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Susceptibility of neem to attack by the Formosan subterranean termite, *Coptotermes formosanus* Shir. (Isopt., Rhinotermitidae)

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Abstract: The neem tree, *Azadirachta indica*, is a source of natural compounds with potent insecticidal, feeding deterrent and insect growth regulator activity. However, little information is available on the effects of these natural products on termites. We assessed the effects of mulches made from ground neem branches and roots on survival of the Formosan subterranean termite, *Coptotermes formosanus*, and compared termite feeding and survival on neem wood and bark to that on susceptible *Pseudotsuga menziesii* wood. Termite survival was fairly low in both *P. menziesii* heartwood and neem mulches over the 14 day test period, and did not differ significantly among those treatments. However, termites exposed to either *P. menziesii* wood, neem wood, or neem bark for 4 weeks fed significantly less on neem wood and bark. Feeding on neem bark caused significant termite mortality (56.4%) in comparison to that induced by feeding on neem wood (27.1%) or *P. menziesii* wood (12.5%). Thus, although neem is not entirely resistant to termite attack, the antifeedant properties of its wood and bark and the toxicity of neem bark support the use of neem trees for arboriculture in areas where termites are a problem.

1 Introduction

The Formosan subterranean termite, *Coptotermes formosanus* Shir. (Isopt, Rhinotermitidae), is a serious pest of structures throughout the tropics and subtropics (Su and Tamashiro, 1987). For example, the annual costs attributable to *C. formosanus* damage and control in structures in the Hawaiian islands have been estimated to exceed US $60 million (Yates and Tamashiro, 1990). Termite attacks on trees and field crops can also cause significant losses (Harris, 1969; Wood et al., 1980; Johnson et al., 1981; Cooper and Grace, 1987; Cowie et al., 1989; Atkinson et al., 1992; Gitonga, 1992). In Hawaii, the Formosan subterranean termite has been reported to attack at least 48 plant species (Lai et al., 1983), and an additional 9 species were recently identified by us in an unpublished survey of Hawaiian horticulturalists, arboriculturalists, and pest control firms.

In protecting plants as well as structures from termite attack, soil insecticides are currently the principal tools (Wood et al., 1987). Non-chemical control methods include techniques to mitigate termite access to the target plant and the use of less susceptible plants (Logan et al., 1990). Recent interest in the use of neem, *Azadirachta indica* A. Juss (Meliaceae), both for its insecticidal extract (Menn, 1990; Grace and Yates, 1992) and the resistance of living neem trees to insect attack, led us to investigate the effects of neem wood and bark on the Formosan subterranean termite.

Neem seed kernels are the major source of the limonoid azadirachtin and other insecticidal extractives, but biologically active terpenoidal compounds have been isolated from various parts of the tree (Jacobson, 1990). Research on termite sensitivity to natural products from the neem tree has been very limited. Grace and Yates (1992) found significant feeding deterrence of Formosan subterranean termites on papers treated with a commercial azadirachtin and neem oil formulation, although high concentrations were required to elicit this effect. Other reports are largely anecdotal, and contradictory. Schmutterer (1990b) mentioned successful control with neem cake of termites in tree crops, but Sen-Sarma et al. (1975) reported attacks by *Coptotermes kishori* Roon. & Chhot. on neem trees, logs and stumps in India. Zanno et al. (1975) cited a personal communication indicating the azadirachtin was a potent termite antifeedant, but Butterworth and Morgan (1971) cited a personal communication to the effect that azadirachtin had no effect on feeding or survival of *Reticulitermes santonensis* Feyt.

Both the growth regulator effects (Subrahmanyam, 1990) and cumulative toxicity of neem extractives with longer exposures suggest a potential for greater mortality when insects are exposed to a living neem tree rather than to isolated extractives. Gitonga (1992) reported that neem tree seedlings were attacked by termites in Kenya, damaging 7.3% of the crop, but no neem tree deaths occurred in the same vicinity where *Eucalyptus camaldulensis* trees experienced high mortality due to termites.

In the present study, we investigated the effects of neem wood and bark obtained from living trees on the feeding and mortality of Formosan subterranean termites. We were interested in both the potential use of neem as a protective mulch around susceptible plants, and its possible value as a termite-resistant tree for the urban landscape in Hawaii.

2 Material and methods

2.1 Neem mulches

Formosan subterranean termites, *C. formosanus*, were collected from an active field colony on the Manoa campus of

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the University of Hawaii, using a trapping method described by TAMASHIRO et al. (1973). In brief, foraging termites were aggregated in a wooden box, covered by a metal can and placed on the soil surface over a stake extending into the soil. Forty-five termite workers (pseudergates, or undifferentiated individuals older than the third instar as determined by size) and five soldiers, to mimic natural caste proportions, were placed in a 55 ml polystyrene vial (60 × 35 mm diameter) containing 5 g of one of the following wood mulches, dampened by addition of 8 ml distilled water: (1) neem branches from a dead section of an *A. indica* tree on the university campus, (2) neem branches from a live section of the same tree, (3) neem roots, or (4) Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) heartwood as a control substrate. The woods were ground in a Wiley Mill (Thomas Co., Philadelphia, PA) with a No. 26 screen in order to obtain homogenized mulches of similar texture. Each treatment was replicated five times. Vials were capped (with air holes created in the caps with a heated insect pin), and held in unlit incubator at 29°C for 14 days.

Termite behavior in the wood mulches was examined daily. After 14 days, termites were gently removed from the vials and mortality was recorded. Percentage mortality data were transformed by the arcsine of the square root and 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, (SAS INSTITUTE, 1987).

2.2 Neem wood and bark

Neem branches at least 25 mm in diameter were randomly selected from a tree on the Manoa campus of the University of Hawaii and cut into 25 mm square blocks for use in this study. Bark was mechanically removed from neem branches, and bark pieces were used as the second treatment. Douglas-fir heartwood lumber was cut into 25 mm blocks for use as the control. Blocks and bark pieces were dried (7 days at 60°C) to a constant weight prior to bioassay.

One dried wooden block (either Douglas-fir or neem) or several pieces of neem bark weighing approximately the same as a wooden block were placed on top of 150 g of sterile silica sand in an 8 × 10 cm plastic jar, to which 28 ml of distilled water was added. Four hundred termites (360 workers and 40 soldiers) were collected as described above and added to each jar. Six replicates were prepared for each of the three treatments. Jars were loosely capped and held in an incubator as described above. After 28 days, wood and termites were gently removed from the jars and termite mortality was recorded. Wood and bark pieces were cleaned with a soft brush to remove sand and termite debris, dried in a forced-air oven (7 days at 60°C) and weighed to determine mass loss due to termite feeding. Percentage mortality data were transformed by the arcsine of the square root and termite mortality and wood mass losses were analysed as described above.

3 Results and discussion

Within 2 days after being placed on wood mulches, termites had tunneled through the entire Douglas-fir mulch, while most termites had remained on top of the neem mulches. By the fifth day, all of the neem mulches had been penetrated by tunneling termites. However, tunnels were largely limited to the top and sides of each vial, with extensive interior tunneling only through the Douglas-fir mulch. Moribund termites could be seen in the neem mulches, although termite mortality did not differ among the treatments at the end of the 14 day period (table 1). The relatively poor survival of *C. formosanus* in *P. menziesii* sawdust was somewhat surprising, since this species is usually considered highly susceptible to subterranean termite attack (SU and TAMASHIRO, 1987). However, SMYTHE and CARTER (1970) also reported poor termite survival in *P. menziesii* heartwood sawdust, and this variability may be attributable to intraspecific variation in heartwood extractive content.

Table 1. *Mortality of* C. formosanus *termites after 14 days of exposure to neem or Douglas-fir mulches*

Treatment	Termite mortality (%)
Douglas-fir heartwood	68.4 ± 12.1a
Neem (dead branches)	77.6 ± 26.6a
Neem (live branches)	67.2 ± 14.9a
Neem roots	60.4 ± 5.18a

Means (±SD) of 5 replicates of 50 termites each. Means followed by the same letter are not significantly different at the 5% level.

When termites were held in jars containing sand and wood or bark pieces, significantly greater mortality resulted from exposure to neem bark than to either neem wood or Douglas-fir (table 2). Termites also fed significantly less on both neem wood and bark than on the Douglas-fir controls. Thus, *A. indica* has antifeedant properties towards *C. formosanus*, and should be considered a less preferred, although not completely resistant, substrate for termite feeding. This significant, but limited, feeding deterrence is consistent with that reported by GRACE and YATES (1992) when *C. formosanus* workers were exposed to azadirachtin concentrations of 100 ppm or greater. Further comparison of our results with those of GRACE and YATES (1992) indicates that the toxicity of neem bark to *C. formosanus* is likely attributable to extractives other than azadirachtin.

Our results suggest that mulching with neem may not be a very successful strategy for preventing attack by *C. formosanus* on susceptible plants. Similarly, LOGAN (1992) reported that woody residues surrounding tree seedlings in a nursery in South Africa reduced damage by smaller Macrotermitinae species, but not by *Macrotermes* sp., and led to increased damage by *Coptotermes* sp. in Malaysia. However, the antifeedant properties of neem wood and bark, and toxicity of neem bark, lend support to the use of neem trees for arbori-

Table 2. *Feeding and mortality of* C. formosanus *termites after 28 days of exposure to neem wood or bark*

Treatment	Termite mortality (%)	Wood mass loss (g)
Douglas-fir wood	12.5 ± 5.4a	1.88 ± 0.17a
Neem wood	27.1 ± 6.9a	0.72 ± 0.99c
Neem bark	56.4 ± 11.9b	1.25 ± 0.24b

Means (± SD) of 6 replicates of 400 termites each. Means within each column followed by the same letter are not significantly different at the 5% level.

culture in areas where termites are a problem. Like *Acacia albida* (MITCHELL, 1992) and other tree species, *A. indica* should be considered less susceptible, but certainly not immune to termite attack. Local site conditions and environmental stress are also known to affect both the general susceptibility of trees to termite attack (AMADALO, 1992) and the production of insecticidal compounds by *A. indica* (SCHMUTTERER, 1990a). Screening of *A. indica* strains from various locales could lead to identification of strains with higher concentrations of wood and bark extractives and greater termite tolerance.

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