Sonderdruck aus: **Material und Organismen** 13. Bd. 1978 Heft 3

Verlag Duncker & Humblot, 1000 Berlin 41

How Moisture and Pit Aspiration Affect Decay of Wood by White-rot and Brown-rot fungi

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1. Introduction

In aboveground situations, white-rot fungi are generally associated with decay of hardwoods and brown-rot fungi with decay of softwoods (E. B. COWLING, 1961). The phenomenon of host-wood preference, however, is much more pronounced within the white-rot fungi. In laboratory agar-block tests designed to simulate aboveground decay conditions, white rotters had a greater intrinsic capacity to decay hardwoods than softwoods (W. E. ESLYN and T. L. HIGHLEY, 1976). The white-rot fungi are also ineffective in decaying nondurable coniferous woods in laboratory soil-block tests (C.A. PETERSON and E.B. COWLING, 1964, 1973; T.C. SCHEFFER and E.B. COWLING, 1966; and W.S. THOMPSON, 1965). Brown-rot fungi, however, have been shown by laboratory tests to be capable of producing significant decay in both hardwoods and softwoods (W. E. ESLYN and T. L. HIGHLEY, 1976; C. A. PETERSON and E. B. COWLING, 1964; T. C. SCHEFFER and C. G. DUNCAN, 1947; W. S. THOMPSON, 1965). Thus, the failure of brown rotters to occur commonly on hardwoods in nature may result from greater competitive abilities of white rotters on hardwood substrates (C. A. PETERSON and E. B. COWLING, 1964). Host-

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wood preferences are of interest because of the clues they may give to wood properties or weaknesses of the fungi that can be utilized to develop new means of protection.

Natural decay resistance of heartwood is usually attributed to extraneous materials that inhibit fungal growth (T. C. SCHEFFER and E. B. COWLING, 1966). However, there is evidence that the resistance of some nondurable softwood species to decay by white-rot fungi is not due to extraneous inhibitory material in softwoods (C. A. PETERSON and E. B. COWLING, 1964; W.S. THOMPSON, 1965). Other factors that can account for resistance of wood to certain fungi are (1) culture conditions unfavorable to optimum fungal decay, (2) differences in structural material or anatomy, and (3) differences in quantity and availability of essential growth factors.

Moisture is probably the most important condition for culture that governs the activity of wood-decaying fungi and may well be a significant factor in the host specificity of some fungi. For instance, the lower moisture requirement of brown rotters than that of white rotters may explain why in aboveground exposures, such as millwork and decking where moisture content is relatively low, brown rotters are most frequently isolated. In softwood chips in piles in which wood is stored green and moisture content is often high, white-rot fungi are the primary basidiomycetes isolated (J. K. SHIELDS, 1967). T. L. HIGHLEY and T.C. SCHEFFER (1970) found that by substituting a filter paper feeder for a wood feeder to provide a wetter test block in the soil-block test, white rot by *Coriolus versicolor* was increased in many tropical hardwoods. C. A. PETERSON and E. B. COWLING (1973), however, found that a high initial moisture content in test blocks did not increase decay of Sitka spruce and sweetgum by C. versicolor in soil-block tests with wood feeders. They concluded that decay resistance of Sitka spruce to C. versicolor was an attribute of the structural materials (cellulose, hemicelluloses, and lignin) of the wood cell walls.

C.G. DUNCAN, based on work at the Forest Products Laboratory, proposed that anatomical differences between hardwoods and softwoods were the cause of decay resistance of softwoods to white rot. In decay tests DUNCAN found the white-rot fungus, C. versicolor, could degrade water-saturated spruce as readily as the brown-rot fungus Poria placenta degraded sweetgum containing 30 to 60% moisture. She hypothesized the white rotter needed more water to decay spruce than to decay sweetgum because the white-rot fungus cannot penetrate the pit torus in the aspirated condition, whereas in the unaspirated condition of the wet wood, C. versicolor moves rapidly through the wood and decay may occur although drying commences. *P. placenta,* by contrast,

can penetrate a torus, and move rapidly through the wood. However, rewetting previously dried wood to any moisture content will not reopen pit membranes (F. W. JANE, 1970).

The objective of this investigation was to determine how the following affect decay by brown-rot and white-rot fungi: (1) Moisture; (2) pit aspiration; and (3) wood species.

2. Materials and Methods

2.1 Wood and Fungal Species

Blocks, 1 (2.5 cm) by 1 (2.5 cm) by 3/8 inch (0.9 cm) with the 3/8-inch dimension in the grain direction were cut from the sapwood of the following species:

Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco)
Engelmann spruce (*Picea engelmannii* Parry)
Red pine (*Pinus resinosa* Ait.)
Sitka spruce (*Picea sitchensis* (Bong.) Carr.)
Ponderosa pine (*Pinus ponderosa* Laws.)
Western white pine (*Pinus monticola* Dougl.)
Western hemlock (*Tsuga heterophylla* (Raf.) Sarg.)
Western redcedar (*Thuja plicata* Donn.)
Redwood (*Sequoia sempervirens* (D. Don) Endl.)
Southern pine (*Pinus* sp.)
Western white spruce (*Picea glauca var. albertiana* (S. Brown) Sarg.)
Lodgepole pine (*Pinus contorta* Dougl.)
Balsam poplar (*Populus balsamifera* L.)
Eucalyptus (*Eucalyptus* sp.)
Sweetgum (*Liquidambar styraciflua* L.)
Red alder (*Alnus rubra* Bong.)

For each species, four sapwood slabs were obtained; each slab was presumed to have come from a different tree.

2.2 Decay Tests for Natural Durability

Six replicate blocks cut from each slab were airdried at room temperature, conditioned at 27° C and 70% relative humidity for at least 5 days, then weighed. Blocks were steam sterilized at 100° C for 30 minutes before being placed into decay chambers.

Five white-rot fungi and four brown-rot fungi were used. The white-rot fungi included *Coriolus versicolor* (L. ex Fr.) (Madison 697), *Ganoderma applanatum* (Fr.) (Madison 708), *Phanerochaete chrysosporium* Bards. (ME 461), *Lentinus tigrinus* (Bull.) Fries (ME-6), and *Poria subvermispora* Pilat (ME-485). (The "*Poria*" has been designated "Polyporus sp." or "Unknown Basidiomycete" (W. E. ESLYN, 1973a. W. E. ESLYN, 1973b, W. E. ESLYN and T. L. HIGHLEY, 1976).)

The four brown-rot fungi used included *Poria placenta* (Madison 698), Gloeophyllum trabeum (Pers.) Murr. (Madison 617), *G. saepiarium* (Wulf.) Karst (Madison 604), and *Lentinus lepideus* (Fr.) (Madison 534).

Test blocks were exposed in the standard ASTM soil-block method (American Society for Testing and Materials, 1971) on a vigorously growing fungus mycelium via a pine feeder for brown rotters and via a filter paper feeder for white rotters. After 12-week incubation at 27° C, the blocks were removed from test, reconditioned, weighed, and their weight losses calculated.

2.3 Decay Tests With Green and Water-Saturated Softwoods

High initial moisture contents of Douglas-fir, Sitka spruce, hemlock, and redwood blocks were obtained by placing sterile, preweighed, conditioned blocks in a vacuum, then saturating the blocks with sterile distilled H_2O. In addition, to determine the effect of unaspirated pits on decay, green Douglas-fir and southern pine were exposed to decay. Green blocks were sterilized with propylene oxide for 2 hours in a vacuum dessicator. The conditioned weight of the green blocks before exposure to decay was computed using moisture contents of matched blocks that were not decayed (conditioned weight $= \frac{\text{Green weight}}{1 + \%\ \text{moisture}}$). Saturated and green blocks were exposed to decay by the soil-block and purified agar-block methods (W. E. ESLYN and T. L. HIGHLEY, 1976). Following incubation for 12 weeks, blocks were again conditioned and weight losses calculated.

3. Results and Discussion

Average weight losses due to decay by the white-rot and the brown-rot fungi in the sapwood from the various species exposed over soil are given in Table 1. Using the ASTM (American Society for Testing and Materials, 1971) classification for natural decay resistance, all of the sapwood was nonresistant (> 44% weight loss) when decayed by the most destructive white- or brown-rot fungus in the soil-block test.

Applying the ASTM classification to decay caused by brown-rot fungi, all sapwoods were nonresistant (> 44% weight loss) except that of redwood, which was moderately resistant (25 - 44% weight loss). The four hardwood sapwoods were nonresistant to the decay caused by the white-rot fungi; 7 out of 12 softwood sapwoods, nonresistant; the remaining softwood sapwoods, moderately resistant. As would be expected, decay by the fungi was greater in the blocks exposed over soil than in the sapwood exposed in purified agar-block tests with minimal nutrients (W. E. ESLYN and T. L. HIGHLEY, 1976); in some blocks, the decay was as much as two or three times greater.

The ability of a particular fungus to decay the sapwood of the various species differed greatly. This was particularly true for Phanerochaete chrysosporium, where weight loss in hemlock and redwood, for example, was only 1% but in sweetgum, 55%. Resistance of heartwood to decay is usually attributed to inhibitory extractive materials (T. C.

SCHEFFER and E. B. COWLING, 1966). Because these materials are usually negligible in sapwood, factors other than extractives probably contribute to the variable decay resistance of the sapwood to the different fungi used in this investigation.

In ground contact, differences in resistance of softwoods to white rot and brown rot tend to be small. Contrarily, laboratory decay tests with soil are reported in which white-rot decay in softwoods was considerably less than that in hardwoods (C.A. PETERSON and E.B. COWLING, 1964, 1973; and W. S. THOMPSON, 1965). In the present soil-block tests, however, differences in resistance of softwoods to brown rot and white rot often were not great (Table 1). *Coriolius versicolor* was the only white-rot fungus that decayed all of the hardwood sapwoods at a faster rate than it did the softwood sapwoods. However, weight loss produced by *C. versicolor* and the other white-rot fungi in several softwoods approached or exeeded that by the brown rotters. Insufficient moisture may have limited white rot in softwoods in the previous soil-block tests. In the previous tests, the test block was placed on a wood feeder block that was placed on soil. In the present soil-block tests, filter paper was used as the feeder because white rot had been increased in several tropical hardwoods when a filter-paper feeder was used (T. L. HIGHLEY and T.C. SCHEFFER, 1970). Thus the increased weight loss by white rotters in softwoods in the present soil-block tests may be caused by the higher and more optimum moisture content in test blocks provided by the filter-paper feeders. Initial wetting of softwood test blocks to create a high initial moisture content, however, did not increase white rot (Table 2). C. A. PETERSON and E. B. COWLING (1973) also found that decay of Sitka spruce by C. versicolor was the same irrespective of the initial moisture content.

The findings in this investigation did not support C. G. DUNCAN's proposal. She suggested that the lower rate of white-rot decay in softwoods than in hardwoods was caused by the white rotter's slower rate of movement in softwoods than in hardwoods because it cannot penetrate the pit torus of softwoods in the aspirated condition. Green Douglas-fir and southern pine (unaspirated pits) were not attacked by the white rotters to any greater extent than was airdried wood (Table 3). It might be of interest to determine how rate of decay by white-rot fungi is affected by treating softwoods with pectolytic bacteria that degrade pit membranes.

Softwood sapwood apparently is not as adequate a food source as is hardwood sapwood, but given an exogenous nutrient source provided by soil and adequate moisture, many softwood sapwoods become susceptible to white rot. Where white rot advances rapidly in softwoods

Table 1. Weight losses produced by white-rot and brown-rot fungi in sapwood in soil-block tests[a])

Wood species	Percent weight loss produced by								
	White-rot fungi					Brown-rot fungi			
	Coriolus versicolor	*Phanerochaete chrysosporium*	*Lentinus tigrinus*	*Ganoderma applanatum*	*Poria subvermispora* (ME-485)	*Gloeophyllum trabeum*	*Gloeophyllum saepiarium*	*Poria placenta*	*Lentinus lepideus*
Softwoods									
Douglas-fir	24 ± 13.2	10 ± 6.6	39 ± 9.9	29 ± 3	29 ± 3	58 ± 11.9	57 ± 6.3	57 ± 3	37 ± 9.9
Engelmann spruce	35 ± 6.9	41 ± 14.9	58 ± 9.6	—	50 ± 13.3	—	57 ± 2.4	61 ± 3.7	—
Lodgepole pine	37 ± 8.9	28 ± 3.2	44 ± 8.0	47 ± 10.2	47 ± 17.5	68 ± 9.9	59 ± 4.4	62 ± 3.7	48 ± 11.9
Ponderosa pine	60 ± 10.7	16 ± 6.9	44 ± 15.7	64 ± 11.2	36 ± 3	60 ± 2.4	49 ± 7.8	60 ± 2.4	64 ± 11.7
Red pine	46 ± 11.6	31 ± 10	53 ± 4.4	56 ± 8.9	64 ± 9.4	69 ± 7.3	65 ± 5.9	57 ± 1.7	56 ± 17.0
Redwood	29 ± 9.7	1 ± 0	8 ± 2.2	27 ± 12.2	47 ± 7.4	24 ± 7.2	33 ± 3	43 ± 6.5	35 ± 2
Southern pine	29 ± 6.7	10 ± 5	18 ± 5.2	40 ± 8.9	46 ± 18.2	55 ± 11.3	45 ± 8.8	51 ± 6.2	41 ± 7.1
Sitka spruce	34 ± 10.6	26 ± 7.1	45 ± 11.0	42 ± 11.9	36 ± 6.7	43 ± 13.5	55 ± 1.0	65 ± 2.6	38 ± 14.2
Western hemlock	23 ± 5.6	1 ± 0	10 ± 6.5	27 ± 17.5	33 ± 4.9	53 ± 6.3	49 ± 3.0	53 ± 6.3	26 ± 3.5
Western redcedar	12 ± 5.7	24 ± 9.0	25 ± 4.4	—	39 ± 21	—	56 ± 5.1	58 ± 4.2	—
Western white pine	57 ± 6.8	33 ± 2.2	43 ± 6.4	47 ± 6.6	41 ± 3.3	68 ± 4.2	56 ± 1.4	63 ± 5.3	43 ± 5.5
Western white spruce	41 ± 3.9	19 ± 6.7	30 ± 13.2	25 ± 4.5	26 ± 3.0	33 ± 5.5	51 ± 6.8	58 ± 8.1	34 ± 5.6
Hardwoods									
Balsam poplar	81 ± 13.0	52 ± 8.9	62 ± 5.0	51 ± 12.1	47 ± 6.7	62 ± 9.2	49 ± 5.7	62 ± 5.0	37 ± 8.2
Eucalyptus	73 ± 15.0	32 ± 1.0	33 ± 3.5	41 ± 7.4	33 ± 11.2	19 ± 2.0	9 ± 4.5	51 ± 6.5	9 ± 8.4
Red alder	71 ± 21.5	10 ± 9.3	57 ± 19.4	43 ± 12.8	69 ± 14.7	44 ± 8.4	39 ± 5	48 ± 4.5	37 ± 6.4
Sweetgum	70 ± 7.3	55 ± 7.5	—	44 ± 2.8	—	42 ± 8.7	—	67 ± 3.2	26 ± 9.1

a) Average of 24 blocks with standard deviation.

Table 2. Effect on decay of a high initial moisture content (in sapwood of softwoods[a])

	Fungus	Percent weight loss produced in b)							
		Western white spruce		Western hemlock		Redwood		Douglas-fir	
		Satur. c)	Contr.	Satur.	Contr.	Satur.	Contr.	Satur.	Contr.
Brown-rot fungi	*Gloeophyllum trabeum*	33	33	22	26	30	24	32	46
	Lentinus lepideus	37	34	26	24	15	35	24	37
	Poria placenta	37	60	34	55	42	45	56	62
White-rot fungi	*Coriolus versicolor*	31	35	11	18	28	29	13	30
	Ganoderma applanatum	24	25	23	30	39	27	17	30
	Phanerochaete chrysosporium	13	22	0	0	0	0	10	14

a) Initial moisture content of blocks saturated with water under vacuum were: Spruce, 240%; hemlock, 188%; redwood, 369%; and Douglas-fir, 143%.
b) Values are average of six blocks; decay period was 12 weeks.
c) Satur. = Saturated, Contr. = Control.

Table 3. Decay in green sapwood of Douglas-fir and southern pine after 12-week exposure

	Fungus	Percent weight loss produced in[a]			
		Douglas-fir[b]		Southern pine[c]	
		Green	Air-dried	Green	Air-dried
Brown-rot fungus	*Poria placenta*	59	62	32	51
White-rot fungi	*Coriolus versicolor*	33	30	18	34
	Ganoderma applanatum	33	30	22	44
	Phanerochaete chrysosporium	7	14	6	11

a) Values are average of six blocks.
b) Moisture content of blocks ranged from 92 to 111%.
c) Moisture content of blocks ranged from 92 to 107%.

in soil contact, the soil may provide the necessary growth factors that are lacking. Where white rot is still slight in softwood sapwood despite soil contact, differences in the nature of the interrelationships between the carbohydrates and the lignin may be important (C. A. PETERSON and E. B. COWLING, 1973).

Except for the low weight loss in eucalyptus by three of the brown-rot fungi, the brown-rot fungi did not show a preference for either hardwood or softwood sapwood, although these fungi are most often associated with softwood used in structures. This agrees with findings in which brown-rot fungi produced substantial decay in both softwoods and hardwoods (W. E. ESLYN and T. L. HIGHLEY, 1976; C. A. PETERSON and E. B. COWLING, 1964; and W. S. THOMPSON, 1965).

In tests with minimal nutrients, brown-rot fungi were unable to cause significant weight loss in eucalyptus (W. E. ESLYN and T. L. HIGHLEY, 1976). In the soil-block tests reported here, however, all of the brown-rot fungi could produce some decay and subsequent weight loss in eucalyptus; Poria placenta produced the greatest weight loss (51%). Therefore, the inability of the brown-rot fungi to decay eucalyptus in minimal nutrient tests may be at least partially caused by a deficiency of essential growth factors in eucalyptus. Another possibility is that the sapwood of eucalyptus could contain slightly toxic substances that are ineffective against the vigorously growing mycelium of the brown-rot fungi in soil-block tests (W. E. HILLIS and Y. YAZAKI, 1973).

4. Summary

Sapwood from 4 hardwoods and 12 softwoods was exposed to four brown-rot and to five white-rot fungi in soil-block tests. The sapwood from all of the species was not durable; this was indicated by weight loss by the most destructive fungus. However, there was large disparity in ability of a particular fungus to decay sapwood. The greater weight loss by white rotters in softwood in the soil-block tests may result from more optimum moisture adjustments in test blocks provided with filter-paper feeder strips. High initial moisture content did not increase white rot in softwoods. White-rot decay also was not increased in green softwoods with unaspirated pits.

Zusammenfassung

Wie Feuchtegehalt und Tüpfelverschluß den Holzabbau durch Weiß- und Braunfäulepilzebeeinflussen

Das Splintholz von 4 Laubhölzern und 12 Nadelhölzern wurde im Erde-Klötzchen-Verfahren dem Angriff von 4 Braunfäule- und 5 Weißfäulepilzen ausgesetzt. Das Splintholz aller Arten besaß keine natürliche Dauerhaftigkeit; dies wurde durch Gewichtsverluste bewiesen, die der am stärksten abbauende Pilz verursachte. In der Fähigkeit eines bestimmten Pilzes, das Splintholz anzugreifen, bestanden jedoch erhebliche Unterschiede. Der größere Gewichtsverlust, der von den Weißfäulepilzen an Nadelholz in Erde-Klötzchen-Versuchen verursacht wurde, könnte auf eine optimalere Feuchteanpassung in den Versuchsklötzchen zurückzuführen sein, die auf Filtrierpapierstreifen gelegt waren, die zur Anzucht der Weißfäulepilze benutzt wurden. Eine

hohe Ausgangsfeuchte erhöhte den Weißfäuleangriff in Nadelhölzern nicht. Weißfäuleangriff wurde auch in frischem Nadelholz mit unverschlossenen Tüpfeln nicht verstärkt.

Résumé

Comment l'humidité et l'aspiration par les perforations affecte la décomposition du bois par les champignons de pourriture blanche et de pourriture brune

L'aubier de 4 feuillus et de 12 conifères a été expose à quatre champignons de pourriture brune et à cinq champignons de pourriture blanche dans des essais de blocs de terre. L'aubier de toutes les espèces n'offrait pas de résistance aux champignons, ce qui était indiqué par la perte de poids provoquée par le champignon le plus destructeur. Cependant, il y avait une grande disparité dans la capacité de destruction de l'aubier d'un champignon particulier. La plus grande perte de poids par la pourriture blanche chez les conifères dans les essais de blocs de terre peut résulter d'ajustements plus favorables de l'humidité dans les blocs d'essai munis de bandes de papier filtre d'alimentation en eau. Une forte teneur initiale en humidité n'a pas augment6 la pourriture blanche chez les conifères. De même, la pourriture blanche n'a pas été accrue chez les conifères verts à perforations ouvertes.

Resumen

De cómo la humedad y el cierre de punteaduras afectan la degradación de la madera por hongos causantes de la pudrición blanca y parda

Aplicando el método de bloques de tierra, se procedió a exponer la albura de cuatro maderas de fronda y doce de coniferas al ataque de cuatro hongos causantes de la pudrición parda y cinco, de la pudrición blanca. La albura de todas las especies no disponía de una durabilidad natural, lo cual quedó demostrado por pérdidas de peso causadas por el hongo de mayor actividad degradante. Hubo, no obstante, una gran disparidad en la capacidad de un determinado hongo de atacar la albura. La mayor pérdida de peso ocasionada en maderas de coniferas por hongos de la pudrición blanca en ensayos de bloques de tierra podría resultar de una mejor adaptación de la humedad en los bloques de prueba, colocados sobre tiras de papel de filtro para una alimentación adicional. Un mayor contenido de humedad inicial no aumentó el ataque de la pudrición blanca en maderas de coniferas. Tampoco quedó demostrado un aumento de la pudrición blanca en maderas tiernas de coníferas con las punteaduras sin cerrar.

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