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ASSESSMENT OF NATURAL-BASED PRODUCTS FOR BED BUG (HEMIPTERA: CIMICIDAE) CONTROL

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Abstract Four essential oil-based products and a liquid-based borate spray were tested for their efficacy against adult, pyrethroid-resistant, field-strain and Harold Harlan susceptible-strain bed bugs using direct spray applications. The most effective product was Green Bug (100% mortality in one hour or less based on strain) followed by Bed Bug Patrol (100% mortality in one-two weeks based on strain). All other products failed to exceed 70% mortality over the two-week trial. Despite promising results of two of the products tested, results of field applications may differ due to: a) the difficulty of locating bed bugs for direct applications, b) the uncertainty of repellency in the presence of hosts and associated host cues, c) a lack of data on mortality as a result of contacting an insecticide-treated surface, and d) the duration of product efficacy (repellency or mortality) when applied to a surface. Considerations for future research are discussed.
Key words *Cimex lectularius*, insecticides, essential oils.

INTRODUCTION

The bed bug (*Cimex lectularius* L.) is a cryptic, nocturnal, hematophagous insect that has been a pest of humans for at least four millennia (Panagiotakopulu and Buckland, 1999). While *C. lectularius* was considered to be fairly common in the USA and other countries until the middle of the 20th century (Usinger, 1966), the 1940's marked the advent of dichlorodiphenyltrichloroethane, an insecticide more commonly known as "DDT". At first considered highly effective, some bed bug populations had begun showing resistance to DDT as early as the 1940's, with Johnson and Hill (1948) reporting a pesticide resistant population from Pearl Harbor in 1947. DDT was banned in the 1970's due mainly to environmental concerns and resistance. Next generation insecticides (carbamates and organophosphates) replaced DDT and were generally effective, but have since been banned due to regulatory concerns (Weeks et al., 2011,; Boase, 2001). Our most effective modern insecticides, particularly pyrethroids, are now showing poor control due to widespread insecticide resistance (Romero et al., 2007).

Today, integrated pest management (IPM) techniques are needed and used to control bed bug infestations. Aspects of IPM programs may involve proper inspection, isolation, and treatment of infested items/areas prior to the arrival of a pest control firm, which may use heat, cold, or pesticide treatments singularly or in conjunction (Potter, 2008, Lewis et al., 2009). Such involved and expensive treatments have opened a market for alternative strategies. As expected, a variety of "do it yourself" bed bug products have emerged on the scene. Claiming to kill or repel bed bugs, these products consist principally of extracts from aromatic plants (thyme, cedar, lemongrass, etc.). Although essential oils have been shown to be environmentally safe, and exhibit repellent and insecticidal properties (Isman, 2000), there is a lack of scientifically credible data on the application of these products for bed bug

control. An essential oil may prove to be a valuable tool when attempting to control bed bugs, but an ineffective oil may serve no other purpose than to delay the implementation of effective treatment.
The objective of this study was to examine the efficacy of four commercially available essential oil products and one liquid-based borate product when applied as a direct spray to adult, field-strain, pyrethroid-resistant (referred to as field-strain bugs) and Harold Harlan-strain, susceptible bed bugs (referred to as Harold Harlan strain bugs).

MATERIALS AND METHODS

Four commercially available essential oil products and a borate-based spray were examined for direct-spray efficacy. Four of these products were specifically labeled for bed bugs, including Bed Bug Patrol® (Nature's Innovation: Buford, GA), Green Bug (All Natural Pest Control: Beaufort, SC), Cymex® (Nisus Corporation: Rockford, TN), and Rest Easy® (Green Rest Easy: Memphis, TN). Triple Action Neem Oil® (Southern Agricultural Insecticides, Inc.: Boone, NC) was also examined to compare bed bug products to an essential oil not labeled for bed bugs. Bed Bug Patrol ingredients included 0.03% Clove Oil, 1.0% Peppermint Oil, 1.3% Sodium Lauryl Sulfate, and Citric acid, Glycerin, Oleic acid, and water as 97.67% inert ingredients. Green Bug ingredients consisted of 90% silane fluid and 10% cedar oil. Cymex consisted of 8.5% Disodium Octaborate Tetrahydrate and 91.5% "other ingredients". Triple Action Neem oil included 70% clarified hydrophobic extract of neem oil and 30% inert ingredients. A control treatment consisting of distilled water was included.
A total of 240 adult bed bugs (120 Harold Harlan strain, 120 field strain) maintained at 26°C, ~40% R/H, and 12L/12D photoperiod were removed from colony and fed defribrinated rabbit blood five days prior to treatment. Bed bugs were fed to repletion (~30 minutes) using an artificial feeding system. Bed bugs were housed in altered condiment cups during and after direct sprays. Each container was created by removing the bottom of a 59 ml (~60 mm diameter x ~30 mm height), plastic condiment cup with scissors before using melted wax to fasten one piece of 90 mm Whatman filter paper to the bottom of the cup, forming a new base. This base was intended to absorb excess essential oil and prevent pooling and envelopment of bed bugs. A snap-on lid was modified for each cup by removing a circle ~2.5 cm in diameter from the lid's center. A small circle of mesh was then waxed over the hole. This design prevented escape, and provided bed bugs with a fresh air supply. Five bed bugs were placed in each of 48, 30 ml (~40 mm diameter x ~45 mm height) medicine cups several hours before spray applications. As bed bugs were incapable of climbing medicine cups, but were able to climb the sides of the larger condiment cups, bed bugs were dumped from medicine cups to condiment cups seconds prior to being sprayed. Although the essential oil products examined did not include label rates, bed bugs were sprayed using a Pistol Pro (B&G Equipment Company: Jackson, GA) at a rate similar to commonly available industry products. The mortality of bed bugs was assessed at 1 minute, 1, 3, 6, 12, and 24 hours, and once per day for 14 days by prodding bed bugs with a toothpick. One toothpick was used per condiment cup to avoid transferring product to other bed bugs. Bed bugs that exhibited no movement were marked as dead. Proportion of bed bugs killed per product, per time, were compared within each strain using ANOVA followed by Fisher's LSD test. The model used for the analyses included terms for product (d.f.=5), block (d.f.=3), and error (d.f.=15). Products were considered significantly different when p-values were less than α=0.05.

RESULTS AND DISCUSSION

The efficacy of the products differed based on product and time post application (Figures 1 and 2). Green Bug produced 100% mortality among Harold Harlan-and field-strain bugs within one hour, while Bed Bug

Patrol produced 100% mortality at 7 days among field-strain bugs, and 14 days among Harold Harlan-strain bugs. Though comparisons among all products and all time blocks are too detailed to present in full, Fisher's LSD tests revealed that Green Bug differed significantly from all other products until Bed Bug Patrol reached a similar mortality at day two (field strain bugs) or day five (Harold Harlan-strain bugs). Within the exception of Bed Bug Patrol (day 13), Green Bug and Bed Bug Patrol differed from all other products throughout the remainder of the trial. Rest Easy and Cymex were moderately effective. Rest Easy differed from the control from 1 hour until the end of the trial for field-strain bugs, and from 1 hour until the end of the trail for Harold Harlan-strain bugs, with the exception of day 10. Cymex differed from the control for days 12-14 only for both bed bug strains, and only differed from Rest Easy at 1 hour for Harold Harlan-strain, and 1 hour through 13 days for field strain. Triple Action Neem Oil failed to differ significantly from the control at any time for either strain. Curiously, Triple Action Neem Oil, Bed Bug Patrol, and even the control applications produced higher mortality at an earlier period for pyrethroid resistant bed bugs. This may be due to some unknown fitness cost associated with resistance, a phenomenon which has been documented among insect resistance to *Bacillus thuringiensis* (Gassmann et al., 2009).

Of the five products tested, only Green Bug and Bed Bug Patrol produced mortality exceeding 70%. As studies of bed bug population dynamics have shown that infestations often originate from a few bed bugs or even a single mated female (Booth et al., 2012), 70% is an unacceptable mortality level. Considering that bed bugs were directly sprayed, maintained on a sprayed surface, and deprived of nutrition and harborage for 14 days, even these generally poor kill rates likely exceed those that would occur in the field, where bed bugs would have the option of returning to an untreated harborage to aggregate and await additional blood feeding opportunities. Previous research has shown that bed bug aggregations reduce mortality (Benoit et al., 2007), and that some insects can recover from insecticides when provided with meals during or after exposure (Cox and Parish, 1991).

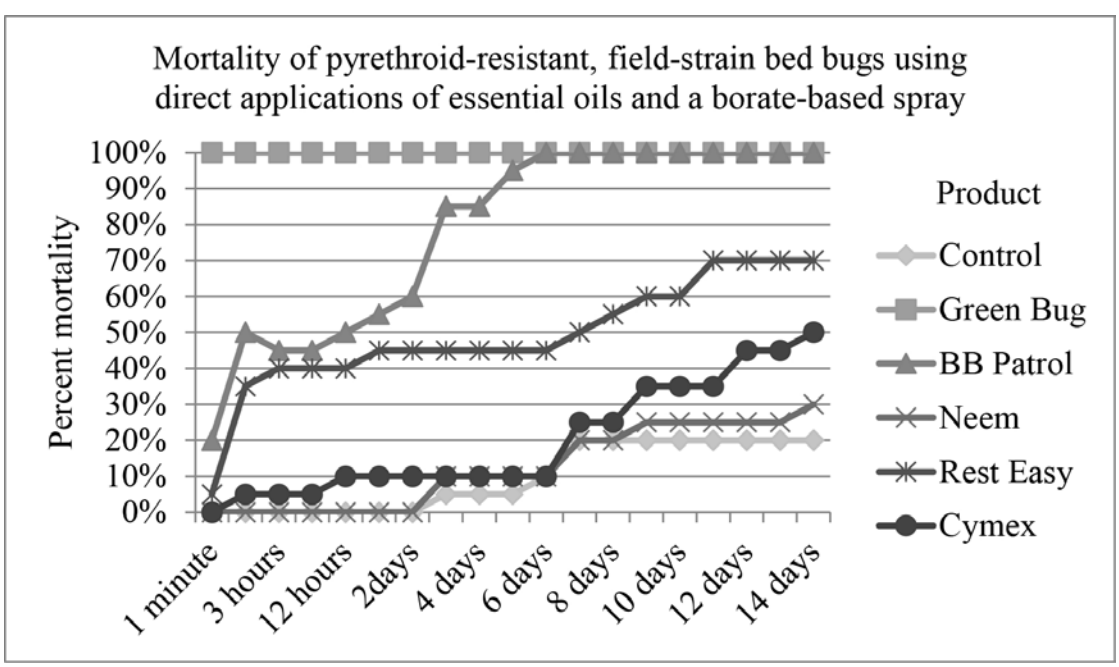

Figure 1. Mortality of pyrethroid-resistant, field-strain bed bugs expressed as percent mortality over a 14 day period.

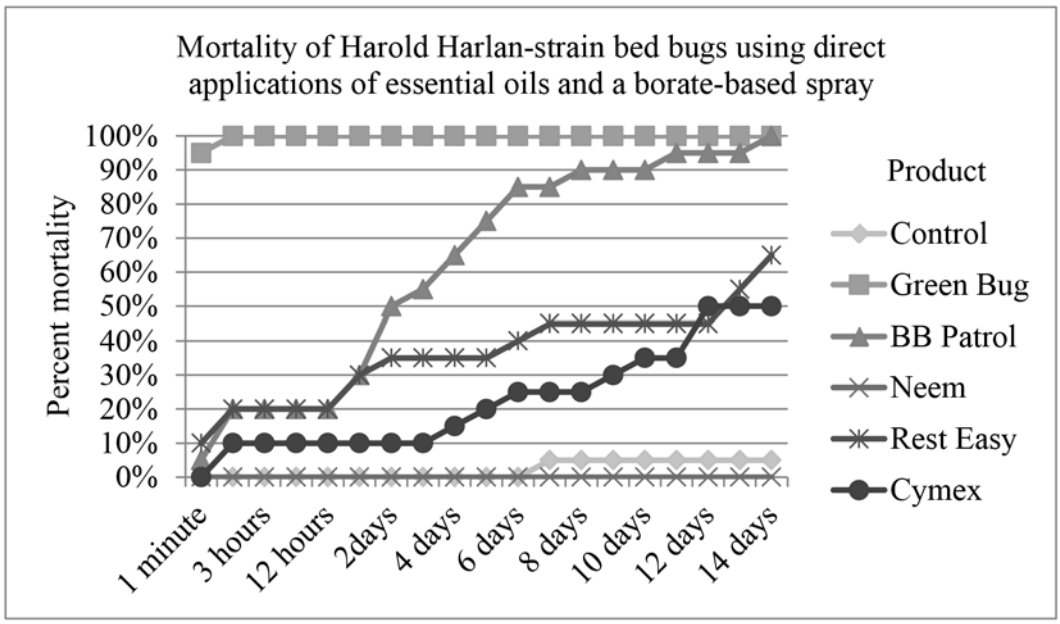

Figure 2. Mortality of Harold Harlan-strain bed bugs expressed as percent mortality over a 14 day period.

CONCLUSION

Although Green Bug produced 100% mortality within 1 hour for both strains, such seemingly effective products should still be viewed with skepticism. Effective bed bug products should have residual efficacy, due to the fact that bed bugs are difficult to locate and eliminate with direct sprays (Romero et al., 2009). Many manufacturers of essential oils claim that their products kill or repel bed bugs, yet fail to define any parameters relating to such claims. Future research will focus on whether these products yield any level of mortality when applied to a surface, as well as the duration of the product's efficacy. Claims of repellency, and duration, should be investigated by other researchers, and should be defined as repellency in the presence or absence of a host. Whether these products leave any type of stain or residue should also be investigated. Additional, replicated and controlled studies should examine silane fluid and cedar oil separately to determine factors that contributed to the high mortality rate produced by Green Bug.

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