Quantitative Changes in Structural Components of Conifer Woods During Decay by White- and Brown-Rot Fungi

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ABSTRACT

Quantitative changes in lignin, glucan, mannan, and xylan during decay of five conifer woods by three white-rot and three brown-rot fungi were determined. (Glucan, mannan, and xylan provided estimates of cellulose and the hemicelluloses galactoglucomannan and arabin-4-O-methylglucuronoxylan, respectively.) All the white-rot fungi removed all the major wood components progressively during decay; the brown-rot fungi removed the polysaccharides but not lignin. The white- and brown-rot fungi removed the mannan, and usually xylan, faster than glucan, but the difference was not as pronounced for the white-rot as for the brown-rot organisms. The brown-rot fungi all had similar effects on the chemical composition of all the woods. In the white-rot type of decay there was variation in the effects on the chemical composition; this appeared to depend more on the wood being decayed than the fungus involved.

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Additional key words: *Polyporus versicolor*, *Ganoderma applanatum*, *Peniophora “G”, Polia monticola*, *Lenzites trabea*, *Lentinus lepidus*.

Very few studies have been made of the relative rates of removal of the structural components of wood (cellulose, hemicelluloses, and lignin) during decay by white-rot and brown-rot fungi (5). This is particularly true for conifer woods. To our knowledge, quantitative determinations of changes in the individual types of structural sugar polymers (glucan, mannan, and xylan) during the decay of conifer woods by either white-rot or brown-rot fungi have not been made. For hardwoods, such detailed analyses seem to have been done only by Cowling (3). The present study determined changes in the composition of representative conifer woods during decay by white- and brown-rot fungi commonly used in laboratory tests at the U.S. Forest Products Laboratory. The specific purposes of obtaining these
data were: (i) to provide information on the
time of hemicellulose decomposition during
decay; (ii) to evaluate variation in the relative rates of
removal of the major wood components, both among
the different fungi with a given wood, and among
different woods with a given fungus; and (iii) to
better characterize the specific effects of our
common wood-decay test organisms on the chemical
composition of conifer woods.

MATERIALS AND METHODS.—Wood samples and
decay.—Sapwood blocks 25.4 × 25.4 × 9.5 mm
(1 × 1 × 3/8 inches), the small dimension with the
grain, were cut from western hemlock [Tsuga
erophylla (Raf. & Sarg.), western white spruce
[Picea glauca var. albertiana (S. Brown) Sarg.], Sitka
spruce [Picea sitchensis (Bong.) Carr.], western white
pine [Pinus monticola Douglas.] and southern pine
(probably loblolly pine, Pinus taeda L.). These were
decayed in soil block (1) or agar block (10) chambers
for various periods of time to obtain samples of
various extents of decay. Percentage weight loss, the
measure of decay, was calculated from the weights of
the decayed blocks after equilibration at 70% relative
humidity and 27 C. The blocks decayed more slowly
in the agar block chambers and most of the samples
of small weight loss were from those chambers.

Nonincubated blocks served as controls.

Blocks were decayed by three white-rot fungi,
Polyergus versicolor (L. ex Fr.) (Madison 698),
Ganoderma applanatum [Pers. ex Wallr. (Pat.)]
(Madison 708), and Peniophora “G” (ME 461, not
identified to species); and three brown-rot fungi,
Porzia monticola (Murr.) (Madison 698), Lenzites
trabea (Pers. ex Fries) (Madison 617), and Lentinus
lepidicola (Fries) (Madison 534).

Analytical techniques.—Decayed and control
blocks were ground to pass a 40-mesh screen and the
wood meal dried in a vacuum oven at 45 C.

The wood meals were analyzed, without
extraction, for sulfuric acid lignin, and for total
reducing sugars in acid hydrolysates (determined
colorimetrically as glucose) (9). Relative amounts of
glucose, xylose, and mannose, and the total reducing
sugars, as glucose, in acid hydrolysates were
determined colorimetrically after paper
chromatographic separation (9). From these values
the glucan, xylan, mannan, and lignin and the losses of
each during decay were calculated (12).

Acid hydrolysis of conifer woods yields 0.5-2%
each of arabinose and galactose, which arise from the
hemicelluloses (13). In the analysis used here, these
two sugars are not separated from the main sugars
glucose, mannan, and xylose) and, therefore,
contribute to the value obtained for total reducing
sugars. On paper chromatograms, the galactose is not
separated from the glucose, and the arabinose is not
separated from the mannan. (To separate out these
sugars requires an additional step and decreases the
accuracy of the analyses of all the sugars) (9).

Therefore, the presence of these two minor sugars
leads to a slight overestimate of glucan and mannan
and a slight underestimate of xylan. These errors,
however, are considered to be insignificant in the
present work.

Conifer wood is composed mainly of cellulose, a
hemicellulose of the galactoglucomannan type
(approximately 70% mannan), and lignin, plus a
smaller percentage of a hemicellulose of the
arabinogalactan type (about 65% xylan) (13). Consequently, determination of glucan
gave an estimate of cellulose (with a small error due to
the glucose in glucomannan), mannan an estimate of
the major hemicellulose, and xylan an estimate of
the minor hemicellulose.

RESULTS.—Table 1 gives the composition of the
sound woods. These woods contained from 27-32%
lignin, 41-46% glucan (mostly cellulose), 15-17% mannan (in glucomannan), 4-7% xylan (in
glucuronoxylan), and 6-10% "other" materials. The
6-10% of each sample labeled "other" materials includes extractives, acid-soluble lignin, acetyl,
inorganic components, and uronic acid.

The percentage of this "other" material increased
during decay by each fungus, up to 12-22% at the
highest weight losses when expressed on the basis of
the decayed sample. This increase is considered to
reflect: (i) failure of the organisms to attack some of
these materials (e.g., the inorganic components,
certain extractives), and (ii) formation of additional
materials (acid-soluble degraded lignin, fungus
products) that did not analyze as one of the major
wood components. These materials are not
considered further in this report, since they do not
affect our conclusions concerning the major
structural components.

The analytical values for the decayed woods are
summarized in Tables 2 and 3 as losses in lignin,
glucan, mannan, and xylan, with results expressed as
a percentage of the original amounts of each. In
addition, data for the Sitka spruce decayed by
Polyergus versicolor and Porzia monticola are
illustrated graphically in Figures 1 and 2.

Though lignin was removed progressively by all

<table>
<thead>
<tr>
<th>Wood species</th>
<th>lignin (%)</th>
<th>glucan (%)</th>
<th>mannan (%)</th>
<th>xylan (%)</th>
<th>other (%)</th>
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</thead>
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<td>45.9</td>
<td>15.0</td>
<td>5.9</td>
<td>6.2</td>
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</table>

a The analytical methods used here were developed to
give accurate results with various wood samples (9). To
estimate the precision of the methods, 12 replicate analyses
were made over a period of time for a homogenous sample of
aspen wood, with statistical results as follows (data given in
the following order: component analyzed, sample mean,
standard deviation, 95% confidence interval for the
true mean): glucan, 50.76, 0.31, 50.57 - 50.95; mannan,
2.36, 0.07, 2.31 - 2.41; xylan, 18.92, 0.33, 18.71 - 19.13;
and lignin, 18.19, 0.32, 17.99 - 18.39.

b Includes extractives, acid-soluble lignin, acetyl, uronic
acids, etc.
TABLE 2. Loss of major structural components\(^a\) from conifer woods after various extents of decay by white-rot fungi

<table>
<thead>
<tr>
<th>Wood, Fungus</th>
<th>In total weight (%)(^b)</th>
<th>In lignin (%)(^c)</th>
<th>In glucan (%)(^c)</th>
<th>In mannan (%)(^c)</th>
<th>In xylan (%)(^c)</th>
</tr>
</thead>
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<tr>
<td>Western white pine, <em>Polyporus versicolor</em></td>
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<td>Western white pine, <em>Ganoderma applanatum</em></td>
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<td>15</td>
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<tr>
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</table>

\(^a\) Expressed on the basis of the original amount of each component in the sound wood (Table 1).
\(^b\) Decayed blocks were selected so that those combined for analysis were within a 3% weight loss interval.
\(^c\) These data are based on a single determination of each component in each sample. The methods used have proven to give reproducible values (see footnote “a”, Table 1).

The white-rot fungi, the rate of removal was not usually linear. The relative extents of removal of the lignin and other components also varied during the decay process; for example, at a 22% weight loss of western white pine inoculated with *P. versicolor*, 33% of the lignin and only 17-23% of the other components had been removed, whereas at a 55% weight loss all the components had been depleted to a comparable extent. There was also some variation in relative extents of removal of the wood components.

**Fig. 1.** Progressive loss of major structural components in the decay of Sitka spruce wood by *Polyporus versicolor.*

**Fig. 2.** Progressive loss of major structural components in the decay of Sitka spruce wood by *F. monticola.*
TABLE 3. Loss of major structural components from conifer woods after various extents of decay by brown-rot fungi

<table>
<thead>
<tr>
<th>Wood, Fungus</th>
<th>In total weight (%)</th>
<th>In lignin (%)</th>
<th>In glucan (%)</th>
<th>In mannan (%)</th>
<th>In xylan (%)</th>
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<td>Western hemlock,</td>
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* a Expressed on the basis of the original amount of each component in the sound wood (Table 1).
* b Decayed blocks were selected so that those combined for analysis were within a 3% weight loss interval.
* c These data are based on a single determination of each component in each sample. The methods used have proven to give reproducible values (see footnote "a", Table 1).

among different fungi on a given wood. For example, lignin was removed from white pine wood ahead of the other components by Ganoderma applanatum; whereas, with Penicillium, at weight losses above about 25%, the hemicellulose removal exceeded lignin removal (Table 2). The variation with a given fungus on different woods was somewhat more pronounced, and is well illustrated by comparing western white pine and Sitka spruce decayed by P. versicolor or these woods decayed by Ganoderma applanatum (Table 2). The lignin generally was removed by the white-rot fungi somewhat more preferentially than carbohydrates from the white pine, but not from southern pine or Sitka spruce (Table 2).

With the brown-rot fungi, the lignin was generally only slightly depleted but the values were irregular.

The lignin analysis is reproducible, but it is based simply on the acid-insolubles in the samples following acid hydrolysis. Although the analysis is as accurate as any other for sound conifer wood, it is clearly not definitive or absolute, and is particularly problematical for samples such as brown-rotted wood (2), which contain modified lignin (4). Thus, the indicated decreases (and in some cases increases) in the lignin content of the brown-rotted samples, undoubtedly in part reflect idiosyncrasies of the analysis. White-rotted wood apparently contains only a small amount of degraded lignin (6), so the lignin analysis is more reliable.

The cellulose (glucan) was usually removed from the woods at a relatively constant, or slightly increasing, rate by both white- and brown-rot fungi. In the white rots, this rate was approximately the same as the loss in total weight; whereas, in the brown rots the loss of cellulose was always greater than the loss in total weight, which reflects the failure to deplete the lignin.

The rates of removal of the mannan and especially xylan were more variable than was the rate of removal of the glucan by white- and brown-rot fungi. In all of the woods, and with both white-rot and brown-rot fungi, the major hemicellulose (mannan) was removed faster than the cellulose (glucan) (Tables 2 and 3). This was much more pronounced with the brown rots.

Our results suggest a greater effect of the wood than of the decay fungus in determining the relative rates of removal of the major structural components by the white-rot fungi from the woods examined here. The similarities of the effects of different fungi on the same wood are illustrated by results with white pine and Sitka spruce. With white pine, the three fungi used were generally similar in their relative rates of removal of the mannan, glucan, and lignin—lignin and mannan being removed faster than the glucan during most of the decay. For Sitka spruce decayed with the two fungi used, the patterns of these rates of removal were very similar. With the same fungi on different woods, the effects were more variable. P. versicolor removed the major components at different relative rates from the three different woods, and the same was true of G. applanatum with Sitka spruce and white pine (Table 2).

The brown-rot fungi were similar with all the woods in the relative rates of removal of the glucan and mannan—mannan being removed faster in each case. The variation in xylan removal by the brown-rot fungi depended more on the wood than the fungus. Even so, with respect to the lignin, glucan, and mannan, neither the woods nor differences in fungi appeared to markedly influence the pattern of decay by the brown-rot type of organisms.

**DISCUSSION**—The preferential depletion of mannan during brown rot, and to a lesser extent during white rot, has apparently not been noted previously. Seifert (11) analyzed cellulose, total pentosans (xylan, arabinan), and lignin in pine after various extents of decay by a brown-rot fungus, Coniophora cerebella. He did not assay for the major hemicellulose (glucomannan). In his study, the cellulose and pentosans were depleted approximately simultaneously, in a pattern similar to that with Sitka spruce and *Poria monticola* studied here. Kretzberg et al. (8) showed that the total pentosans are destroyed
faster than the cellulose, and the lignin more slowly than cellulose or pentosans, during the decay of spruce by the white-rot fungus *Trametes trogii* Berk. Again, however, the major hemicellulose was not analyzed. The pattern is similar to that in the 20-50% weight loss interval during decay of southern pine by *P. versicolor* in this study (Table 2).

In the brown-rot type of decay, the cellulose and possibly the hemicelluloses undergo an extensive depolymerization before much weight loss has occurred (3). Subsequent degradation and removal occurs progressively. Our results indicate that glucomannan is removed faster than cellulose from conifer woods and suggest that further degradation and removal of the depolymerized cellulose may depend on prior or concomitant removal of this major hemicellulose component. The same could be true for hardwoods. Cowling (3) found the mannan component to be preferentially removed from sweetgum by *Porina monticola*. However, in hardwoods (such as sweetgum) mannan is a minor component (13).

The white-rot type of decay differs biochemically from brown-rot. In the former, (i) no initial extensive depolymerization of the cellulose occurs (3), and (ii) the lignin is decomposed and removed. In other respects the two types are similar; i.e., the progressive removal of all the wood sugar polymers. The results here suggest that this similarity may go even further with conifer woods in that removal of glucomannan may precede removal of cellulose in both brown and white woods. However, analyses of additional wood/fungus combinations should be done before it can be established whether or not this is a valid generalization for white woods. It is clearly not as pronounced as with brown woods. In the white rot of hardwoods, neither the major hemicellulose, xylan, nor the mannan is consistently removed before the glucan (3, 7). Thus, it is possible that only in conifers is the major hemicellulose the most rapidly removed component.

Our results indicate that the selectivity of lignin removal by white-rot fungi depends strongly on the type of wood being decayed. Other recent studies also disclosed similar differences between birch and aspen wood and, more significantly, between hardwoods and conifer woods in this respect (7).

There was no clear relationship between relative rates of removal of the major components and the resistance of the woods to decay by the white- or the brown-rot fungi (the relative decay resistances are indicated by the average loss in weight after 12 weeks of decay by *Polyporus versicolor* and *Poria monticola*, Table 4).

**CONCLUSIONS.**—1) Three white-rot fungi removed all major wood components from conifer woods progressively during decay; three brown-rot fungi removed glucan, mannan, and xylan but not lignin.

2) The brown-rot fungi removed mannan and usually xylan faster than glucan from the five woods. The same was true for the white-rot fungi, but in those cases the difference was not as pronounced as with the brown-rot organisms.

3) The brown-rot fungi all had similar progressive effects on the chemical composition of all the woods. There was variation with the white-rot type of decay in the relative rates of removal of the major structural components—more so with a given fungus among different woods than with different organisms on the same wood.

**LITERATURE CITED**


**TABLE 4. Weight loss produced by *Porina monticola* and *Polyporus versicolor* in sapwood of conifers after 12 weeks in the soil-block test**

<table>
<thead>
<tr>
<th>Wood species</th>
<th>Weight loss (%) caused by:</th>
<th>P. versicolor</th>
<th>P. monticola</th>
</tr>
</thead>
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<td>Western hemlock</td>
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<td>55 ± 3.7</td>
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<tr>
<td>Sitka spruce</td>
<td>29 ± 8.4</td>
<td>65 ± 1.2</td>
<td></td>
</tr>
<tr>
<td>Southern pine</td>
<td>34 ± 9.1</td>
<td>51 ± 2.0</td>
<td></td>
</tr>
<tr>
<td>Western white spruce</td>
<td>35 ± 2.2</td>
<td>60 ± 2.5</td>
<td></td>
</tr>
<tr>
<td>Western white pine</td>
<td>50 ± 5.1</td>
<td>67 ± 1.5</td>
<td></td>
</tr>
</tbody>
</table>

*Average of six blocks with standard deviation.