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TERMITE RESISTANCE OF HAWAIIAN AND PACIFIC WOOD SPECIES

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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*. We conducted laboratory evaluations of the 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 three 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. Increased used of durable woods in forest products may represent a significant trend in an environmentally-conscious world.

Introduction

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. State-wide 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 (Phillips 1993), and the growth of the Hawaii Forest Industry Association (Robinson 1993). 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 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 towards protection of wood products from termite attack (Tamashiro *et al.* 1990, Grace 1995), and surveys of termite incidence on living plants in Hawaii have identified 62 susceptible plant species (Lai *et al.* 1983, Delate 1993, Grace 1993).

Growth of termite-resistant trees (Cooper & Grace 1987, Delate & Grace 1995) and the use of naturally durable woods in manufacturing and construction (Beal *et al.* 1974, Bultman *et al.* 1979, Su & Tamashiro 1986, Grace & Yamamoto 1994) 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 (Carter & de Camargo 1983, Laks *et al.* 1988).

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 Kauai. Douglas fir (*Pseudotsuga menziesii*) and pine (*Pinus* sp.) 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 (Wilcox 1984).

Materials and methods

Wafers (20 × 20 × 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: *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* sp.) were cut into wafers and included as controls.

For the second study, wafers (25 × 25 × 6 mm) cut radially from heartwood of *Eucalyptus microcorys* (tallowwood, Myrtaceae), *E. deglupta* 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 three years under interior conditions, and with wafers from lumber stored on the ground under exterior conditions for three years. Douglas fir wafers were included as controls.

In both studies, individual wafers were exposed to Formosan subterranean termites, *Coptotermes formosanus*, for four weeks in a no-choice laboratory bioassay based upon the AWPA E1-72 and ASTM D3345-74 standard methods accepted by the American Wood-Preservers' Association (AWPA 1994) and the American Society for Testing and Materials (ASTM 1991) respectively. Our bioassay makes two additions to these standard methods: 1) evaluation of termite mortality, and 2) evaluation of the oven-dry wood mass loss due to termite feeding, as well as visually rating the wafers according to the AWPA and ASTM scale of 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 (Tamashiro *et al.* 1973). Test containers were 8 cm diameter by 10 cm high screw-top plastic jars, each containing 150 g washed and oven-dried silica sand and 30 ml distilled water. The test wafers were oven-dried (90°C for 24 hours), 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 placed in an unlighted, controlled temperature cabinet at 28 ± 0.5 °C for 28 days. At the conclusion of the test, percentage termite mortality was recorded, the wafers visually rated according to the 0-10 scale, and the oven-dry mass change measured for each wafer.

Results and discussion

Results of our evaluation of woods grown on the island of Hawaii are presented in Table 1, and those of woods from the island of Kauai are given in Table 2. Based upon both visual ratings of termite damage and wood mass losses, the tree species can be divided 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%; those in the "Moderately resistant" category were rated above 7, with mean mass losses not exceeding 10%; "Slightly resistant" woods were rated above 4, with mass losses not exceeding 20%; while those considered "Susceptible" received visual ratings of 4 or less, and sustained mean mass losses greater than 20%. These are subjective categorizations, but they 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. The wood of *Pandanus tectorius*, for example, is difficult to accurately rate visually due to its texture, and greater reliance should thus be placed on mass loss. This species is the only member of the Pandanaceae native to the Hawaiian islands (Little & Skolmen 1989).

Of the woods from the island of Kauai, only *Eucalyptus microcorys* stored under protected conditions could be considered "resistant" to termite attack. The slightly greater mass loss of *E. microcorys* under exterior exposure for three years, placing these samples in the category of "moderately resistant", indicated that the extractives imparting termite resistance were degraded or leached to some extent under conditions of severe exposure. Unlike *E. microcorys*, both *E. deglupta* and *Albizia falcataria* should be considered "susceptible" to attack by Formosan subterranean termites. The relatively high mortality of termites-fed *E. deglupta* in this test, however, indicated the presence of toxic extractives and suggested that termites foraging under more natural free-choice conditions preferred other available susceptible wood species over wood of *E. deglupta*. This lack of preference for *E. deglupta*, despite its susceptibility, is supported by the results of a six-week multiple-choice field test where feeding of Formosan subterranean termites on Douglas fir, pine, and *Cardwellia sublimis* exceeded feeding on *E. deglupta* (J.K. Grace & D.M. Ewart, unpublished data). In these tests, the wood most resistant to termite attack were *Calophyllum inophyllum* (kamani), *Cordia subcordata* (kou), *Cryptomeria japonica* (Sugi), *Thespesia populnea* (milo), and *E. microcorys* (tallowwood). Both *C. japonica* and *E. microcorys* are extensively used for construction and other purposes in 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 appropri-

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Table 1. Mean termite mortality, mass losses and visual ratings of wood wafers exposed to Formosan subterranean termites for 28 days in a no-choice laboratory test. Wafers (5 replicates of each wood species) were visually rated according to AWPA E1-72 and ASTDM D3345-74 standard methods 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. (Woods from the island of Hawaii)

Common name	Latin name	Mean rating	Mean (mg) mass loss (SD)	Mean (%) mass loss (SD)	Mean (%) mortality (SD)
Kamani	*Calophyllum inophyllum*	9.0	37.94 (25.22)	1.95 (1.32)	36.60 (5.28)
Kou	*Cordia subcordata*	8.8	24.68 (9.46)	1.97 (0.72)	46.35 (4.33)
Sugi	*Cryptomeria japonica*	9.6	60.26 (16.23)	3.71 (1.07)	33.40 (5.87)
Milo	*Thespesia populnea*	9.6	49.52 (5.89)	3.78 (0.66)	29.00 (4.09)
Hala	*Pandanus tectorius*	9.2	120.62 (11.28)	7.85 (0.73)	28.40 (3.12)
Koa	*Acacia koa*	7.4	172.54 (23.90)	10.59 (1.98)	16.75 (4.20)
Ohio lehua	*Metrosideros polymorpha*	7.4	255.60 (20.30)	11.99 (1.12)	20.00 (2.48)
Robusta	*Eucalyptus robusta*	6.4	246.62 (44.20)	11.57 (2.10)	27.85 (8.39)
Silky oak	*Cardwellia sublimis*	2.4	453.68 (37.31)	31.05 (2.39)	6.50 (2.56)
Bagras	*Eucalyptus deglupta*	0	386.68 (18.43)	38.49 (4.75)	13.90 (0.86)
Douglas-fir	*Pseudotsuga mensiesii*	0	536.70 (33.85)	34.82 (2.24)	7.00 (1.83)
Pine	*Pinus* sp.	0	540.90 (19.18)	52.12 (2.82)	6.10 (3.28)

Table 2. Mean termite mortality, mass losses and visual ratings of wood wafers exposed to Formosan subterranean termites for 28 days in a no-choice laboratory test. Wafers (5 replicates of each wood species) were visually rated according to AWPA E1-72 and ASTDM D3345-74 standard methods as 10 (sound), 9 (light attack), 7 (moderate attack), 4 (heavy attack), or 0 (failure). (Woods from the island of Kauai)

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

ate for boat building and cabinet work elsewhere (Little & Skolmen 1989). *Calophyllum inophyllum* is used to some extent in construction outside Hawaii, but its relatively large shrinkage on drying and difficulty in machining (Little & Skolmen 1989) may limit its market potential. *Cordia subcordata* was used extensively by the Hawaiians for tableware, but is currently in very short supply (Little & Skolmen 1989). 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* (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 (Grace & Yates 1992). Neem wood and bark, however, are less preferred by termites than Douglas fir (Delate & Grace 1995), 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 red cedar (*Thuja plicata*) (Su & Tamashiro 1986), bald cypress (*Taxodium distichum*) (Scheffrahn *et al.* 1988), Alaska cedar (*Chamaecyparis nootkatensis*) and teak (*Tectona grandis*) (Grace & Yamamoto 1994).

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 limit insect damage to standing tree crops and promote the use of naturally durable wood products in the tropical Pacific region. 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 from the savings from not needing preservative treatment, and from a preference among some members of the public for use of "natural" or "least toxic" insect control methods. From an environmental, public health and community development standpoint, there is obvious advantage to the promotion of durable, locally grown wood products in the tropical Pacific since this can reduce chemical inputs to the environment as well as decrease reliance upon importation of industrial chemicals and preservative treated wood products.

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