TERMITE RESISTANCE OF WOOD SPECIES GROWN IN HAWAII

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ABSTRACT

The recent decline in plantation agriculture in the Hawaiian Islands has created interest in forestry as an alternative use for former plantation lands. This interest is supplemented by the desire to salvage hurricane-damaged trees, and the need to protect both living trees and wood products from attack by the Formosan subterranean termite, *Coptotermes formosanus* Shiraki. We conducted both no-choice and multiple-choice laboratory and field evaluations of heartwood of indigenous and introduced Hawaiian tree species to determine their comparative resistance to termite attack. *Cryptomeria japonica* (Sugi, Taxodiaceae), *Cordia subcordata* (Kou, Boraginaceae), *Calophyllum inophyllum* (Kamani, Guttiferae), *Thespesia populnea* (Milo, Malvaceae), and *Eucalyptus microcorys* (Tallowwood, Myrtaceae) were very resistant to termite feeding. *Pandanus tectorius* (Hala, Pandanaceae) was moderately resistant, and the resistance of *E. microcorys* was reduced to an equivalent level after 3 years of exterior exposure. *Acacia koa* (Koa, Leguminosae), *Metrosideros polymorpha* (Ohia lehua, Myrtaceae), and *Eucalyptus robusta* (Robusta, Myrtaceae) were slightly resistant to termite attack; while *Eucalyptus deglupta* (Bagras eucalyptus), *Cardwellia sublimis* (Silky oak), and *Albizia falcataria* (Molucca albizia, Leguminosae) were very susceptible. Our results suggest that *C. japonica*, *E. microcorys*, and *T. populnea* may have the greatest potential of the termite-resistant species in Hawaii for expanded cultivation, harvest, and development and marketing of wood products.

Recent declines in sugar cane and pineapple cultivation in Hawaii have created interest in both diversified agricultural crops and forestry as alternative uses for former plantation lands. Statewide interest in forestry is evidenced by increased forestry research and extension activities in the College of Tropical Agriculture and Human Resources, University of Hawaii at Manoa (16), and the growth of the Hawaii Forest Industry Association (17). Damage to forests in Hawaii in 1992 by Hurricane Iniki also stimulated interest in possible markets for salvaged logs.

The potential for damage by termites, especially by the Formosan subterranean termite *Coptotermes formosanus* Shiraki (Isoptera: Rhinotermitidae), is an important consideration in the development of forestry in Hawaii and in the manufacture and use of wood products in the tropical Pacific. A great deal of effort is expended in Hawaii toward protecting wood products from termite attack (10,22), and surveys of termite incidence on living plants in Hawaii have identified 62 susceptible plant species (7,9,13).

Growth of termite-resistant trees (6,8) and the use of naturally durable woods in manufacturing and construction (3,4,11,20) represent alternatives to the use of soil insecticides and wood preservatives to protect susceptible trees and lumber. It has also been suggested that extractives from naturally durable woods could be applied to susceptible timbers or used as models for new wood preservatives (5,14).

The studies reported here were performed to evaluate the termite resistance of heartwood from Hawaiian-grown tree species. In the first study, we surveyed a series of trees grown on the island of Hawaii; in the second study, we evaluated wood from trees grown on the island of Kauai. Douglas-fir (*Pseudotsuga menziesii*) and pine (*Pinus* spp.) were included as controls, since these are both susceptible to attack by the Formosan subterranean termite. Douglas-fir is the principal wood used in building construction in Hawaii (23).

MATERIALS AND METHODS

NO-CHOICE TESTS

Wafers (20 by 20 by 6 mm) cut cross-grain from the heartwood of logs harvested on the island of Hawaii were purchased from a specialty sawmill (Winkler Wood Products, Kailua-Kona, Hawaii). Woods obtained were (scientific name, common name, family): *Cryptomeria japonica* (Sugi, Taxodiaceae), *Cordia subcordata* (Kou, Boraginaceae), *Calophyllum inophyllum* (Kamani, Guttiferae), *Thespesia populnea* (Milo, Malvaceae), *Pandanus tectorius* (Hala, Pandanaceae), *Acacia koa* (Koa, Leguminosae), *Metrosideros polymorpha* (Ohia lehua, Myrtaceae), *Eucalyptus robusta* (Robusta, Myrtaceae), *Eucalyptus deglupta* (Bagras eucalyptus), and *Cardwellia sublimis* (Silky oak). Douglas-fir (*Pseudotsuga menziesii*) and pine (*Pinus* spp.) were cut into similar wafers and included as controls.

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TABLE 1. — Mean termite mortality, mass losses, and visual ratings of wood wafers exposed to Formosan subterranean termites for 4 weeks in a no-choice laboratory test. Wafers were visually rated as 10 (sound), 9 (light attack), 7 (moderate attack), 4 (heavy attack), or 0 (failure). Dashed lines indicate suggested species groupings in terms of resistance to termite attack.

Common name	Latin name	Mean rating	Mean mass loss	Mean mass loss	Mean mortality
			(mg)	(%)	
Kamani	*Calophyllum inophyllum*	9.0	37.94 (25.22)A[a]	1.95 (1.32)	36.60 (5.28)B
Kou	*Cordia subcordata*	8.8	24.68 (9.46)A	1.97 (0.72)	46.35 (4.33)A
Sugi	*Cryptomeria japonica*	9.6	60.26 (16.23)A	3.71 (1.07)	33.40 (5.87)B
Milo	*Thespesia populnea*	9.6	49.52 (5.89)A	3.78 (0.66)	29.00 (4.09)B
Hala	*Pandanus tectorius*	9.2	120.62 (11.28)B	7.85 (0.73)	28.85 (3.12)B
Koa	*Acacia koa*	7.4	172.54 (23.90)C	10.59 (1.98)	16.75 (4.20)D
Ohia lehua	*Metrosideros polymorpha*	7.4	255.60 (20.30)D	11.99 (1.12)	20.00 (2.48)CD
Robusta	*Eucalyptus robusta*	6.4	246.62 (44.20)D	11.57 (2.10)	27.85 (8.39)BC
Bagras	*Eucalyptus deglupta*	0	386.68 (18.43)E	38.49 (4.75)	13.90 (0.86)D
Silky oak	*Cardwellia sublimis*	2.4	453.68 (37.31)F	31.05 (2.39)	6.50 (2.56)E
Douglas-fir	*Pseudotsuga menziesii*	0	536.70 (33.85)G	34.82 (2.24)	7.00 (1.83)E
Pine	*Pinus spp.*	0	540.90 (19.18)G	52.12 (2.82)	6.10 (3.28)E

[a] Values in parentheses are standard deviations; means within a column followed by the same capital letter are not significantly different at the 5 percent level.

For the second study, wafers (25 by 25 by 6 mm) cut radially from heartwood of *Eucalyptus microcorys* (Tallowwood, Myrtaceae), *Eucalyptus deglupta* (Bagras eucalyptus), and *Albizia falcataria* (Molucca albizia, Leguminosae) were provided by William Cowern, Kua Orchards, Lawai, Kauai. We were provided with wafers cut from *E. microcorys* lumber that had been stored for 3 years under interior conditions, and with wafers from lumber stored on the ground under exterior conditions for 3 years. Douglas-fir wafers were included as controls.

In both studies, individual wafers were exposed to Formosan subterranean termites, *Coptotermes formosanus*, for 4 weeks in a no-choice laboratory bioassay based upon the AWPA E1-72 and ASTM D3345-74 standard methods (1,2). Our bioassay makes two additions to these standard methods: 1) evaluation of termite mortality; and 2) evaluation of the ovendry wood mass loss due to termite feeding, as well as visually rating the wafers according to the AWPA and ASTM scale: 10 (sound), 9 (light attack), 7 (moderate attack), 4 (heavy attack), or 0 (failure).

Formosan subterranean termites were collected from an active field colony on the Manoa campus of the University of Hawaii immediately before their use in laboratory assays, using a trapping technique (21). Test containers were 80-mm-diameter by 100-mm-high screw-top plastic jars, each containing 150 g of washed and ovendried silica sand and 30 mL of distilled water. The test wafers were ovendried (90°C for 24 hr.), weighed, and allowed to equilibrate to laboratory conditions for several hours before test initiation. In both studies, one test wafer was placed on the surface of the damp sand, and 400 termites (360 workers and 40 soldiers, to approximate natural caste proportions) were added to each jar. Each wood species was replicated five times, and the jars were placed in an unlighted controlled-temperature cabinet at 28±0.5°C for 4 weeks (28 days). At the conclusion of the test, percentage termite mortality was recorded, the wafers were visually rated according to the 0 to 10 scale, and the ovendry mass change was measured for each wafer.

In both tests, wood mass loss data and proportional termite mortality, transformed by the arcsine of the square root, were subjected to analysis of variance (ANOVA), and means significantly different at the 0.05 level were separated by the Ryan-Einot-Gabriel-Welsch multiple F test (18).

MULTIPLE-CHOICE TESTS

For both laboratory and field multiple-choice tests, wood wafers from the heartwood of logs harvested on the island of Hawaii were prepared as just described. In the laboratory tests, a 10-mm layer of crushed coral sand was placed in the bottom of an 80-mm-diameter by 100-mm-high screw-top plastic jar. A disk of wire mesh, skirted to elevate it about 5 mm above the surface of the sand, was placed in the jar. Five randomly chosen wood wafers were placed on top of the mesh disk and covered by a disk of corrugated cardboard, and another mesh disk (with five more wood wafers) was placed on top of the cardboard. Each jar contained five layers of wood wafers, with each layer separated by wire mesh and a cardboard disk. The sand was moistened with 25 mL distilled water and 500 termites (465 workers and 35 soldiers) were placed in each jar. The lids were loosely replaced and the jars were incubated in an unlighted temperature-controlled cabinet at 28°C for 4 weeks. There were 10 replicates of each wood species (2 wafers of each species per jar), and the test was repeated with termites collected from 3 separate field colonies. After 4 weeks, the wafers were carefully brushed clean and weighed to determine mass loss due to termite feeding. Wood wafers were air-dried to a constant weight both before and after termite exposure. Mass loss data were subjected to analysis of variance (ANOVA), blocked by termite colony, and means significantly different at the 0.05 level were separated by Tukey's studentized range test using the SAS general linear models procedure (18).

The multiple-choice field test was also conducted with woods from the island of Hawaii, and was designed in the same fashion as the laboratory test. This test was replicated at each of the three field sites representing the three termite colonies used in the laboratory evaluation. Two of these were located on the Manoa campus of the University of Hawaii and the third was located in a residential yard in Kaneohe, Oahu.

In the field test, 10 layers, each consisting of 4 randomly assigned wood wafers placed on a wire mesh disk and covered by a disk of corrugated cardboard, were arranged within a 200-mm-long by 80-mm-diameter length of plastic (ABS) pipe, and the pipe was placed vertically over a similar length of pipe containing cut pieces of Douglas-fir as "bait" wood to encourage termite activity. In turn, this lower length of pipe was placed vertically over a Douglas-fir stake extending into the soil at the field site and containing actively feeding termites at the time of test initiation. The top piece of pipe, containing the test wafers, was capped, and the apparatus was left in the field for a period of 6 weeks. There were five replicate wafers of each wood species, contained within three pipes, for each of the three field colonies. At the conclusion of the field exposure, the wafers were air-dried to a constant mass, weighed to determine mass losses, and the mass loss data were analyzed as previously described.

RESULTS AND DISCUSSION

Results of our no-choice laboratory evaluations of woods grown on the island of Hawaii are presented in **Table 1**. Based upon both visual ratings of termite damage and wood mass losses, these tree species are devisable into four categories of relative termite resistance: resistant, moderately resistant, slightly resistant, and susceptible. Resistant woods were visually rated as 9 or better, with mean mass losses not exceeding 5 percent; those in the moderately resistant category were rated above 7, with mean mass losses not exceeding 10 percent; slightly resistant woods were rated above 4, with mass losses not exceeding 20 percent; those considered susceptible received visual ratings of 4 or less, and sustained mean mass losses greater than 20 percent. These are subjective categorizations, but provide a good description of the woods listed in **Table 1**, and include our recognition that visual ratings and mass loss data are not always in complete agreement. *Pandanus tectorius*, for example, is difficult to accurately rate visually due to the texture of this wood, and greater reliance should thus be placed on mass loss. *Pandanus tectorius* is the only member of the Pandanaceae native to the Hawaiian islands (15).

The multiple-choice laboratory and field tests (**Table 2**) were characterized both by very limited feeding on all of the Hawaiian-grown woods, in comparison to Douglas-fir and pine, and by a great deal of within-species variation in the degree of termite attack. Although the wood wafers were randomly distributed within each experimental replicate, this great variation in termite attack could have resulted from the close proximity of either more or less attractive woods within the confines of each replicate. In the laboratory multiple-choice test, greatest termite attack occurred on *Eucalyptus robusta*, followed by *Cardwellia sublimis*, and the least feeding occurred on *Cordia subcordata*. In the field test, *C. sublimis* sustained the greatest damage, followed by *Acacia koa*; and again, *C. subcordata* was fed upon least.

Of the woods from the island of Kauai (**Table 3**), only *Eucalyptus microcorys* stored under protected conditions can be considered "resistant" to termite attack. The slightly greater mass loss of *E. microcorys* stored in exterior exposure for 3 years, placing these samples in the category of "moderately resistant," indicates that the extractives imparting termite resistance are degraded or leached to some extent under conditions of severe exposure. Unlike *E. microcorys*, both *E. deglupta* and *Albizia falcataria* should be considered to be susceptible to attack by Formosan subterranean termites. The relatively high mortality of termites fed *E. deglupta* in this test, however, indicates the presence of toxic extractives and suggests that this wood might be less preferred than other available susceptible wood species by termites foraging under more natural free-choice conditions. This lack of preference for *E. deglupta*, despite its susceptibility, is supported by the results of the multiple-choice field test in which Formosan subterranean termite feeding on Douglas-fir, pine, and *Cardwellia sublimis* exceeded feeding on *E. deglupta*.

In these tests, the woods most resistant to termite attack were *Calophyllum inophyllum* (Kamani), *Cordia subcordata* (Kou), *Cryptomeria japonica* (Sugi), *Thespesia populnea* (Milo), and *Eucalyptus microcorys* (Tallowwood). Both *C. japonica* and *E. microcorys* are extensively used for construction and other purposes in

TABLE 2. — Mean mass losses of Hawaiian-grown woods exposed to Formosan subterranean termites in multiple-choice tests in the laboratory (4 weeks) and field (6 weeks).

Common name	Latin name	Laboratory test: Mean mass loss (mg)	Laboratory test: Mean mass loss (%)	Field test: Mean mass loss (mg)	Field test: Mean mass loss (%)
Kamani	*Calophyllum inophyllum*	20.16 (27.31)AB[a]	1.42 (1.63)	9.55 (11.80)A	0.49 (0.60)
Kou	*Cordia subcordata*	9.28 (37.45)A	0.71 (2.80)	1.94 (4.51)A	0.15 (0.38)
Sugi	*Cryptomeria japonica*	23.86 (30.90)AB	1.45 (1.84)	20.78 (4.93)A	1.26 (0.31)
Milo	*Thespesia populnea*	44.36 (87.90)ABC	3.66 (9.04)	25.65 (33.83)A	1.64 (1.93)
Hala	*Pandanus tectorius*	24.63 (14.01)AB	1.65 (1.12)	14.82 (10.12)A	0.94 (0.63)
Koa	*Acacia koa*	23.84 (27.31)AB	1.42 (1.63)	395.51 (303.14)B	23.14 (17.65)
Ohia lehua	*Metrosideros polymorpha*	26.68 (28.96)AB	1.25 (1.37)	10.54 (17.83)A	0.49 (0.82)
Robusta	*Eucalyptus robusta*	71.32 (101.33)C	3.46 (5.34)	52.78 (73.87)A	2.43 (3.33)
Bagras	*Eucalyptus deglupta*	39.88 (49.45)ABC	3.77 (4.54)	21.06 (20.17)A	2.04 (2.00)
Silky oak	*Cardwellia sublimis*	58.33 (44.03)BC	3.79 (2.96)	533.42 (409.87)C	34.87 (26.41)

[a] Values in parentheses are standard deviations; means within a column followed by the same capital letter are not significantly different at the 5 percent level. Mass losses of control woods were as follows: Douglas-fir = 20.22% (2.19) lab, 48.12% (3.11) field; Pine = 15.70% (2.06) lab, 67.39% (2.67) field.

TABLE 3. — Mean termite mortality, mass losses, and visual ratings of wood wafers exposed to Formosan subterranean termites for 4 weeks in a no-choice laboratory test. Wafers were visually rated as 10 (sound), 9 (light attack), 7 (moderate attack), 4 (heavy attack), or 0 (failure).

Common name	Latin name	Lumber storage	Mean rating	Mean mass loss (mg)	Mean mass loss (%)	Mean mortality (%)
Tallowwood	*Eucalyptus microcorys*	Interior (3 yr.)	9.0	32.58 (44.89)A[a]	5.33 (1.38)	99.90 (0.22)A
		Exterior (3 yr.)	9.0	187.88 (33.50)B	6.64 (1.18)	77.35 (17.08)B
Bagras	*Eucalyptus deglupta*	Interior (2 yr.)	4.0	375.23 (27.43)C	25.91 (1.66)	86.10 (12.43)B
Molucca albizia	*Albizia falcataria*	Interior (2 yr.)	0	387.52 (54.52)C	51.15 (7.69)	42.70 (3.76)C
Douglas-fir	*Pseudotsuga menziesii*	Unknown	0	945.88 (49.95)D	38.79 (2.59)	21.40 (14.38)C

[a] Means within a column followed by the same capital letter are not significantly different at the 5 percent level.

Japan and Australia, respectively. *Thespesia populnea* is used for bowls and craftwork in Hawaii, but its low shrinkage and moderately heavy density have made it appropriate for boat building and cabinet work elsewhere (15). *Calophyllum inophyllum* is used to some extent in construction outside of Hawaii, but its relatively large shrinkage in drying and difficulty in machining (15) may limit its market potential. *Cordia subcordata* was used extensively by the Hawaiians for tableware, but is currently in very short supply (15). Thus, *C. japonica*, *E. microcorys*, and *T. populnea* may have the greatest potential of the termite-resistant species in Hawaii for expanded cultivation, harvest, and development and marketing of wood products.

The neem tree, *Azadirachta indica* A. Juss (Meliaceae) is also cultivated in Hawaii. Although the principal chemical constituent of neem, azadirachtin, is deterrent or toxic to many insect species, it is only slightly deterrent to Formosan subterranean termites (12). Neem wood and bark, however, are less preferred by termites than Douglas-fir (8), suggesting that this tree could be useful for ornamental arboriculture in Hawaii even if not suitable for wood harvesting.

Although our focus in these studies was to identify Hawaiian-grown wood species with potential for expanded cultivation and use, a number of woods harvested in other regions have also been found to resist termite attack and may have potential for greater importation to the Pacific and use in lieu of preservative-treated lumber. These woods include Western redcedar (*Thuja plicata*) (20), bald cypress (*Taxodium distichum*) (19), Alaska-cedar (*Chamaecyparis nootkatensis*), and teak (*Tectona grandis*) (11).

Certainly, selection of termite-resistant tree species for cultivation and harvest is not necessarily the most important factor in developing viable forest industries in Hawaii and other Pacific regions. However, growth and harvest of such species can serve to limit insect damage to standing tree crops, identify useful trees for salvage, and promote the use of naturally durable wood products in the tropical Pacific. From a marketing standpoint, naturally durable woods frequently have greater value than less durable species that require chemical treatment for use under conditions of high termite hazard. This added value results both from the costs of preservative treatment, and from a preference among some members of the public for use of "natural" or "least-toxic" insect control methods. From environmental, public health, and community development standpoints, there are obvious advantages to the promotion of durable locally grown wood products in the tropical Pacific since this can lessen chemical inputs to the environment as well as decrease reliance upon importation of industrial chemicals and preservative-treated wood products.

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