ASSESSING FUNGAL DECAY OF WOOD BY SMALL-SCALE TOUGHNESS TESTS[1]

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(Received November 1992)

ABSTRACT

Impact bending and breaking radius were used to measure loss in toughness caused by basidiomycetes isolated from wood. Small test pieces were used to accelerate testing. Wide differences were found among, and sometimes within, the 26 species tested. Brown-rot fungi tended to cause greater losses than white-rot fungi, but no consistent difference was found between monokaryons and dikaryons of the same species.

Keywords: Wood decay, wood strength, impact bending, breaking radius.

INTRODUCTION

Isolation studies of wood products frequently produce numerous isolations of basidiomycetes that may decay wood. Potential decay capability of these isolates is conventionally assessed in decay trials in which wood weight loss is the measure of fungal activity. Such methods often require long incubations and procedures that are not practical in screening large numbers of isolates (American Society for Testing and Materials 1963, 1977).

Many studies have shown that wood strength can change significantly with very minor changes in weight (Wilcox 1978). Microbial attack on wood can be assessed in terms of its effects on mechanical properties such as modulus of rupture, modulus of elasticity, or work to maximum load, as well as by wood weight loss (Mulholland 1954; Richards 1954; Hartley 1958; Kennedy 1958; Hardie 1980). These properties, however, normally are measured on larger wood samples that must be exposed to the fungus for relatively long periods. Wood toughness is another property suitable for assessing microbial effects. Toughness is highly sensitive to the early stages of fungal attack, and many methods for assessing changes in this property have been developed (Scheffer and Duncan 1944; Pillow 1950; Waterman and Hansbrough 1957; Drow et al. 1965; Bravery and Grant 1971; Safo-Sampah and Graham 1976; Scheffer 1979). Variability tends to be high in toughness tests (Drow et al. 1965), reflecting both natural wood variability and differences in the degree of fungal colonization of individual samples; however, large numbers of relatively small samples can be tested in this manner.

[1] This is Paper 2844 of the Forest Research Laboratory, Oregon State University, Corvallis, Oregon.

Wood and Fiber Science, 25(4), 1993, pp. 375–383

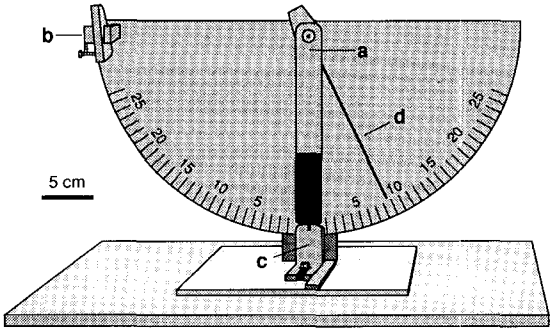

FIG. 1. Diagram of the apparatus used for testing impact-bending of specimens of Douglas-fir. The arm (a) is released from the holder (b) and strikes the specimen positioned at (c). The pointer (d) indicates the height attained by the arm.

The breaking-radius and the impact-bending toughness tests are potentially useful for assessing the decay capabilities of large numbers of organisms. In the breaking-radius test, small wafers exposed to the test fungus are bent around a series of cylinders of decreasing diameter until the wood fails. The radius of the cylinder provides an indirect measure of toughness. In the impact-bending test, wafers are placed in the path of a weighted pendulum; the distance the pendulum travels after passing through the specimen provides a measure of the energy absorbed by the wood. These simple, rapid tests permit evaluation of many samples in a relatively short time. In this study, the effects of basidiomycetes isolated from air-seasoning Douglas-fir poles were evaluated by both breaking-radius and impact-bending tests.

MATERIALS AND METHODS

The methods were chosen on the basis of extensive preliminary screening with *Postia placenta* (Fr.) M. Lars. & Lomb. and *Antrodia carbonica* (Overh.) Ryv. & Gilbn. as the test fungi. In these studies, the effects of specimen thickness, wood moisture content during both incubation and testing, and length of incubation were evaluated (Sexton 1988).

Toughness testing

At the end of the incubation period, specimens for breaking-radius tests were oven-dried overnight at 100 C and tested immediately after removal from the oven. Specimens for impact-bending tests were soaked in water for 15 minutes before testing to raise the wood moisture content above the fiber saturation point.

Breaking-radius tests were conducted on wooden mandrels with radii ranging from 8.9 to 0.32 cm. The mandrels decrease in size by 0.64 cm from 8.9 cm to 1.9 cm, then by 0.32 cm from 1.9 to 0.32 cm. The same apparatus was used by Scheffer (1979) and Safo-Sampah and Graham (1976). Contact with the mandrel was maintained throughout testing. The breaking-radius value is the radius of the mandrel upon which the specimen broke. Any visibly detectable fiber failure was considered breakage. Most specimens did not actually break in two. Decayed or weaker specimens broke over correspondingly larger mandrels than did sound specimens. Sixteen specimens were evaluated for each fungal isolate tested.

In impact-bending tests, a swinging metal arm bearing a 19.8-cm, 520-g pendulum struck the specimen at the nadir of the arc. Impact-bending value is a unitless number representing the distance the arm traveled along the arc after passing through the specimen. Twelve specimens were evaluated for each isolate tested (Fig. 1).

Fungal colonization

The fungi tested were isolated from air-seasoning poles of Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) located throughout the Pacific Northwest (Przybylowicz et al. 1987; Sexton et al. 1992) (Table 1). From 1 to 17 isolates were tested per fungal species. Seventeen isolates of *Peniophora* (*sensu stricto*) spp. were tested, because this genus includes many species and high variation was expected. The test fungi were grown on 1.25% malt extract agar in plastic petri dishes containing 4 sterile raschig rings (glass rings 6 mm in diameter by 7–10 mm high) on the agar surface. The rings were placed in the plates before agar addition and coated with agar to encourage upward microbial growth. The center of each

TABLE 1. *Number of isolates tested, mean (standard deviation) of impact-bending values and breaking radii, and percent of white-rot isolates with values greater than the control.*

Species	No. of isolates	Impact-bending value	% isolates > control[a]	Breaking radius (cm)	% isolates > control[a]	Decay capacity classification[b]
Cystostereum pini-canadense (Schw.) Pharm.	2	3.86 (2.09)	0 (−)	3.30 (0.38)	100 (−)	2
Diplomitoporus linbladii (Berk.) Gilbn. & Ryv.	5	2.71 (3.41)	0 (−)	3.05 (0.53)	21 (−)	3
D. linbladii monokaryon	6	4.81 (3.54)	33 (−)	3.28 (0.48)	100 (−)	2
Heterobasidion annosum (Fr. : Fr.) Bref.	6	1.58 (1.94)	0 (−)	4.01 (0.61)	67 (−)	2
Peniophora spp.	17	3.68 (4.61)	12 (−)	3.20 (0.58)	82 (−)	2
Phanerochaete gigantea (Fr. : Fr.) Rattan	3	3.64 (2.62)	0 (−)	3.28 (0.56)	100 (−)	2
Phanerochaete sordida (Karst.) J. Eriks. & Ryv.	9	3.98 (5.37)	22 (−)	3.20 (0.48)	67 (−)	2
Phellinus weirii (Murr.) Gilbn.	1	9.37 (5.15)	100 (NA)	3.02 (0.53)	0 (NA)	2
Phlebia albida Fr.	1	2.87 (0.47)	0 (NA)	3.07 (0.56)	0 (NA)	3
P. albida monokaryon	1	4.05 (2.33)	0 (NA)	3.38 (0.38)	100 (NA)	2
Phlebia concentrica (Cooke & Ellis) Kropp & Nakas.	3	3.72 (1.25)	0 (−)	3.18 (0.43)	67 (+)	2
P. concentrica monokaryon	6	3.84 (1.96)	0 (−)	3.10 (0.48)	50 (+)	2
Phlebia merismoides (Fr. : Fr.) Fr.	4	4.14 (3.12)	0 (−)	3.38 (1.09)	50 (−)	2
P. merismoides monokaryon	6	2.71 (3.12)	0 (−)	3.00 (0.46)	17 (−)	3
Phlebia rufa (Fr. : Fr.) Chris	3	4.19 (2.70)	0 (−)	2.90 (0.48)	0 (−)	3
P. rufa monokaryon	14	2.53 (3.71)	0 (−)	3.20 (0.53)	0 (−)	2
Phlebia subserialis (Boudin & Galzin) Donk	6	3.59 (1.18)	0 (−)	3.12 (0.53)	67 (−)	2
P. subserialis monokaryon	1	4.03 (2.25)	0 (NA)	3.10 (0.56)	0 (NA)	3
Pleuroflammula puberula (Peck) Singer	1	4.82 (3.46)	0 (NA)	2.84 (0.41)	0 (NA)	3
Schizophyllum commune Fr. : Fr.	6	4.32 (1.98)	0 (−)	3.10 (0.48)	33 (−)	3
S. commune monokaryon	6	3.41 (1.38)	0 (−)	3.10 (0.51)	67 (−)	2
Sistotrema brinkmanii (Bres.) J. Eriks.	6	4.07 (1.62)	0 (−)	3.12 (0.51)	50 (−)	2
Stereum hirsutum (Willd. : Fr.) S. F. Gray	10	5.73 (4.91)	30 (−)	3.10 (0.58)	30 (+)	2
Stereum sanguinolentum (Alb. & Schw. : Fr.) Fr.	7	4.52 (5.08)	14 (−)	3.28 (0.64)	75 (−)	2
Trametes versicolor (L. : Fr.) Pilát	7	4.60 (5.05)	29 (−)	3.07 (0.46)	86 (−)	2
T. versicolor monokaryon	9	6.73 (5.15)	56 (−)	3.20 (0.69)	89 (−)	1
Non-decayed control		3.93 (1.32)		2.84 (0.46)		

[a] Figures in parentheses indicate the presence (+) or absence (−) of a difference between isolates of a species. NA = not applicable, only one isolate tested.
[b] 1 = aggressive, 2 = moderate, 3 = mild.

plate was inoculated with a small agar plug of the test fungus; four wood specimens were placed on the rings 7 days later. Specimens were incubated for 4 weeks at 27 C.

Wood specimens

Specimens of Douglas-fir (1.7 mm thick by 9.4 mm wide by 51 mm long) were cut from straight-grained heartwood (specific gravity

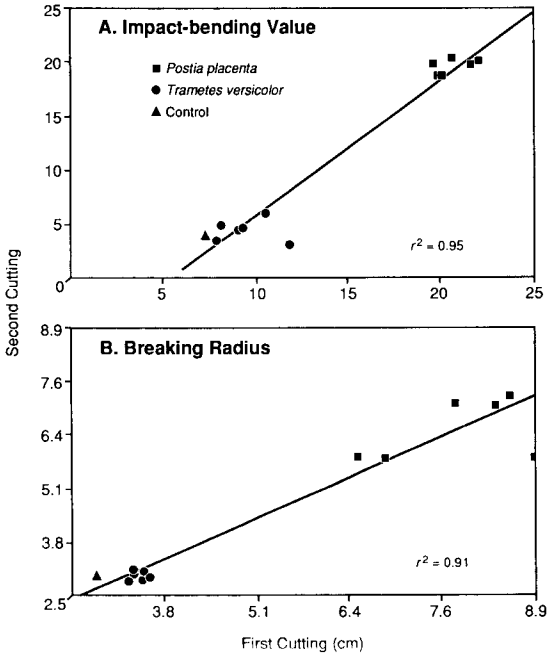

FIG. 2. Relationship between A) impact-bending values and B) breaking radii for two cuttings of Douglas-fir sticks decayed and sampled under the same conditions.

0.44) so that only the broad radial faces were tested. Although every attempt was made to assure uniformity, the large number of specimens needed required that samples be cut from two boards having slightly different breaking-radius and impact-bending values. This problem was partially overcome by using a correction curve constructed from matched tests of wood samples from the two boards that were either exposed to *Postia placenta* or *Trametes versicolor* (L.:Fr.) Pilát or not inoculated (Fig. 2). This curve permitted comparisons among all isolates in the study.

Wood specimens were soaked for 5 minutes in distilled water and then sterilized (121 C for 20 minutes) before use.

Data analysis

The results from each isolate were compared by a Students t-test ($\alpha = 0.05$) with a common control that had not been exposed to fungi. Comparisons between mono- and dikaryons of the same species were made by a z-test ($\alpha = 0.05$) for differences between means of large samples. All isolates of a given species were pooled for z-tests; differences between isolates of the same species were detected with an F statistic ($\alpha = 0.05$) for comparison of more than two sample means. In one case (*Phlebia albida* Fr.) a t-test was used because too few isolates were available for a z-test.

The species were classified into three arbitrary categories based on decay capacity: aggressive decayers (50% or more of the isolates significantly reduced wood strength in both tests), moderate decayers (30% or more of the isolates significantly reduced wood strength in both tests, or 50% reduced strength in at least one of these tests), and mild decayers (meeting neither criterion). Because monokaryons and dikaryons were tested separately, many species fell into two categories. Most of those classified as mild decay fungi based on one life stage (either monokaryon or dikaryon) fell into either the serious or moderate categories based on the other life stage.

RESULTS AND DISCUSSION

Breaking radius and impact bending: values and correlation

Nondecayed control specimens had an average breaking radius of 2.8 cm and impact-bending value of 3.93 (maximum possible value = 23). Breaking-radius values for samples exposed to fungi ranged from 2.8 cm for *Pleuroflammula puberula* (Peck) Singer (Table 1) to 7.2 cm for *Antrodia xantha* monokaryon (Table 2), a 0 to 251% increase over the control, respectively. Impact-bending values for exposed samples ranged from 2.53 for *Phlebia rufa* (Fr.:Fr.) Chris. monokaryon to 20.85 for *A. xantha* monokaryon, 36 to 530% increases over the control, respectively (Tables 1 and 2).

The ability to decay wood, as measured by a significant difference from the uninoculated control, was more difficult to show with the impact-bending test. The variances and sample sizes of the two tests account for this. The coefficient of variation averaged 44% (range 8–126%) for impact bending, but 20% (range 11–

TABLE 2. *Number of isolates tested, mean (standard deviation) of impact-bending values and breaking radii, and percent of brown-rot isolates with values greater than the control.*

Species	No. of isolates	Impact-bending value	% isolates > control[a]	Breaking radius (cm)	% isolates > control[a]	Decay capacity classification[b]
Antrodia carbonica (Overh.) Ryv. & Gilbn.	9	8.17 (5.10)	68 (+)	4.78 (1.91)	100 (+)	1
A. carbonica monokaryon	8	9.43 (4.45)	88 (+)	3.89 (1.30)	100 (−)	1
Antrodia serialis (Fr. : Fr.) Donk	4	7.59 (6.60)	50 (+)	4.27 (1.17)	100 (+)	1
A. serialis monokaryon	1	3.71 (1.23)	0 (NA)	3.10 (0.56)	0 (NA)	3
Antrodia xantha (Fr. : Fr.) Ryv.	6	17.31 (5.22)	100 (+)	6.30 (1.78)	100 (+)	1
A. xantha monokaryon	5	20.85 (2.07)	100 (+)	7.16 (1.85)	100 (+)	1
Crustoderma dryinum (Berk. & Curt.) Parm.	7	16.84 (5.12)	86 (+)	5.54 (1.91)	100 (+)	1
C. dryinum monokaryon	1	6.89 (5.00)	100 (NA)	3.81 (0.94)	100 (NA)	1
Fomitopsis cajanderi (P. Karst.) Kotl. & Pouz.	5	11.03 (6.69)	100 (+)	4.27 (1.24)	100 (+)	1
F. cajanderi monokaryon	5	7.05 (5.58)	60 (−)	3.66 (0.79)	100 (−)	1
Fomitopsis pinicola (Sw. : Fr.) P. Karst.	2	15.22 (5.62)	100 (+)	5.84 (2.11)	100 (+)	1
F. pinicola monokaryon	6	6.40 (5.05)	50 (+)	4.62 (1.63)	100 (+)	1
Gloeophyllum saepiarium (Wulf. : Fr.) P. Karst.	9	2.88 (5.10)	11 (+)	3.45 (0.86)	89 (−)	2
Postia placenta (Fr.) M. Lars. & Lomb.	10	19.59 (2.73)	100 (+)	6.60 (1.73)	100 (+)	1
P. placenta monokaryon	10	20.36 (1.73)	100 (+)	6.07 (1.75)	100 (+)	1
Non-decayed control		3.93 (1.32)		2.84 (0.46)		

[a] Figures in parentheses indicate the presence (+) or absence (−) of a difference between isolates of a species. NA = not applicable, only one isolate tested.
[b] 1 = aggressive, 2 = moderate, 3 = mild.

36%) for breaking radius. Although the sample size was developed from estimates of standard deviation in preliminary sampling, actual variability proved higher. Larger sample sizes might have lowered the standard deviation. The high variation in strength losses reflects the range of decay capabilities of the isolates and highlights the difficulty of using fungal isolation data as the sole assessment of the extent of decay in a wood sample. Large populations of species that cause little damage may be less of a problem than small populations of aggressive decayers.

Data from the breaking-radius and the impact-bending tests were highly correlated (r^2 = 0.79) when all isolates were considered (Fig. 3). Because the range of breaking radii for white-rot fungi was narrower than that of impact-bending values, there was no correlation between the breaking-radius and impact-bending tests when only white-rot fungi were considered (r^2 = 0.02). Brown-rot fungi produced a wide range of values in both tests, and tests of these fungi were more closely correlated (r^2 = 0.70).

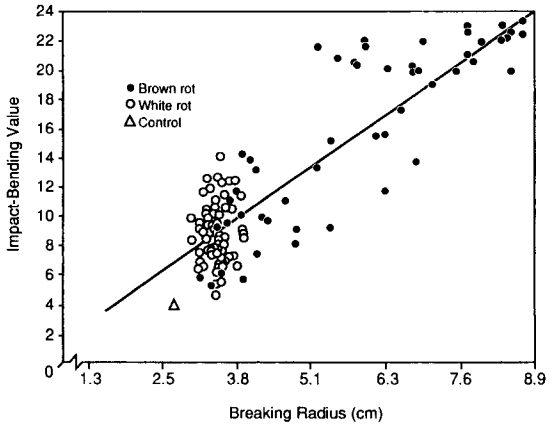

FIG. 3. Correlation between impact-bending values and breaking radii of 117 isolates of 10 representative species of basidiomycetes isolated from air-seasoning Douglas-fir.

The lack of correlation between the tests with white-rot fungi may reflect differing sensitivities in the lower ranges of strength loss. Impact bending measures a continuum of values based on the amount of energy required to cause failure, whereas the mandrel measures the discrete value of the breaking radius. Too few breaking radii were available to permit detection of subtle differences at the lower end of strength values, where the white-rot fungi were clustered. The result was a wider range of impact-bending values corresponding to a narrow range of breaking radii and no correlation.

Classification of decay capability

Seven of the eight species classified as aggressive decayers (Tables 1 and 2) were brown-rot fungi, which are believed to cause the majority of decay problems in Douglas-fir utility poles (Eslyn 1970; Graham and Corden 1980; Zabel et al. 1980). The aggressive white-rot fungus was a *Trametes versicolor* monokaryon. This fungus, which is common in woody debris, is considered an efficient wood rotter (Watling 1982) and is often used as a representative white-rot fungus in wood decay tests. The brown-rot fungi included several species that decay standing trees or timber. *Antrodia carbonica* is known especially for causing decay in Douglas-fir utility poles (Eslyn 1970; Zabel et al. 1980).

Of the eighteen species that fell into the moderate decay category, all but one, *Gloeophyllum saepiarium* (Wulf.:Fr.) Karst., were white-rot fungi. Several of these species are common decayers of trees or woody debris. *Heterobasidion annosum* (Fr.) Bref. causes an important root rot of coniferous trees (Watling 1982). *Stereum hirsutum* Willd. ex Fr.) S.F. Gray and *S. sanguinolentum* (Alb. & Schw.: Fr.) Pouz., common but weak wood rotters, are considered important in woodland ecology (Watling 1982). *Stereum sanguinolentum* inhabits living trees and has been isolated from wounds on Douglas-fir trees (Hubert and Krueger 1962).

Eight species were classified as mild decayers. All were white-rot fungi except *Antrodia serialis* (Fr.) Donk. monokaryon, but only one isolate of this fungus was available.

How rapidly or completely a particular fungus degrades wood is more useful information if some estimation of its population size is available. The three fungi isolated most frequently, *S. sanguinolentum, Peniophora* sp., and *Sistotrema brinkmanii* (Bres.) J. Erikss., caused moderate decay, but did little damage to wood in 1 month. After several years, however, large populations of these fungi could cause considerable decay.

Decay capacities of white- and brown-rot fungi

White- and brown-rot fungi fell into distinct categories in each test. In general, the brown-rot fungi decayed wood more effectively than did the white-rot fungi (Fig. 3). Differential rates of decay and the mechanics of the tests contributed to the differences in the effects of white- and brown-rot fungi. Brown-rot fungi were used as test species in devising the test methods because of their importance in decay of coniferous wood products. Brown-rot fungi were also expected to be isolated more frequently than white rot, but greater numbers and more species of white-rot fungi were actually obtained (Przybylowicz et al. 1987). The two types of decay fungi have been reported to affect toughness equally (Richards 1954; Hardie 1980), but this was not the case in this study. Brown-rot fungi decay wood more quickly than do white-rot fungi, especially in the early stages of attack. The short incubation time of 4 weeks may have limited damage

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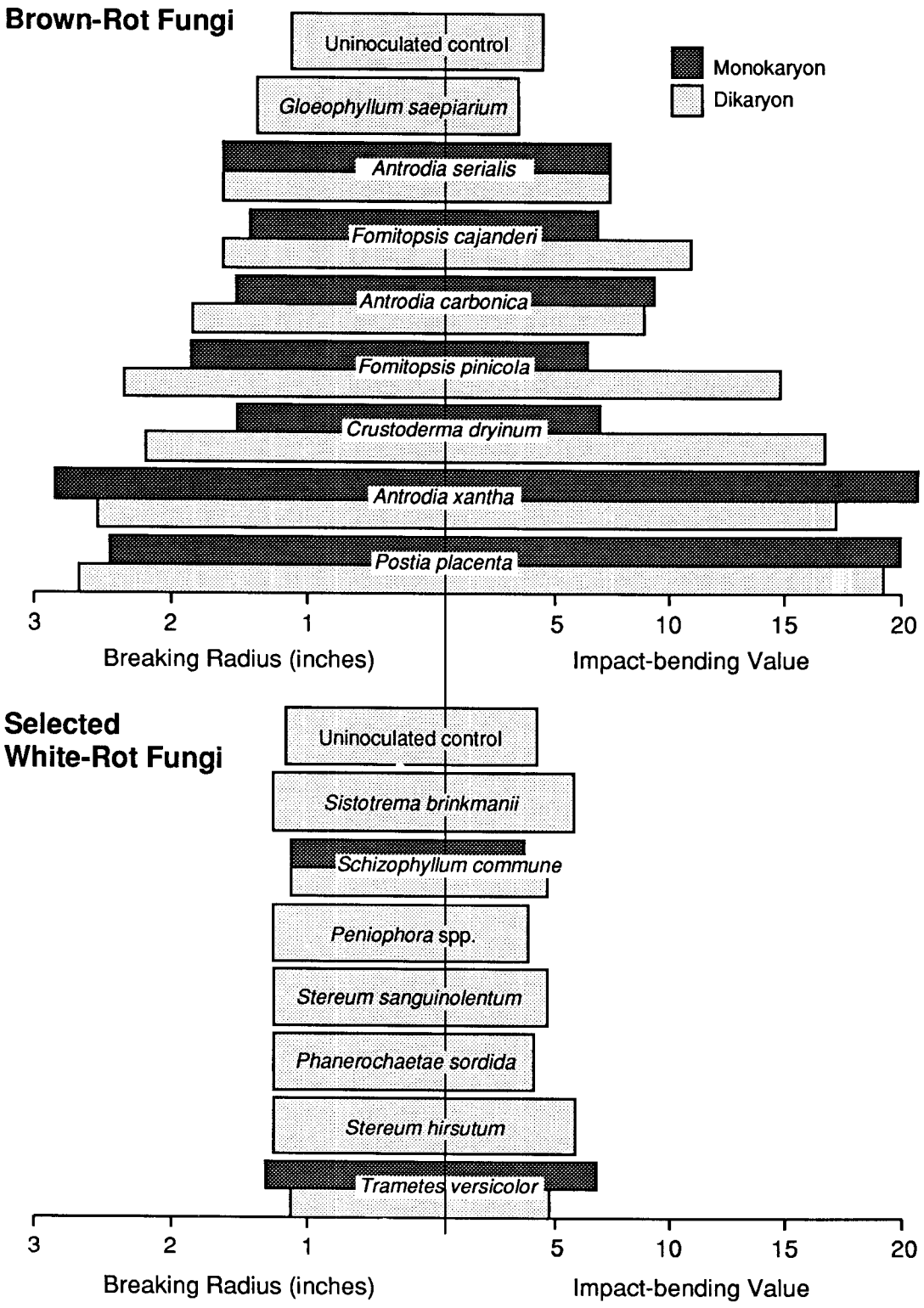
FIG. 4. Relative wood decay ability, as measured by breaking radius and impact-bending value, of brown- and white-rot fungi, including selected monokaryon-dikaryon pairs, isolated from air-seasoning Douglas-fir poles.


Brown-Rot Fungi
Uninoculated control
Gloeophyllum saepiarium
Antrodia serialis
Fomitopsis cajanderi
Antrodia carbonica
Fomitopsis pinicola
Crustoderma dryinum
Antrodia xantha
Postia placenta
Monokaryon
Dikaryon
3
2
1
5
10
15
20
Breaking Radius (inches)
Impact-bending Value
Selected White-Rot Fungi
Uninoculated control
Sistotrema brinkmanii
Schizophyllum commune
Peniophora spp.
Stereum sanguinolentum
Phanerochaetae sordida
Stereum hirsutum
Trametes versicolor
3
2
1
5
10
15
20
Breaking Radius (inches)
Impact-bending Value

caused by the slower-acting white-rot fungi. Longer incubation periods might permit more accurate assessment of the decay capability of white-rot fungi.

Another factor contributing to the difference between white- and brown-rot fungi is the inability of some fungi, mainly white-rot fungi, to degrade Douglas-fir heartwood. Heartwood was chosen because sapwood should be completely penetrated by preservative during treatment and thus be relatively decay-resistant. The heartwood, then, is more vulnerable to decay during service, but only those fungi able to survive or enter after treatment will cause degradation. If Douglas-fir sapwood had been used, white-rot fungi might have caused more decay; however, the frequent presence of white-rot fungi in the heartwood of seasoning poles suggests that these fungi may decay this substrate (Sexton et al. 1992).

Differences in decay capacity of isolates of the same species

Of the 45 taxa tested (monokaryons and dikaryons considered separately), 22 showed no difference between isolates in breaking radius and 26 did not differ in impact bending. Sixteen taxa differed significantly in breaking radius and 12 in impact bending ($\alpha = 0.05$). Only one isolate of the remaining seven fungi was available for testing (Tables 1 and 2).

Differences between isolates are more likely to occur with species that decay wood more rapidly. All of the fungi classified as aggressive decayers in our study showed differences between isolates among the monokaryons, the dikaryons, or both. With the exception of *Stereum hirsutum,* all isolates of species that were classified as aggressive or moderate decayers were capable of decay. About 30% of the isolates of *S. hirsutum* were capable of decay; the remainder had little effect on either breaking radius or impact-bending strength. These differences highlight the wide degree of decay capabilities possible within a species. Under the circumstances, some decay capability should be suspected in all basidiomycetes until it has been shown otherwise.

Decay capacity of monokaryons and dikaryons

Within the same species, neither monokaryons nor dikaryons had consistently greater decay capacity (Fig. 4). Nine of the 15 pairs evaluated produced similar results with both tests. Monokaryons of four species caused more decay, while dikaryons of the other five were more damaging. The monokaryon of *Postia placenta* caused a greater increase in breaking radius, but a lesser increase in impact bending, than did the dikaryon.

All of the isolates used in this study were field isolates and, thus, cannot be assumed to be closely related. Most studies involving differences between monokaryons and dikaryons employ synthesized cultures of known relationship (Amburgey 1970; Elliot et al. 1979). Dikaryons of *Serpula lacrymans* (Wulf.:Fr.) Schroet. caused less weight loss than both component monokaryons in 57% of the cases and more weight loss in 10% of the cases (Elliot et al. 1979). In the remaining 33%, the dikaryon fell between the monokaryons. Amburgey (1970) found no consistent relationship between weight loss caused by component monokaryons and the resulting dikaryon of *Lenzites trabea* Pers. ex Fries. Based on these studies and the present study, both mono- and dikaryons of wood decay fungi must be presumed to be capable of destroying wood unless it has been proven otherwise.

CONCLUSIONS

Nearly 82% of the species tested were capable of moderate to aggressive decay. While the majority of aggressive decayers were brown-rot fungi, short incubations may have limited damage by white-rot fungi. Nevertheless, the results indicate that toughness tests are a simple technique for rapidly assessing the decay potential of a large number of basidiomycetes.

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