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COMPARISON OF NATURAL AND CONVENTIONAL INSECTICIDES AGAINST FORMOSAN TERMITES (ISOPTERA: RHINOTERMITIDAE)

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Abstract Five natural and 16 synthetic compounds were evaluated for termiticidal activity against the Formosan subterranean termite, *Coptotermes formosanus* Shiraki (Isoptera: Rhinotermitidae). The naphthoquinones menadione, plumbagin, and juglone, and the benzoquinones thymoquinone, and coenzyme Q_1 killed all the termites at their higher rates. However, these naturally derived compounds were generally less active when compared with the conventional insecticides: permethrin, cis-permethrin, trans-permethrin, cypermethrin, α-cypermethrin, ß-cypermethrin, bifenthrin, fenvalerate, cyfluthrin, ß-cyfluthrin, deltamethrin, tralomethrin, chlorpyrifos, propoxur, imidacloprid, and boric acid. Evaluated natural products displayed minimal termiticidal activity at < 0.5 % wt:wt. All of the synthetic insecticides caused 100 % mortality at < 0.05 % wt:wt except boric acid.

Key Words *Coptotermes formosanus*, natural products, termiticides

INTRODUCTION

The Formosan subterranean termite, *Coptotermes formosanus* Shiraki, was introduced into the United States in thousands of tons of wooden military cargo and ballast shipped back from the Asian theater following Word War II (La Fage, 1985). New Orleans, LA, USA was one of the most active ports of entry. Populations of Formosan termites flourish in the warm, humid climate of New Orleans, virtually blanketing the city over the last half century. *C. formosanus* commonly infests structures as well as living urban trees in the greater New Orleans area (Osbrink and Lax, 2003; Osbrink et al., 1999). Natural products are a promising source of compounds exhibiting pesticidal activities (Ibrahim et al., 2004; Lax and Osbrink, 2003; Maistrello et al., 2001a; b; Nix et al., 2003; Zhu et al., 2001a, b, 2003). Nature has produced a large variety of plants with an array of survival and defensive chemical strategies including insecticidal and antifeeding components (Duke et al., 2003). The chemical diversity found in plants yield active compounds with previously unknown modes of action against insects. Safe pesticides with new modes of action are needed both to delay the development of pesticide resistance and to help meet increasingly stringent health and environmental regulations (Anonymous, 2000). Although there are a very large number of studies on the constituents of plants, relatively small percentages of these compounds have been subjected to bioassay guided isolation.

Natural antitermitic compounds may have a different type of activity against different species of termites (Becker, 1975; Becker et al., 1972; Osbrink et al., 2001). If a chemistry is to be developed for use against *C. formosanus*, it must be evaluated against the same termite species. A number of antitermitic compounds or natural substrates may have been discounted in past studies because they did not compare well to pesticides which have since been banned or discontinued (Wolcott, 1951). These previously discarded compounds should be revisited. Therefore, natural products are an attractive research subject. Many synthetic pesticides are similar to naturally existing compounds e.g. pyrethroids and nicotinoids. Antitermitic studies are focused on investigating plants or woods for resistance or toxicity to *Coptotermes* spp. Such studies include investigations of wood and plant species from around the world (Beal et al., 1974; Bultman and Southwell, 1976; Carter and Camargo, 1983; Wilkins, 1992; Wolcott, 1950). A detailed review of natural products as pesticidal agents for control of *C. formosanus* is provided by Tellez et al. (2003).

The purpose of this research was to compare the termiticidal activity of the most active natural compounds with synthetic insecticides using modified plate tests.

MATERIALS AND METHODS

Termites from four colonies of *C. formosanus* were obtained from field sites in New Orleans, Louisiana, using bucket traps (Su and Scheffrahn, 1986), and maintained on spruce (*Picea* spp.) slats (10 x 4 x 0.5 cm) under conditions of ca. 100 % relative humidity and 26.6º C. Termites were identified using keys for soldier identification from Scheffrahn and Su (1994).

Preliminary screenings were conducted with extracts collected from plants or trees as follows. Dried plant materials (>100 g) were ground into powder and extracted for 1 minute in a blender consecutively with pentane, acetone, pentane: acetone: water (54: 44: 2), methanol, and water followed by soxhlet extraction with pentane, acetone, and methanol for 1 week with each solvent. Solvents were removed under vacuum except for water that was removed by freeze-drying. Quinones and synthetic insecticides were purchased from commercial sources (Aldrich, Milwaukee, WI and Chem Services, West Chester, PA, respectively) and dissolved in acetone. It was determined through these preliminary screenings that the quinonoids menadione (2-methyl-1,4-naphthoquinone or vitamin K3), plumbagin (2-methyl-5-hydroxy-1,4-naphthoquinone), juglone (5-hydroxy-1,4-naphthoquinone), and the benzoquinones thymoquinone, and coenzyme Q_1 (CoQ_1 or ubiquinone) were the most active of the natural products tested against *C. formosanus* (Tellez et al., 2003) and were tested here. The 16 synthetic insecticides chosen for comparison were the pyrethroids, permethrin, cis-permethrin, trans-permethrin, cypermethrin, ß-cypermethrin, α-cypermethrin, bifenthrin, fenvalerate, cyfluthrin, ß-cyfluthrin, deltamethrin, tralomethrin, the organophosphate chlorpyrifos, the carbamate propoxur (baygon), the chloronicotinyl imidacloprid, and lastly the inorganic boric acid.

One hundred µL of an acetone solution of the test compounds was pipetted onto pre-weighed air-dry 2.5 cm. diam. Whatman #1 filter paper. The acetone was allowed to evaporate from the filter paper for several hours. Treated filter paper disks were placed in plastic Petri dishes (35 x 10 mm) and moistened with 100-µL water. Twenty *C. formosanus* workers (3rd instar or greater as determined by size) and a single soldier were placed on each treatment. Treatments were replicated 4 times with termites for each replicate originating from a different *C. formosanus* colony. Petri dishes were maintained at ca. 100 % R.H. and 26.6º C. Filter paper disks receiving water alone served as controls. It was previously determined that the filter paper treated with acetone solvent alone had no discernible effect on termite mortality or consumption.

Data Analysis. Daily termite mortality was evaluated for 3 weeks. Consumption was determined by subtracting post-treatment from pre-treatment dried filter paper weights. Cumulative daily mortality and consumption (mean and standard deviation) were calculated from the four replicates (n = 21 termites) of each treatment. Treatments were compared using ANOVA and means separated using a protected Fisher least-significant difference (LSD) test ($P < 0.05$; PROC GLM, SAS Institute 1990). LSD means separations test followed transformation to arcsine square root percent mortality (SAS Institute 1990). Actual percent mortality is reported in the tables.

RESULTS AND DISCUSSION

The Naphthoquinones, menadione, juglone and plumbagin resulted in 100% mortality at ≥ 0.5%. (Table 1). Thymoquinone and coenzyme Q_1 (benzoquinones) showed 100% mortality at > 0.5% (Table 3). Reduced feeding was evident for these compounds at the higher concentrations, probably as a result of the induced mortality (Tables 2 and 4). Juglone, plumbagin, thymoquinone and coenzyme Q_1 showed numeric but non-significant increase in consumption at the lower application levels. Feeding stimulation is not unusual when filter paper is modified by treatment with compounds at levels not harmful to termites.

The use of plant derived compounds as termite control agents is not an original concept (Carter, 1976). Naphthoquinones and other related quinonoid compounds are one of the major natural product classes with varied biological activities (Ganapaty et al., 2004). Specifically, the naphthoquinones plumbagin and its close analogue juglone, compounds containing the juglone moiety, and menadione, have been previously shown to have termiticidal activity (Carter et al., 1978; Ganapaty et al., 2004; Tellez et al., 2003; Wolcott, 1947). Menadione has been shown to have direct effects on the activity of the rotenone sensitive NADH portion of the electron transport system (Briere et al., 2004). In this regard several quinone derivatives have been shown to differentially divert electron flow from mitochondrial respiratory chain complex I. This appears to be a potentially common mechanism among all of the most active natural quinonoid compounds against termites found in this study. Electron diverting properties make these compounds potentially biologically active. For

example, plumbagin has been shown to have a broad range of biological activities such as anti-cancer, anti-mutagenic, anti-microbial and anti-pest properties (Nahalka et al., 1998). Juglone is also proposed to disrupt growth and energy metabolism in soybean (*Glycine max* L.) and corn (*Zea mays* L.) through the electron transport functions in mitochondria (Hejl and Koster, 2004). This mode of action would appear to be molecule specific as other quinones tested showed little activity against *C. formosanus* (Tellez et al., 2003).

Table 1. Cumulative % mortality of *C. formosanus* on filter paper.

Treatment (% wt:wt)	% Mortality (Mean ± S.D.) [1] Days					
	1	3	7	11	16	21
Menadione						
0.5	81.7 ± 27.5A	100.0 ± 0.0A	100.0 ± 0.0A	100.0 ± 0.0A	100.0 ± 0.0A	100.0 ± 0.0A
0.1	0B	6.7 ± 7.6B	11.7 ± 16.1B	11.7 ± 16.1B	18.3 ± 12.6B	26.7 ± 11.6B
0.05	0B	0C	0B	0B	3.3 ± 2.9C	16.7 ± 15.3B
Untreated	0B	0C	1.3 ± 2.5B	1.3 ± 2.5B	1.3 ± 2.5C	1.3 ± 2.5B
Juglone						
0.5	100.0 ± 0.0A	100.0 ± 0.0A	100.0 ± 0.0A	100.0 ± 0.0A	100.0 ± 0.0A	100.0 ± 0.0A
0.1	63.3 ±32.2B	63.3 ± 32.2B	63.3 ± 32.2B	63.3 ±32.2B	63.3 ± 32.2B	76.7 ± 25.2B
0.05	31.7 ±30.6C	43.3 ± 22.6CB	43.3 ± 22.6CB	43.3 ± 22.6CB	43.3 ± 22.6CB	51.7 ±30.6CB
0.01	3.3 ± 2.9C	11.7 ± 7.6CD	16.7 ± 7.6CD	16.7 ± 7.6C	16.7 ± 7.6C	18.3 ± 10.4CD
Untreated	0C	0D	0D	1.3 ± 2.5C	1.3 ± 2.5C	1.3 ± 2.5D
Plumbagin						
0.5	100.0 ± 0.0A	100.0 ± 0.0A	100.0 ± 0.0A	100.0 ± 0.0A	100.0 ± 0.0A	100.0 ± 0.0A
0.1	88.3 ± 20.2A	88.3 ± 20.2A	88.3 ± 20.2AB	88.3 ± 20.2A	88.3 ± 20.2A	88.3 ± 20.2AB
0.05	51.7 ± 33.3B	53.3 ± 31.8B	58.3 ± 36.2B	58.3 ± 36.2B	58.3 ± 36.2B	58.3 ± 36.2B
0.01	1.7 ± 2.9C	6.7 ± 2.9C	8.3 ± 5.8C	1.7 ± 2.9C	6.7 ± 2.9C	10.0 ± 8.7C
Untreated	1.3 ± 2.5C	1.3 ± 2.5C	1.3 ± 2.5C	1.3 ± 2.5C	1.3 ± 2.5C	1.3 ± 2.5C

[1] Means within a column/treatment with the same letter are not significantly different, LSD: P > 0.05.

The active quinonoid compounds are all highly lipophilic with constituents that are strong electron acceptors, suggesting the cell membrane redox systems might be the main target of toxicity. Tested benzoquinones, thymoquinone and CoQ_1 affect the cellular redox state (NADH-NAD^+). CoQ_1 has a known electron transport function as part of Complex I in the inner mitochondrial membrane function. It may be expected that high concentrations of such quinones may cause a disruption of normal functioning of these cellular processes. Non-specific binding on hydrophobic enzyme sites could also have lethal effects. The short and flexible isoprenoid tail of CoQ_1 is likely to have the capability of non-physiological binding (Nakashima et al., 2002). Thus, a quinonoid ring such as those found in ubiquinones (specifically CoQ_1) and K vitamins (specifically K_3 or menadione) has the property of generally being lipophilic while still having an electron attracting part (Pal et al., 2004). Further structural activity comparisons should elucidate the nature of the toxicity of these compounds.

With the exception of inorganic boric acid, the synthetic insecticides tested showed 100% mortality at levels of ≤ 0.01% (Tables 5, 7, 9, 11, and 13). *Cis*-permethrin appeared slightly more active than permethrin and *trans*-permethrin (Table 5). ß-cypermethrin appeared more active than α-cypermethrin which was more active than cypermethrin (Table 7). ß-cyfluthrin did not appear to have higher activity than cyfluthrin (Table 9). The organophosphate chlorpyrifos appeared to have higher activity than the chloronicotinyl imidacloprid, which appeared more active than the carbamate propoxur (Table 13). Chlorpyrifos and imidacloprid had activity comparable to the most active of the pyrethroids. Boric acid acted as more of a chronic toxicant than an acute toxicant with 100% mortality occurring only at > 0.5% (Table 15) and a general non-significant reduction in feeding (Table 16). The non-significance may be an artifact attributed to the high standard deviation which occurred in the control because of high mortality in one of the replicates (Table 16). The lower concentration threshold for 100% mortality was not reached at 0.001% active ingredient wt:wt for ß-cypermethrin, tralomethrin,

Table 2. Filter paper consumed (Mean ± S.D.) by *C. formosanus*

Treatment	Sample (% wt:wt)	Consumption [1] (mg)
Menadione	0.5	2.9 ± 0.7B
	0.1	42.2 ± 20.4A
	0.05	54.6 ± 5.6A
Untreated	-	54.4 ± 20.7A
Juglone	0.5	4.7 ± 0.3C
	0.1	5.6 ± 3.5C
	0.05	32.7 ± 31.1BC
	0.01	71.3 ± 24.5AB
	0.001	80.4 ± 16.0A
Untreated	-	54.4 ± 20.7AB
Plumbagin	0.5	4.6 ± 1.5B
	0.1	4.7 ± 2.6B
	0.05	20.7 ± 25.2B
	0.01	69.1 ± 3.3A
	0.001	83.4 ± 17.7A
Untreated	-	54.4 ± 20.7A

[1] Means within a treatment with the same letter are not significantly different, LSD: P > 0.05.

Table 3. Cumulative % mortality of *C. formosanus* on filter paper.

Treatment (% wt:wt)	% Mortality (Mean ± S.D.) [1] Days					
	1	3	7	11	16	21
Thymoquinone						
1.5	96.7 ± 5.8B	100.0 ± 0.0B	100.0 ± 0.0B	100.0 ± 0.0B	100.0 ± 0.0B	100.0 ± 0.0B
0.5	0A	0A	1.7 ± 2.9A	6.7 ± 7.6A	10.0 ± 8.7A	18.3 ± 11.6A
0.1	0A	0A	0A	1.7 ± 2.9A	6.7 ± 7.6A	8.3 ± 10.4A
Untreated	0A	0A	0A	1.3 ± 2.5A	1.3 ± 2.5A	1.3 ± 2.5A
Coenzyme Q1						
1.5	41.7±7.6B	70.0±27.8B	80.0±34.6B	100.0±0.0B	100.0±0.0B	100.0±0.0B
0.5	3.3 ± 2.9A	3.3 ± 2.9A	3.3 ± 2.9A	3.3 ± 2.9A	5.0 ± 5.0A	8.3 ± 10.4A
0.1	0A	0A	0A	0A	0A	8.3 ± 2.9A
Untreated	0A	0A	0A	0A	1.3 ± 2.5A	1.3 ± 2.5A

[1] Means within a column/treatment with the same letter are not significantly different, LSD: P > 0.05.

cyfluthrin, ß-cyfluthrin, fenvalerate, and chlorpyrifos, indicating how extremely toxic to termites these chemicals are. Most of the synthetic organic insecticides did not act as feeding deterrents at levels below which they cause significant mortality (Tables 6, 8, 10, 12, and 14) with the exceptions of trans-permethrin (0.001%) and cypermethrin (0.001%) (Tables 6 and 8).

Specific levels of activity in a plate type test conducted in this study are not predictors of how a compound will perform in the role of protecting a structure in a field environment. The test as conducted here also provides little information regarding the stability and longevity of the chemicals. However, It does provide an indication of relative levels of innate termiticidal activity of the chemicals as well as some indication of the relative minimum levels of the chemical necessary to kill *C. formosanus*. Thus, a minimum cost could be calculated to determine economic feasibility of treating the areas around and under a structure using these natural products.

Table 4. Filter paper consumed (Mean ± S.D.) by *C. formosanus*

Treatment	Sample (% wt:wt)	Consumption [1] (mg)
Thymoquinone		
	1.5	0B
	0.5	93.1 ± 22.6A
	0.1	83.5 ± 28.3A
Untreated	-	54.4 ± 20.7A
Coenzyme Q1	1.5	16.9 ± 8.1B
	0.5	95.8 ± 15.9A
	0.1	101.6 ± 14.7A
Untreated	-	78.2 ± 26.7A

[1] Means within a treatment with the same letter are not significantly different, LSD: P > 0.05.

Table 5. Cumulative % mortality of *C. formosanus* on filter paper.

Treatment (% wt:wt)	% Mortality (Mean ± S.D.) [1] Days					
	1	3	7	11	16	21
Permethrin						
0.01	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A
0.001	0B	3.3 ± 5.7B	5.0 ± 5.0B	16.7 ± 7.6B	20.0 ± 5.0B	25.0 ± 8.7B
Untreated	0B	0B	0C	0C	0C	0C
cis-Permethrin						
0.05	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A
0.01	95.0 ± 5.0A	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A
0.001	36.7 ± 41.9B	68.3 ± 41.9B	76.7 ± 40.4A	78.3 ± 37.5A	78.3 ± 37.5A	78.3 ± 37.5A
Untreated	0C	0C	0B	1.70 ± 2.9B	6.70 ± 2.9B	6.70 ± 2.9B
trans-Permethrin						
0.05	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A
0.01	45.0 ± 47.7B	88.3 ± 20.2A	91.7 ± 14.4A	93.3 ± 11.6A	96.7 ± 5.8A	100 ± 0A
0.001	0C	6.7 ± 5.8B	11.7 ± 7.6B	11.7 ± 7.6B	16.7 ± 5.8B	21.7 ± 12.6B
Untreated	0C	0B	0C	1.7 ± 2.9C	6.7 ± 2.9C	8.3 ± 2.9C

[1] Means within a column/treatment with the same letter are not significantly different, LSD: *P* > 0.05.

This information has value in deciding whether to pursue the commercial development of the chemistry. For example, it requires substantially more of the most active quinonoids to kill termites than of the tested synthetic insecticides. Without the addition of regulatory, health, environmental, or other financial incentives into the cost benefit equation, continued pursuit of the less active compounds may not prove economically viable. Continued research involving chemical modification of these existing active natural compounds to increase their activity is valuable, as is continued bioassay-driven searches for novel new chemistries.

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Table 6. Filter paper consumed (Mean ± S.D.) by *C. formosanus*

Treatment	Sample (% wt:wt)	Consumption [1] (mg)
Permethrin		
	0.01	0B
	0.001	31.7 ± 14.3A
Untreated	--	50.9 ± 17.8A
cis-Permethrin		
	0.05	0B
	0.01	0B
	0.001	7.5 ± 4.9B
Untreated	--	50.9 ± 17.8A
trans-Permethrin		
	0.05	0C
	0.01	3.2 ± 3.6C
	0.001	22.1 ± 11.6B
Untreated	--	50.9 ± 17.8A

[1] Means within a treatment with the same letter are not significantly different, LSD: $P > 0.05$.

Table 7. Cumulative % mortality of *C. formosanus* on filter paper.

Treatment (% wt:wt)	% Mortality (Mean ± S.D.) [1] Days					
	1	3	7	11	16	21
Cypermethrin						
0.01	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A
0.001	0C	21.7 ± 10.4B	21.7 ± 10.4B	21.7 ± 10.4B	23.3 ± 11.6B	26.7 ± 15.3B
Untreated	0C	1.70 ± 2.9C	1.70 ± 2.9C	1.70 ± 2.9C	1.70 ± 2.9C	1.70 ± 2.9C
α-Cypermethrin						
0.05	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A
0.01	75.0 ± 21.8B	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A
0.001	53.3 ± 24.7C	81.7 ± 31.8A	81.7 ± 31.8A	83.3 ± 28.9A	85.0 ± 26.0A	88.3 ± 20.2A
Untreated	0D	0B	0B	1.7 ± 2.9B	6.7 ± 2.9B	8.3 ± 2.9B
β-Cypermethrin						
0.05	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A
0.01	71.7 ± 16.1B	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A
0.001	38.3 ± 12.6C	95.0 ± 8.7A	96.7 ± 5.8A	100 ± 0A	100 ± 0A	100 ± 0A
Untreated	0D	0B	0B	1.7 ± 2.9B	6.7 ± 2.9B	8.3 ± 2.9B

[1] Means within a column/treatment with the same letter are not significantly different, LSD: $P > 0.05$.

Table 8. Filter paper consumed (Mean ± S.D.) by *C. formosanus*

Treatment	Sample (% wt:wt)	Consumption [1] (mg)
Cypermethrin		
	0.01	0B
	0.001	20.4 ± 3.9B
Untreated	--	50.9 ± 17.8A
α-Cypermethrin		
	0.05	0B
	0.01	0B
	0.001	5.8 ± 2.6B
Untreated	--	42.1 ± 31.1A
β-Cypermethrin		
	0.05	0B
	0.01	2.9 ± 1.5B
	0.001	4.1 ± 0.9B
Untreated	--	50.9 ± 17.8A

[1] Means within a treatment with the same letter are not significantly different, LSD: $P > 0.05$.

Table 9. Cumulative % mortality of *C. formosanus* on filter paper.

Treatment (% wt:wt)	% Mortality (Mean ± S.D.) [1] Days					
	1	3	7	11	16	21
Deltamethrin						
0.001	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A
Untreated	0B	0B	0B	5.0 ± 0B	5.0 ± 0B	5.0 ± 0B
Tralomethrin						
0.01	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A
0.001	88.3 ± 20.2A	98.3 ± 2.9A	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A
Untreated	0B	0B	0B	1.7 ± 2.9B	6.7 ± 2.9B	8.3 ± 2.9B
Cyfluthrin						
0.01	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A
0.001	96.7 ± 5.8A	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A
Untreated	0B	0C	0C	0C	0C	0C
β-Cyfluthrin						
0.05	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A
0.01	98.3 ± 2.9A	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A
0.001	53.3 ± 2.9A	75.0 ± 8.7A	93.3 ± 5.8A	100 ± 0A	100 ± 0A	100 ± 0A
Untreated	0B	0B	0B	1.7 ± 2.9B	6.7 ± 2.9B	8.3 ± 2.9B

[1] Means within a column/treatment with the same letter are not significantly different, LSD: $P > 0.05$.

Table 10. Filter paper consumed (Mean ± S.D.) by *C. formosanus*

Treatment	Sample (% wt:wt)	Consumption [1] (mg)
Deltamethrin		
	0.001	0B
Untreated	--	30.7 ± 6.1A
Tralomethrin		
	0.01	3.8 ± 1.3B
	0.001	3.6 ± 0.9B
Untreated	--	50.8 ± 17.8A
Cyfluthrin		
	0.01	0B
	0.001	4.2 ± 2.1B
Uuntreated	--	50.9 ± 17.8A
β-Cyfluthrin		
	0.5	2.5 ± 2.5B
	0.1	12.2 ± 10.9B
	0.05	0B
	0.01	2.7 ± 1.0B
	0.001	1.8 ± 1.2B
Untreated	--	50.9 ± 17.8A

[1] Means within a treatment with the same letter are not significantly different, LSD: $P > 0.05$.

Table 11. Cumulative % mortality of *C. formosanus* on filter paper.

Treatment (% wt:wt)	% Mortality (Mean ± S.D.) [1] Days					
	1	3	7	11	16	21
Bifenthrin						
0.01	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A
0.001	63.3 ± 55.1A	71.7 ± 49.1A	73.3 ± 46.2A	73.3 ± 46.2A	76.7 ± 40.4A	76.7 ± 40.4A
Untreated	0B	0B	0B	0B	5.0 ± 0B	5.0 ± 0B
Fenvalerate						
3.77	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A
0.5	95.0 ± 5.0A	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A
0.1	90.0 ± 10.0A	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A
0.05	80.0 ± 10.0B	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A
0.01	26.7 ± 12.3C	70.0 ± 15.0B	88.3 ± 10.4A	93.3 ± 7.6A	96.7 ± 5.8A	100 ± 0A
0.001	0D	10.0 ± 8.7C	18.3 ± 11.6B	21.7 ± 15.3B	23.3 ± 12.6B	100 ± 0A
Untreated	0D	1.67 ± 2.9D	3.3 ± 5.8C	3.3 ± 5.8C	5.0 ± 8.7C	6.7 ± 11.6C

[1] Means within a column/treatment with the same letter are not significantly different, LSD: $P > 0.05$.

Table 12. Filter paper consumed (Mean ± S.D.) by *C. formosanus*

Treatment	Sample (% wt:wt)	Consumption [1] (mg)
Bifenthrin		
	0.01	0A
	0.001	18.2 ± 25.5AB
Untreated	--	42.1 ± 31.1B
Fenvalerate		
	3.77	0C
	0.5	3.5 ± 1.8C
	0.1	4.2 ± 1.3C
	0.05	3.0 ± 1.7C
	0.01	5.3 ± 0.8C
	0.001	13.7 ± 4.5B
Untreated	--	30.8 ± 6.1A

[1] Means within a treatment with the same letter are not significantly different, LSD: $P > 0.05$.

Table 13. Cumulative % mortality of *C. formosanus* on filter paper.

Treatment (% wt:wt)	% Mortality (Mean ± S.D.) [1] Days					
	1	3	7	11	16	21
Propoxur						
0.05	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A
0.01	83.3 ± 28.9A	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A
0.001	10.0 ± 13.2B	21.7 ± 22.6B	23.3 ± 20.2B	30.3 ± 27.8B	38.3 ± 22.6B	38.3 ± 22.6B
Untreated	0B	0C	0C	1.7 ± 2.9C	6.7 ± 2.9C	8.3 ± 2.9C
Chlorpyrifos						
0.001	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A
Untreated	0B	0B	3.33 ± 5.8B	8.33 ± 10.4B	8.33 ± 10.4B	11.7 ± 10.4C
Imidacloprid						
0.1	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A
0.05	80.0 ± 22.9B	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A
0.01	80.0 ± 8.7B	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A
0.001	31.7 ± 10.4C	55.0 ± 5.0B	80.0 ± 17.3B	81.7 ± 16.1B	91.7 ± 14.4A	91.7 ± 14.4A
Untreated	0D	0C	0C	1.7 ± 2.9C	6.7 ± 2.9B	8.3 ± 2.9B

[1] Means within a column/treatment with the same letter are not significantly different, LSD: $P > 0.05$.

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Table 14. Filter paper consumed (Mean ± S.D.) by *C. formosanus*

Treatment	Sample (% wt:wt)	Consumption [1] (mg)
Propoxur		
	0.05	0B
	0.01	4.9 ± 1.4B
	0.001	39.3 ± 20.5A
Untreated	--	47.1 ± 14.2A
Chlorpyrifos		
	0.001	0B
Untreated	--	42.1 ± 31.1A
Imidacloprid		
	0.1	0B
	0.05	7.1 ± 1.8B
	0.01	6.2 ± 1.2B
	0.001	6.7 ± 2.1B
Untreated	--	34.6 ± 21.4A

[1] Means within a treatment with the same letter are not significantly different, LSD: $P > 0.05$.

Table 15. Cumulative % mortality of *C. formosanus* on filter paper.

Treatment (% wt:wt)	% Mortality (Mean ± S.D.) [1] Days					
	1	3	7	11	16	21
Boric Acid						
0.56	36.7 ± 18.9A	76.7 ± 20.8AB	100 ± 0A	100 ± 0A	100 ± 0A	100 ± 0A
0.5	23.3 ± 20.2A	56.7 ± 42.5AB	60.0 ± 40.0AB	65.0 ± 37.8AB	66.7 ± 38.2AB	68.3 ± 38.8AB
0.1	16.7 ± 28.9A	50.0 ± 42.7AB	60.0 ± 42.7AB	60.0 ± 42.7AB	60.0 ± 42.7AB	60.0 ± 42.7AB
0.05	16.0 ± 23.9A	48.0 ± 41.6AB	58.1 ± 40.8AB	58.1 ± 40.8AB	58.1 ± 40.8AB	58.1 ± 40.8AB
0.01	30.0 ± 52.0A	48.3 ± 45.4AB	48.3 ± 45.4AB	48.3 ± 45.4AB	48.3 ± 45.4AB	50.0 ± 44.4AB
0.001	18.3 ± 23.6A	48.3 ± 44.8AB	50.0 ± 43.6AB	50.0 ± 43.6AB	50.0 ± 43.6AB	50.0 ± 43.6AB
Untreated	0A	1.7 ± 2.9B	1.7 ± 2.9B	1.7 ± 2.9B	1.7 ± 2.9B	1.7 ± 2.9B

[1] Means within a column/treatment with the same letter are not significantly different, LSD: $P > 0.05$.

Table 16. Filter paper consumed (Mean ± S.D.) by *C. formosanus*

Treatment	Sample (% wt:wt)	Consumption [1] (mg)
Boric Acid		
	0.56	4.2 ± 1.4A
	0.5	18.8 ± 20.3A
	0.1	10.8 ± 8.0A
	0.05	4.4 ± 1.7A
	0.01	7.9 ± 4.1A
	0.001	9.2 ± 5.2A
Untreated	--	42.1 ± 31.1A

[1] Means within a treatment with the same letter are not significantly different LSD: $P > 0.05$

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