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A comparison of the resistance of pyrethroid-treated wood to damage by *Coptotermes acinaciformis* in Australia and *C. formosanus* in China and the USA

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ABSTRACT

Field trials, using a single aboveground method of exposure, were used to assess a range of retentions of two pyrethroids (bifenthrin and permethrin) in *Pinus radiata* D. Don sapwood against two species of *Coptotermes* in three countries to provide directly comparable results. *Coptotermes acinaciformis* (Froggatt) in Australia, *C. formosanus* Shiraki in China and *C. formosanus* in the USA consumed similar amounts of non-treated wood. Both termite species demonstrated a dose response to wood treated with the two pyrethroids; less wood was consumed as retention increased. Overall, *C. acinaciformis* consumed relatively little of the treated wood. In comparison, *C. formosanus* consumed 20-90% of the wood treated at the lowest retentions of the pyrethroids evaluated. Results indicated that *C. acinaciformis* was more sensitive to pyrethroid toxicity/repellency compared with *C. formosanus*. Employing a single aboveground method of exposure across three countries, that suited both species of *Coptotermes*, made it possible to determine unambiguously the actual differences between the species in their tolerances to the two pyrethroid insecticides.

Keywords: bifenthrin, *Coptotermes acinaciformis*, *C. formosanus*, permethrin, pyrethroids, termites

1. INTRODUCTION

Species of the genus *Coptotermes* Wasmann are among the most important pests of wood and wood products. They commonly infest live trees, consuming both sapwood and heartwood (Gay and Calaby 1970; Cowie *et al* 1989; Creffield 1996). There is considerable variation in the natural termite resistance between the sapwood and heartwood of timbers (Ruyooka and Groves 1980; Kennedy *et al* 1996; Peters and Fitzgerald 2004). In addition, to prevent or minimize damage to many susceptible timbers by termites, a wide range of wood preservative formulations is available. Pyrethroids are among the most widely used insecticides in wood preservation, used either alone or in combination with other biocides (Schultz *et al* 2007). Efficacy evaluations of pyrethroids are typically conducted on a country-by-country basis, but it has been unclear to what extent it is possible to compare performance data against one species of termite from one location/country with those from another species in a different location/country.

The only known previous attempts to compare the response of different *Coptotermes* species to pyrethroids were laboratory bioassays in which *C. acinaciformis* in Australia and *C. formosanus* in China were exposed to duplicate sets of insecticide-treated wood specimens. However, the results were difficult to interpret due to differences in testing protocols between laboratories. Accordingly, it was decided to adopt an established field test method (Scown and Creffield 2009) for the comparative study reported here, that was considered suitable for both *C. acinaciformis* and *C. formosanus*. The identical protocol was followed at all field locations. Respective consumption rates of softwood test specimens treated to several retentions with each of two pyrethroids were used to compare the responses of *C. acinaciformis* and *C. formosanus*.

2. MATERIALS AND METHODS

Full details of the materials and methods used in the work are given in Creffield *et al* (2013). A brief overview is given in the following.

Test specimens measuring 25 x 25 x 100 mm were cut from *Pinus radiata* D. Don sapwood grown in Australia, and randomly allocated into groups prior to treatment. Treatments were non-treated controls, solvent (white spirit) controls, bifenthrin and permethrin. After treatment, excess solution was wiped from the surfaces of the specimens and then the latter were weighed to determine pyrethroid active ingredient (a.i.) retentions; nominal target and actual retentions, are shown in Table 1.

Table 1: Mean (range) of actual retentions of bifenthrin and permethrin a.i. in treated specimens (N = 22).

Preservative	Nominal retention [g a.i./m^3]	Actual retention [g a.i./m^3]	Actual retention [% wt:wt (x10^{-3}), OD*]
Bifenthrin	0.5	0.49 (0.35-0.55)	0.11 (0.08-0.14)
	1.0	1.01 (0.91-1.09)	0.23 (0.20-0.26)
	2.0	1.99 (1.82-2.19)	0.45 (0.36-0.54)
	5.0	5.03 (4.46-5.60)	1.26 (0.94-2.40)
	10.0	9.99 (9.12-10.77)	2.25 (1.88-2.48)
	20.0	20.17 (18.44-21.59)	4.66 (4.04-5.17)
Permethrin	2.5	2.48 (2.29-2.72)	0.57 (0.50-0.75)
	5.0	4.79 (4.53-5.48)	1.08 (0.96-1.35)
	10.0	10.30 (9.39-10.94)	2.46 (1.96-2.79)
	20.0	19.86 (18.33-21.78)	4.69 (3.94-5.41)
	45.0	46.05 (44.10-48.34)	10.75 (9.54-11.80)
	90.0	88.34 (80.31-94.79)	19.57 (17.30-22.10)

*OD = oven dried

After air-drying for four weeks, treated test specimens were artificially weathered to satisfy aboveground and protected exposure conditions (Australian Hazard Class H2) by vacuum oven drying for five days at 40°C and 0.04 mBar, as specified in the Australasian Wood Preservation Committee Protocols for Assessment of Wood Preservatives (AWPC 2007) (note that H2 exposure conditions are equivalent to American use categories UC1 and UC2 (AWPA 2011)). After removal from the vacuum ovens, test specimens were cooled in desiccators before being weighed to obtain initial weights.

An established aboveground field method for exposing treated wood specimens to termites in an H2 situation was used (Scown and Creffield 2009). The target species of *Coptotermes* was aggregated prior to installation of the field trials to ensure rapid discovery of the replicate sets of specimens confined within exposure containers. The aggregation sites were prepared by burying layers of wooden slats of a palatable Australian timber adjacent to active foraging sites. Infestation of the aggregation wood typically occurred within four weeks. Once the slats became infested, previously backfilled soil and protective plastic sheeting were removed to allow easy placement of the exposure containers on top of the slats.

The rectangular exposure containers had stainless steel sides (300 x 300 x 450 mm high) and a stainless steel mesh floor (25 x 25 mm square apertures) located 80 mm above the base of the container. The cavity below the mesh floor allowed for additional palatable wood to be placed in contact with the top of the buried aggregation wood, which sustained the presence of termites throughout the duration of the field trial. Vented stainless steel lids sealed the containers. Each container enclosed one replicate set of test specimens i.e. one from each treatment, for a total of 14 specimens per container. Test specimens were arranged in three parallel horizontal tiers separated within and between tiers by wooden strips of *P. radiata* sapwood. This arrangement minimized potential between test specimen cross-contamination effects.

The trials were installed at four locations each for *C. acinaciformis* and *C. formosanus*. All *C. acinaciformis* sites were in Australia. Three sites were in tropical Australia near Darwin in the Northern Territory, where this termite builds mounds (Sites 1, 2, 3). The fourth site was near Griffith in New South Wales, where this termite either nests in tree trunks or underground. Three of the *C. formosanus* sites were in the USA, in Baton Rouge and New Orleans, both in Louisiana, and near Poplarville in Mississippi. The fourth site was near Guangzhou in Guangdong Province in southern China. At all sites, three exposure containers were installed. For each location, the exposure containers were placed more than 100 metres apart to target different termite colonies. Field trials commenced when the exposure containers were placed on top of the aggregation wood and were continued until the termites vacated the exposure containers, which usually occurred after all palatable wood had been more or less completely consumed. Termites vacated containers after approximate durations of three to four months at the Darwin, China, and USA sites and six months at the Griffith site. At the conclusion of the trials, specimens were cleaned, vacuum oven dried for five days at 40°C and 0.04 mBar and cooled in desiccators prior to obtaining final weights.

Percentage weight loss data (wood consumption) were statistically analysed to determine the significance of any differences in weight losses between treatments. Full details of the analyses employed and results are provided in Creffield *et al* (2013).

3. RESULTS AND DISCUSSION

A summary of mean wood consumption (g) for all treatments at the conclusion of the field trials is given in Table 2. When averaged over species and locations, termites consumed more non-treated (24.47g) and solvent-treated (26.45g) wood compared with bifenthrin-treated (4.02g) and of permethrin-treated (3.11g) wood. *C. acinaciformis* and *C. formosanus* consumed similar quantities of untreated and solvent-treated control wood. For bifenthrin-treated wood, *C. acinaciformis* consumed almost no wood, whereas *C. formosanus* consumed approximately one third of the available wood. A similar, if less extreme, trend was observed for permethrin-treated wood.

Statistical analysis of the percentage of wood consumed found that two factors, treatment and termite species, and the covariates dose and initial mass, were significant, and that location was not significant. The analysis explained approximately 74% of the variation observed ($r^2 = 0.737$).

The relative size of the *F* ratios indicated that treatment was more important than dose, which was more important than species, which was more important than initial mass.

Table 2: Mean ± SEM*, weight of specimens consumed by both *Coptotermes* species in field trials (N=12 for *C. acinaciformis*, 10 for *C. formosanus*).

Treatment	**Retention [g a.i./m³]**	**Weight loss [g]**	
		C. acinaciformis	***C. formosanus***
Non-treated control	0.0	25.7 ± 1.2	23.0 ± 0.9
Solvent control	0.0	26.9 ± 0.8	25.9 ± 0.7
Bifenthrin	0.5	1.2 ± 0.2	23.0 ± 1.7
	1.0	0.5 ± 0.1	16.5 ± 1.9
	2.0	0.4 ± 0.1	8.3 ± 2.2
	5.0	0.3 ± 0.1	1.1 ± 0.4
	10.0	0.2 ± 0.1	0.4 ± 0.0
	20.0	0.2 ± 0.1	0.4 ± 0.0
Permethrin	2.5	6.6 ± 2.5	17.8 ± 2.0
	5.0	0.6 ± 0.2	9.8 ± 2.8
	10.0	0.5 ± 0.1	1.8 ± 0.8
	20.0	0.4 ± 0.1	0.4 ± 0.1
	45.0	0.3 ± 0.1	0.4 ± 0.0
	90.0	0.3 ± 0.1	0.4 ± 0.0

*Standard Error of the Means

Results from these field trials suggest that specific retentions of pyrethroids in *P. radiata* sapwood that demonstrate efficacy against *C. formosanus* are also most likely to be equally efficacious against *C. acinaciformis*. However, the reverse may not necessarily be true, particularly at lower pyrethroid retentions. In addition, it is not possible to infer the relative responses of others within the genus *Coptotermes* (e.g., the widespread invasive pest *C. gestroi* and other Asian species such as *C. curvignathus* Holmgren and *C. intermedius* Silvestri from Africa) from the data presented here. Several studies have found large differences in tolerances to a range of insecticides, i.e., up to 16 times greater survival between colonies of the same species and between different pest species of termites (Sands 1962; Lenz and Dai 1985; Osbrink et al. 2001; Delgarde and Rouland-Lefèvre 2002). Neither is it possible to consider the effect of these pyrethroids (bifenthrin and permethrin) against other termite species.

The Australasian Wood Preservation Committee Protocols for Assessment of Wood Preservatives (AWPC 2007) state that a given preservative or insecticidal formulation may be considered to have successfully prevented damage to wood by a given termite species if the mean weight loss of treated specimens does not exceed 5%. Using this performance criterion for this study, bifenthrin was rated effective in preventing damage to *P. radiata* specimens at a retention of 1 g/m^3 for *C. acinaciformis* and at 5 g/m^3 for *C. formosanus*. A similar trend was observed for permethrin, with effective protection provided by a 5 g/m^3 retention for *C. acinaciformis* and a 10 g/m^3 retention for *C. formosanus* in the USA, but 25 g/m^3 in China.

The pyrethroid retentions which prevented damage by termites in this study are considerably lower than the required minimum retentions approved for the treatment of solid wood for use in Australia (Standards Australia 2010). This is because the minimum approved retentions set for these pyrethroids in Australia were not just based upon their efficacy against *C. acinaciformis* but also other species of termites including the more voracious *Mastotermes darwiniensis* Froggatt. Furthermore, higher retentions were required to offset the effects of chemical loss over time and to compensate for any potential under-treatment due to substrate variability, as is known for insecticides in treated soil (e.g., chemical type, initial concentration, soil type, soil pH and soil moisture content; Harris 1972; Baskaran *et al* 1999; Standards Australia 2000).

4. CONCLUSIONS

The results of these field trials showed that all populations of *Coptotermes* consumed >90% of the control wood specimens, but considerably less of the pyrethroid-treated wood specimens. However, consumption of the latter differed between species. The data demonstrated that native and introduced field populations of *C. formosanus* are more tolerant of low retentions of pyrethroids in wood compared with native field populations of *C. acinaciformis*.

This study demonstrated that a single method of field exposure was suitable for both target species of *Coptotermes*, thereby allowing valid comparison of efficacy data. This is highly advantageous, as once differences in methodology as a potential factor for differing results between species can be excluded, inherent responses of a given species of termite (e.g., tolerance to insecticides and/or level of aggressiveness towards different materials) can be more readily determined.

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