fact, statistical analysis revealed that even within the control samples for *M. incrassata*, the presence or absence of adhesive did not have a significant effect on the rate of decay. This last result is surprising considering the nature of the adhesive pMDI, which is very toxic in an aqueous state (although less so after it has been cured). It is possible that this is simply a coincidental result of block morphology; the adhesive-containing blocks were smaller because of the amount of materials available for these tests, whereas the adhesiveless blocks were made larger to facilitate fabrication and binding. Smaller blocks would have more surface area for the fungal hyphae to contact and therefore a better chance of being decayed quickly. However, the strands within these smaller blocks were also more tightly packed than the adhesiveless blocks as a result of the OSB manufacturing process. It is also possible that the presence of the adhesive simply had no effect, or a minimal effect, on the growth of *M. incrassata,* because brown rot organisms have been reported to show resistance against certain wood preservatives and other chemicals (Zabel and Morrell 1992; Goodell et al 2003). Some combination of these factors may have therefore contributed to the apparent similarities in decay rates between the adhesive-containing and adhesiveless blocks. However, it must also be noted that the adhesiveless study was not conducted simultaneously with the original time study, and therefore differences from other unknown sources may have affected the results.

CONCLUSIONS

The results presented here indicate that extracting hemicelluloses and other hot water solubles from OSB strands for use in the production of alternative energy does not increase susceptibility to decay by the five isolates of brown rot fungi tested and significantly inhibits decay by the five isolates of white rot fungi. This may be from the removal of the easily accessible hemicelluloses as nutrient sources for these fungi. The fact that hemicellulose removal does not increase decay susceptibility, and in the case of white rot fungi appears to decrease decay susceptibility, may encourage the production of hemicellulose-extracted OSB and development of value-added products that use extracted sugars.

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