Repellency and Toxicity of Mint Oil to American and German Cockroaches (Dictyoptera: Blattidae and Blattellidae)[1]

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ABSTRACT The repellency and toxicity of mint oil to American, *Periplaneta americana* (L.), and German, *Blattella germanica* (L.), cockroaches were evaluated in a series of laboratory experiments. In topical application experiments, mint oil was toxic to both species with toxicities (LD_{50}s) of 2.57 (1.98–4.20) in 10 μl and 3.83 (2.35–7.34)% in 2 μl for American and German cockroaches, respectively. In continuous exposure experiments, Mortality (LT_{50}) values for American cockroaches ranged from 246.8 min with 3% mint oil to 64.2 min with 100% mint oil. LT_{50} values for German cockroaches ranged from 318 to 5.6 min for 3% and 30% mint oil, respectively. American and German cockroaches had knockdown (KT_{50}) values of ≈7.4 and 9.2 h, respectively, when fumigated with 50 μl of 100% mint oil; 100% of both species were killed after 24 h. Mint oil deposits were ≈100% repellent in Ebeling choice boxes to both species during each day of the 14-d experiment. Mint oil-based formulations could provide another integrated pest management tool for cockroach management, especially in situations in which conventional insecticides would be inappropriate.

KEY WORDS *Blattella germanica*, *Periplaneta americana*, mint oil, essential oil, Ebeling choice box, toxicity

American, *Periplaneta americana* (L.), and German, *Blattella germanica* (L.), cockroaches remain two of the most important insect species to homeowners and in food-handling facilities (Bennett et al. 1997). Even though a wide variety of insecticidal products are available for cockroach control, most contain synthetic organic insecticides. With homeowner's increased awareness and concern about traditional insecticides, there is a greater potential for use of less toxic materials for cockroach control.

Naturally occurring insecticides have been used in pest control for centuries (Ebeling 1971, Coats 1994). Many of these compounds, including alkaloids, quinones, essential oils (including terpenoids), glycosides, and flavonoids, are secondary plant substances (Raven et al. 1992). Monoterpenoids are present in cedar, citrus, eucalyptus, mints, and a variety of spices. Many monoterpenoids are

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used as cosmetic, food, and pharmacological additives where they provide flavors and fragrances. Not unexpectedly, these compounds also induce a variety of responses in insects. For example, several monoterpenoids (Inazuka 1982) and cedar oils (Appel & Mack 1989) are repellent to German cockroaches, affect insect growth and development (Hink & Fee 1986, Karr & Coats 1992), or are acutely toxic to insects (Smith 1965, Coyne & Lott 1976, Coats et al. 1991, Rice & Coats 1994). Monoterpenoids are considered neurotoxic because of their speed of action and their effects on neurotransmission (Coats et al. 1991).

The purpose of this study was to determine the repellency and toxicity of mint oil against American and German cockroaches. Toxicity was determined using topical application and continuous exposure methods. Repellency was determined using Ebeling choice boxes and was compared with conventional insecticides.

Materials and Methods

Insects. Insecticide-susceptible American and German cockroaches (American Cyanamid Co., Clifton, New Jersey) were used in the laboratory experiments. Cockroaches were reared in plastic trash cans with cardboard harborage at 25–28°C and 40%–55% RH, were exposed to a photoperiod of 12:12 (L:D) h, and were supplied water and dry dog chow (Purina Dog Chow, Ralston Purina, St. Louis, Missouri) *ad libitum*. Adult males were used in both toxicity and choice box tests. Cockroaches were anesthetized briefly (<5 min) with CO_2 to facilitate handling.

Toxicity tests. Corn mint, *Mentha arvensis* L., oil with a density of 882.54 μg/μl was obtained from Woodstream Corporation, Lititz, Pennsylvania. The oil contained 24.79% *l*-menthol, 24.83% menthone, 8.55% isomenthone, 3.56% neomenthone, and a variety of other terpenoids each comprising <1% of the mixture. Serial dilutions of a stock (100%) mint oil extract were prepared in Fisher Scientific Certified ACS acetone (99.7% purity; Fisher Scientific, Fair Lawn, New Jersey) and were used in both topical application and continuous exposure bioassays. For the topical application experiment, at least four concentrations of mint oil that produced between 1% and 100% mortality were used. Either 2 or 10 μl (for German or American cockroaches, respectively) of a concentration were applied to the abdominal sternites with a Burkard Manufacturing Co. hand microapplicator (Hertfordshire, United Kingdom). A minimum of 60 cockroaches were used for each concentration. After treatment, groups of 10 cockroaches were placed in 0.95-liter glass jars with a small (about 1 cm) piece of moistened cotton wick. The upper inside surface of the jar was lightly greased with petroleum jelly to prevent escape. Mortality was assessed 24 h after treatment and was scored as the inability of a cockroach to move when prodded. There were two different control groups: one treated with either 2 or 10 μl of acetone and the other with either 2 or 10 μl of mineral oil.

Continuous-exposure bioassays were conducted by pipetting 1 ml of a mint oil concentration (prepared as above) into the bottom of a 9-cm diameter glass petri dish and by allowing the acetone to completely evaporate in a laboratory hood (≈1 h). Six petri dishes with either 3 (American) or 10 (German) cockroaches were used for each concentration. Mortality (see above) was assessed after 15, 30, 60, 120, and 240 min, and 24 h of continuous exposure to the residue.

Fumigant activity of mint oil was assessed by sealing either 6 (American) or 10 (German) adult male cockroaches in 0.95-liter glass jars with a 1-cm diameter cotton ball treated with 50 μl of 100% mint oil. Mint oil was injected into the center of each cotton ball to allow volatilization while preventing the cockroaches from contacting the residue. Knockdown (inability to move in a coordinated manner) was recorded hourly, and mortality was recorded at 24 h. Control jars had cockroaches and an untreated cotton ball. There were 6 mint oil and 6 control replicates for each species.

Choice box tests. Cockroach repellency and mortality were determined in Ebeling choice boxes (Ebeling et al. 1966) as described by Appel (1990, 1992). Food and water were placed in the lighted compartment of the choice box. Mint oil (2 ml of stock solution) was pipetted onto an aluminum foil-covered insert (15 × 30.5 × 0.5 cm) that fit snugly into the floor of the dark compartment. Control boxes were also fitted with aluminum foil-covered inserts, but were treated with 2 ml of acetone. Both mint oil- and acetone-treated inserts were dried for 1 h under a laboratory fume hood before being placed into choice boxes. Either 10 American or 20 German cockroaches were released into the untreated compartment of the choice box and were allowed to enter the treated compartment after 4 h. Cockroaches were able to move freely between the dark (treated) and the lighted (untreated) compartments.

Choice boxes were exposed to a photoperiod of 12:12 (L:D) h at 25–28°C. Banks of white florescent lights were 1.6 m above the choice boxes and produced a light intensity in the untreated compartment of 300–350 lux (INS Digital Lux Meter, Markson Scientific, Phoenix, Arizona). The number of live and dead cockroaches in each compartment at 3 to 4 h into the photophase was recorded daily for 14 d. Repellency was defined as the mean percentage of live cockroaches present in the light compartment during the photophase. Six replicates were used for each treatment in a completely randomized design.

Data analysis. Mortality (LT_{50}) in the continuous exposure, and knockdown (KT_{50}) in the fumigation tests were analyzed by probit analysis for correlated data (Throne et al. 1995) because multiple observations were taken on the same individuals. Probit analysis for independent data (SAS Institute 1985) was used to estimate the toxicity (LD_{50}) in the topical application tests. Significant differences in LD_{50}, LT_{50}, and KT_{50} were based on nonoverlap of the 95% confidence intervals (CI). A three parameter exponential decay model of the form: $LT_{50} = a\,[exp(-bx)] + c$, was used to quantify the relationship between LT_{50} and mint oil concentration in the continuous exposure tests (SigmaPlot 5.0; SPSS 1998). In this equation, LT_{50} is the estimated time (min) to reach 50% mortality, a is the estimated augmentation LT_{50} (min) of an untreated control population (i.e., a population treated with a concentration of 0%), b is the rate constant, and c is the asymptotic limit of the minimum LT_{50} for a population exposed to a concentration of 100%. The numerical value of the LT_{50} at 0% concentration is $a + c$ and defines the y-intercept of the model. Biologically, a represents the natural mortality, in LT_{50} terms, of a control population, and c represents the minimum time, again in LT_{50} terms, necessary to kill at the maximum concentration. Speed of penetration, time required to reach the active site(s), and the mechanism of toxicity all contribute to the value of c. This regression model was selected because a linear model was not significant ($P > 0.1$), an exponential model closely resembled a plot of the data, one and two parameter exponential models were not significant ($P > 0.05$), but had increasing R^2 values, and additional variables did not add significantly to the P or R^2 values. Repellency (percentage of live cockroaches in the light side of the choice box) was analyzed using a Mann-Whitney rank sum test (SigmaStat 2.03; Jandel Scientific 1997).

Results

Toxicity. When applied topically, mint oil was toxic to both American and German cockroaches. However, mint oil concentrations ≤1% did not cause any mortality at 24 h for either species. The LD_{50} value was 10 μl of 2.57% mint oil for American cockroaches and 2 μl of 3.83% mint oil for German cockroaches (Table 1). Homogeneity of response (slope of the log-dose probit relationship) was 9.36 for American cockroaches and 5.95 for German cockroaches. There was no control mortality for both species.

In the continuous exposure tests, LT_{50} values for American cockroaches ranged from 469.9 min for 3% mint oil to 10.4 min for 30% mint oil (Table 2). LT_{50} values for German cockroaches ranged from 3,318 to 1.0 min for 3% and 100% mint oil, respectively (Table 2). As with the topical application tests, mint oil concentrations ≤1% did not cause any mortality and there was no control mortality. LT_{50} values for both species declined exponentially with increasing concentration of mint oil. For American cockroaches, LT_{50} = 1,598 (±15) {exp[-0.42 (±0.003) x]} + 10.73 (±0.32); F = 368,679; df = 2, 3; P = 0.0012; R^2 = 0.999; residual mean square error = 0.21. For German cockroaches, LT_{50} = 31,700 (±3,600) {exp[-0.75 (±0.038) x]} + 3.6 (±2.6); F = 4,296,766; df = 2, 3; P = 0.001; R^2 = 0.999; residual mean square error = 13.83. Both models indicate that mint oil has relatively low toxicity at 3%, but toxicity increases at a threshold value of about 10% and increases slightly with increasing concentration.

American and German cockroaches had KT_{50} values of 7.4 and 9.2 h, respectively, when held in sealed jars with 50 μl of 100% mint oil (Table 3). Mortality of both species was 100% after 24 h of exposure to the mint oil; no control knockdown or mortality was observed.

Repellency. Mean repellency of male German cockroaches exposed to mint oil ranged from 92.3% to 100%, and was 100% for male American cockroaches (Fig. 1). Control repellency over the entire 14-d experiment was 2.02% ± 0.19% for American and 13.3% ± 2.5% for German cockroaches. Using daily means as replicates, mint oil was significantly repellent to both American [Mann-Whitney rank sum test; T = 301.00; n (smaller) = 14, n (larger) = 14; P < 0.001] and German cockroaches [Mann-Whitney rank sum test; T = 105.00; n (smaller) = 14, n (larger) = 14; P < 0.001].

Discussion

In concentrations of ≥3%, mint oil is toxic and repellent to both American and German cockroaches. Mint oil also volatilizes rapidly in an open environment unlike most conventional insecticides and leaves little or no residue (Unpublished data). These characteristics, together with its relatively low mammalian toxicity (Reynolds 1982, Dreisbach 1983) and wide spread use in perfumery, liqueurs, flavorings, cough drops, and as a topical anti-puritic, make mint oil an ideal insecticide for the rapid control of insect pests in areas where conventional insecticides are not appropriate.

TABLE 1. Toxicity of mint oil applied topically to adult male American and German cockroaches.

Species	*n*	Slope ± SE	LD_{50}, % (95%CI)	χ^2	*P*
American	60	9.36 ± 1.34	2.57 (1.98–4.20)	89.31	0.0001
German	60	5.95 ± 0.72	3.83 (2.35–7.34)	67.78	0.0001

Mint oil was applied in 10 µl for American cockroaches and 2 µl for German cockroaches.

Unlike conventional insecticides such as carbamates, organophosphates, and pyrethroids, mint oil is much less toxic and therefore requires greater concentrations. For example, bendiocarb, chlorpyrifos, and cyfluthrin have LD_{50} values of 10.89, 3.70, and 0.53 µg/g, respectively, for insecticide-susceptible male German cockroaches (Abd-Elghafar et al. 1990) compared with 1,126.71 µg/g for mint oil. Even though mint oil was more toxic to American (LD_{50} of 250.50 µg/g) than German cockroaches, conventional insecticides are also generally more toxic to American cockroaches (Cornwell 1976). These relatively large LD_{50} values are similar to those found by Lee et al. (1997) for a variety of monoterpenoids tested against adult house flies, *Musca domestica* L. Assuming a mean body mass of 0.0175 g per fly (Liu & Scott 1995), the LD_{50} value for *l*-menthol is 8,400 µg/g.

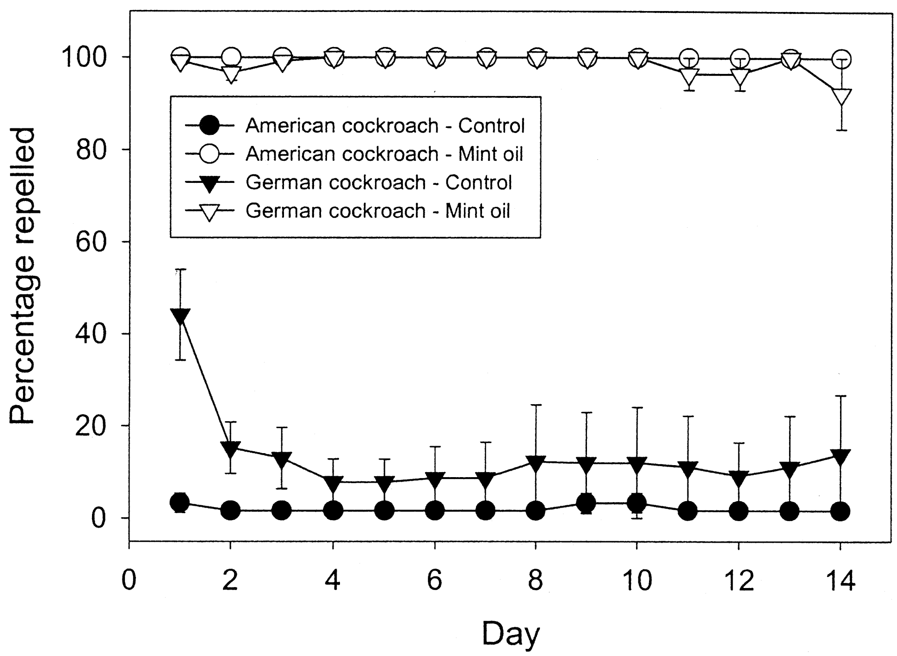

Fig. 1. Repellency of mint oil to American and German cockroaches determined in Ebeling choice boxes. Points represent means ± SE of six replicate boxes containing either 10 American or 20 German cockroaches.

TABLE 2. Contact toxicity of mint oil to adult male cockroaches exposed continuously in glass petri dishes.

Species	Concentration (%)	n	Slope ± SE	LT_{50}, min (95%CI)	χ^2	P
American	3	18	0.50 ± 0.28	469.89 (50.44–1.46 × 10^9)	3.12	0.0942
	10	18	5.68 ± 1.24	35.79 (28.23–45.45)	3.30	0.0271
	30	18	2.14 ± 0.79	10.41 (1.22–19.23)	2.05	0.0523
	100	18	0.98 ± 0.47	11.06 (1.89–84.46)	13.49	0.0003
German	3	60	5.06 ± 4.18	3,318 (1.99–7,845)	1.48	0.0463
	10	60	0.27 ± 0.11	20.65 (1.89–103.18)	313.66	0.0001
	30	60	2.18 ± 0.58	6.26 (1.71–10.12)	2.50	0.1451
	100	60	0.74 ± 0.51	1.03 (0.07–10.59)	1.05	0.2333

Mint oil vapor had fumigant effects against both American and German cockroaches. At a concentration of 46.45 $\mu g\ cm^{-3}$, the KT_{50} for both cockroach species was <10 h, and there was 100% mortality after 24 h of exposure. Menthol alone has a fumigant LC_{50} of 3.6 $\mu g\ cm^{-3}$ to house flies after a 14-h exposure (Rice & Coats 1994). Although fumigation is rarely used for cockroach control (Cornwell 1976, Bennett et al. 1997), there are specialized situations such as in kitchen furniture and equipment, in filing cabinets, and even some parts of sewerage systems where fumigation with mint oil may be appropriate.

A variety of compounds, including commercial repellents (Bodenstein & Fales 1976), conventional insecticides (Ebeling et al. 1966; Appel 1990, 1992), desiccant dusts (Ebeling 1971), essential oils and terpenoids (Inazuka 1982, Steltenkamp et al. 1992), and experimental repellents (e.g., Hagenbuch et al. 1987, Steltenkamp et al. 1992), are repellent to cockroaches. Inazuka (1982) reported that oils of Japanese mint and Scotch spearmint were the most repellent of >80 essential oils tested against German cockroaches. Mint oil extract at the rate of 2 ml of mint oil to 457.5 cm^2 was extremely repellent (≈100%) to American and German cockroaches for 14 d (Fig. 1) in Ebeling choice box assays. Assuming complete volatilization and no adsorption to the walls of the choice box, a mint oil vapor concentration of 453.9 $\mu g\ cm^{-3}$, ≈10 times greater than in the fumigation experiments could be attained. Even after 14 d, the mint odor was readily detected in the choice boxes and a trace of the oil deposit remained on the foil-covered insert. Whether repellency was due to volatile odor perception or direct contact with the mint oil deposit (or adsorbed vapor) was not determined.

The toxicity and repellency of mint oil extract, together with its low mammalian toxicity and status as a natural insecticide, make it an ideal compound for use

TABLE 3. Fumigant activity of mint oil to adult male American and German cockroaches.

Species	n	Slope ± SE	KT_{50}, h (95%CI)	χ^2	P
American	36	6.96 ± 1.57	7.38 (6.84–8.40)	19.70	0.0001
German	60	3.96 ± 0.66	9.21 (8.05–11.71)	36.27	0.0001

in a comprehensive integrated pest management program against cockroaches. Mint oil has been formulated as an aerosol for direct spray onto cockroaches and other pest arthropods (Victor Poison-Free Ant & Roach Killer, Woodstream Corp., 4% mint oil). This formulation rapidly (<2 min) kills both American and German cockroaches on contact (Unpublished data). A controlled release formulation could be developed to be used as a long lasting repellent or fumigant in voids or other harborage areas.

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