N O T E

Laboratory Assays of Various Insecticides Against Bed Bugs (Hemiptera: Cimicidae) and Their Eggs[1]

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Bed bugs, *Cimex lectularius* L., are small wingless ectoparasites that feed on the blood of warm-blooded animals such as humans, bats, birds, and pets (Ryckman et al. 1981, Bull. Soc. Vector Ecol. 6: 93 - 142; Thomas et al. 2004, Int. J. Dermatol. 43: 430 - 459; Reinhardt and Siva-Jothy, 2007, Ann. Rev. Entomol. 52: 351 - 374; Little and West 2008, Abstract 61, Amer. Assoc. Vet. Parasitol. Annual Meeting, July 19 - 22, New Orleans, LA). Bed bugs have been increasingly reported inside U.S. hotel rooms, dorms, and apartments (Cleary and Buchanan 2004, Nurse Pract., 29: 46 - 48; Gangloff-Kauffmann et al. 2006, Pest Control Technology Magazine, November, 44 - 60; Anderson and Leffler 2008, J. Environ. Health 70: 24 - 27). They generally feed at night, hiding in crevices during the day. Hiding places include seams in mattresses, crevices in box springs, and spaces under baseboards or loose wallpaper. Infestations are best handled by a pest management professional who has at his/her disposal an array of treatment tools. Heat treatments, wherein the entire house or apartment is heated to approx. 54°C, are reportedly very successful (Pinto et al. 2007, Bed Bug Handbook, Pinto and Associates, Mechanicsville, MD). Homeowner efforts to find and treat the pests with over-the-counter insecticides invariably fail. Insecticides are effective against bed bugs, except in certain cases where populations of the insects are resistant to the chemicals (Romero et al. 2007, J. Med. Entomol. 44:175 - 178). This study was undertaken to examine effectiveness of several commercially available insecticides against a field population of the common bed bug, *C. lectularius* L.

Bed bugs used in this test were collected from a local poultry house on 18 March 2011, confirmed to be *C. lectularius,* and held in 50-ml plastic containers containing strips of cardboard until used in these experiments. Individual bed bug adults were exposed to various insecticides in 2 ways: (1) direct spray in which bed bugs were placed in Petri dishes and topically sprayed, and (2) dried residual exposure in which filter paper or tiles were sprayed, allowed to air dry for 1 h, then placed in Petri dishes

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and bed bugs added. Products were mixed and applied per label. Aerosol products were ready-to-use and applied straight from the can. In the residual effects assays, filter paper (Fisher Scientific, Pittsburgh, PA) was used as the "soft" substrate, and ceramic tiles (Lowe's Home and Garden Store) were used as the "hard" substrate. One bed bug was used per Petri dish, and each treatment was replicated 10 times, yielding a total of 300 bed bugs tested. Water was used as a control. Bed bugs were observed for knockdown (1 h) and then mortality (24 h).

For egg assays, adult bed bugs collected from the same poultry house (above) were placed, 50 each, in small jars containing small pieces of cardboard (approx. 2 × 2 cm). After 2 days, the cardboard was removed and cut into smaller pieces, eggs on the cardboard pieces counted, and placed (approx. 12 - 14 eggs on each piece) in labeled plastic vials. Cardboard pieces containing attached eggs removed from the vials were sprayed until wet (1 - 2 s) with assorted insecticide products and then returned to their plastic vials. Each treatment was replicated 3X with water serving as a control. Eggs were assumed to be 2 d old upon spraying. Vials were held in the laboratory at 21°C and 38% RH and checked for evidence of hatching 1, 3, 7, and 10 d after treatment. Any nymphs found in vials, dead or alive, were counted as "eggs hatching."

Topical spray effects. All bed bugs in the controls were living 1 h after treatment. Only 1 bed bug in the control group was dead at 24 h after treatment; therefore, all 24-h results were adjusted using the Abbott correction (Abbott 1925, J. Econ. Entomol. 18: 265 - 267). Propoxur (Crack & Crevice II®, Whitmire MicroGen Corporation, St. Louis, MO) killed 100% of bed bugs within a few minutes of treatment, as did Swepe-Tite® (Rite-Kem Co., Tupelo, MS, a (primarily) soybean oil herbal product (Fig. 1). Phantom PI® (BASF Corporation, Research Triangle Park, NC) and and Alpine PI® (BASF Corporation, Research Triangle Park, NC) performed very well, producing 90% and 80% mortality within 1 h. Suspend® (Bayer Corporation, KS City, MO) and Temprid® (Bayer Corporation, KS City, MO) killed 70% of bed bugs within 1 h and

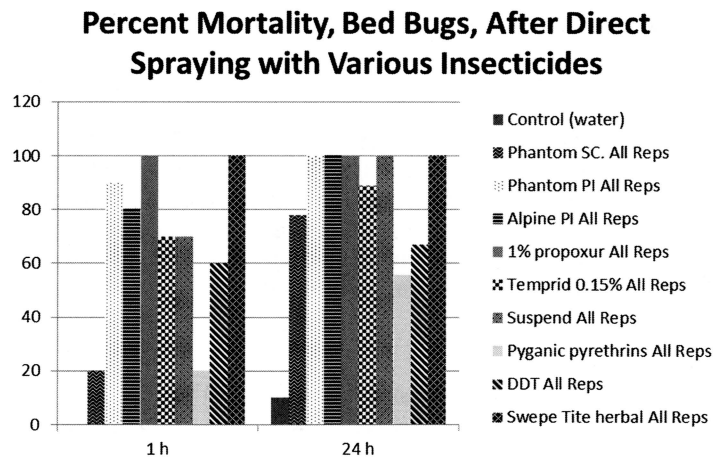

Fig. 1. Percentage mortality of adult bed bugs following direct sprays of various insecticides.

100% and 88.8% by 24 h, respectively. The DDT used in this study (stored since at least 1966) produced 60% mortality at 1 h and 67% at 24 h, although we could not verify its insecticidal activity after long-term storage. Pyganic® (nonsynergized pyrethrins) (MGK Corporation, Minneapolis, MN) was least effective of the materials tested, with 20% mortality at 1 h and only 56% at 24 h, although it should be noted that this pyrethrin product was nonsynergized.

Residual effects. All bed bugs in the control groups placed on paper and tile substrates survived 24 h. Propoxur killed 100% of bed bugs exposed to either paper or tile within 1 h. No product tested, other than propoxur, demonstrated effective residual effects within the first hour (20% was the highest mortality in nonpropoxur products) (Figs. 2, 3). Results from bed bugs walking on filter paper treated with chemicals were mostly poor, although Temprid killed 100% at 24 h, followed by Suspend at 50% at 24 h. Phantom PI and Swepe-Tite (herbal) produced 40% mortality on filter paper at 24 h. Results from exposure to dried chemicals on ceramic tiles were better than those from filter paper. Alpine PI produced 90% mortality at 24 h, followed by Temprid (80%), Swepe-Tite (70%), and Suspend (60%). Pyganic (pyrethrins) and DDT killed only 50% and 40%, respectively, on ceramic tile at 24 h. Results from Phantom SC® (BASF Corporation, Research Triangle Park, NC) revealed almost no residual control on paper or tile within 24 h, although this product has been previously shown to require several days to achieve effectiveness (Moore and Miller 2006, J. Econ. Entomol. 99: 2080 - 2086).

Overall, for residual activity (other than propoxur), Temprid, which contains imidacloprid, produced the best results at 24 h on both soft substrates (paper) and hard substrates (tile) (Fig. 2, 3). Other studies have confirmed the efficacy of imidacloprid against bed bugs (Doggett et al. 2012, Clin. Microbiol. Rev. 25: 164 - 192). Interestingly, Alpine PI produced 90% control of bed bugs on ceramic tiles but only about 10% on paper. Reasons for this discrepancy are unknown. The herbal product, Swepe-Tite,

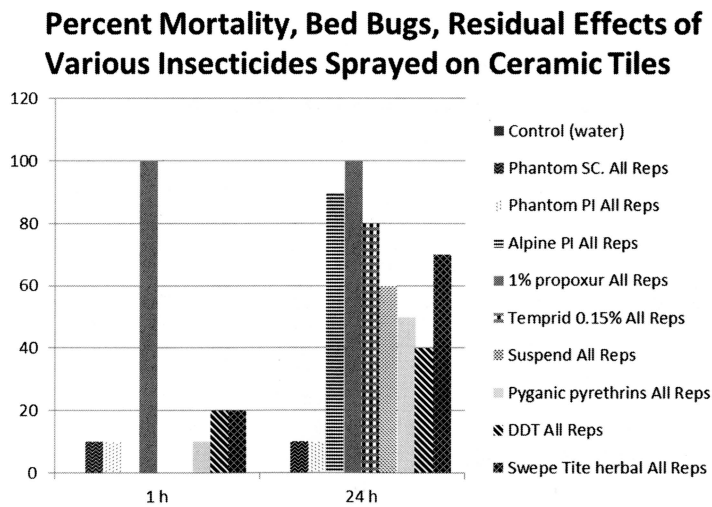

Fig. 2. Percentage mortality of adult bed bugs following placement on ceramic tiles previously sprayed with various insecticides.

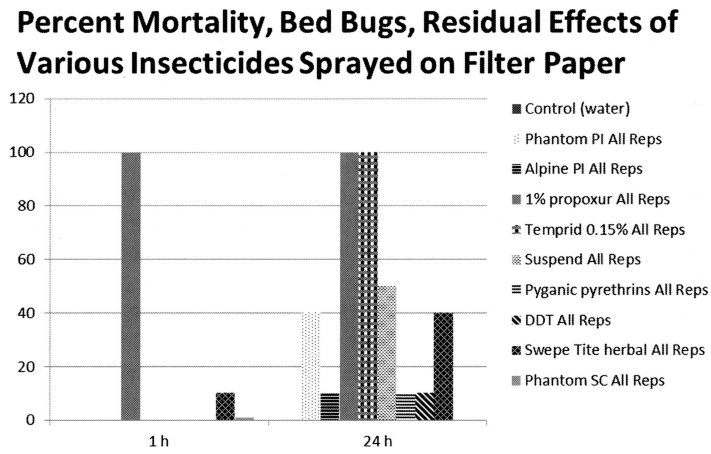

Fig. 3. Percentage mortality of adult bed bugs following placement on filter paper previously sprayed with various insecticides.

produced 70% control on ceramic tiles at 24 h, but this may be a result of its oily consistency, which appears to never dry. The utility of such an oily product on furniture and carpet is questionable due to potential staining.

Bed bug egg assays. All but 3 of 40 eggs in the control group successfully hatched into healthy first-instar bed bugs. Egg hatching accelerated after Day 5. Propoxur killed 100% of bed bug eggs when checked at 10 d after treatment (12 d old), followed by Phantom PI (95%), Alpine PI (89%), and Bedlam® (MGK Corporation, Minneapolis, MN) (76%) (Fig. 4). Phantom SC only produced 20% egg mortality at Day 10.

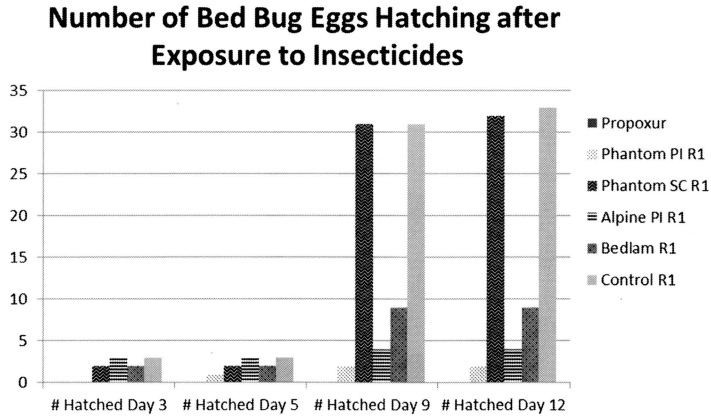

Fig. 4. Numbers of bed bug eggs successfully hatching following exposure to selected insecticides.

Although there are reports of pyrethroid resistance in bed bug populations in many areas of the country (Romero et al., 2007, J. Med. Entomol. 44: 175 - 178), the bed bug population removed from a chicken house and used in these assays appeared to be susceptible to pyrethroids as evidenced by its response to Suspend (a pyrethroid industry standard) killing 70% of the bugs at 1 h and 100% by 24 h. Pest management professionals should not assume pyrethroid resistance, but should be aware that it may occur in their area. As for the products we tested, propoxur, Swepe-Tite, Temprid, Phantom PI, Alpine PI, and Suspend were effective for killing adult bed bugs. The use of propoxur, whereas extremely effective, is not currently allowed by EPA for use in residences (Doggett et al. 2012, Clin. Microbiolo. Rev. 25: 164 - 192). The label specifically states that it can be used in "commercial buildings," even meat-packing plants, but cannot be used where children are present.

As for bed bug egg mortality, only 5 products were tested, and of these, the pressurized insecticide (PI) formulations of Phantom and Alpine (89 - 95%) were efficacious, which make no claim of bed bug egg mortality, followed by Bedlam (76% mortality), which specifically claims bed bug egg mortality on its label. Interestingly, the PI formulation of Phantom killed bed bug eggs, whereas the suspendable concentrate (SC) formulation of the same product was ineffective against bed bug eggs in this study. As with the adults, propoxur was extremely effective at killing bed bug eggs, but is not currently labeled for use in residences.

These results demonstrate that many commercially-available insecticide products are effective tools in managing bed bug infestations, at least in the particular population of bed bugs tested herein. The products, Temprid and Alpine PI, demonstrated good 24-h residual activity against bed bugs on hard surfaces. Even the Swepe-Tite, an herbal product, produced 70% control of bed bugs at 24 h on ceramic tile. These and other products may be useful in spraying bed frames, baseboards, and behind headboards to create a residual insecticide barrier against bed bugs and their eggs.

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