Knockdown and Lethal Effects of Eight Commercial Nonconventional and Two Pyrethroid Insecticides against Moderately Permethrin-resistant Adult Bed Bugs, *Cimex lectularius* (L.) (Hemiptera: Cimicidae)

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ABSTRACT The common bed bug, *Cimex lectularius* (L.) (Hemiptera: Cimicidae) is undergoing a rapid resurgence in the United States during the last decade which has created a notable pest management challenge largely because the pest has developed resistance against DDT, organophosphates, carbamates, and pyrethroids, the latter class of insecticide being most commonly used today. Eight nonconventional insecticides Orange Guard (a.i., *d*-limonene), Natria Home Pest Control (a.i., soy bean oil and eugenol), RestAsure (a.i., sodium laurel sulfate, sodium chloride, and potassium sorbate), CedarCide (a.i. cedar oil), Essentria Broadcast Insecticide (a.i., 2-phenethyl propionate, rosemary oil, and peppermint oil), EcoSmart Organic Home Pest Control (a.i., 2-phenethyl propionate, clove oil, rosemary oil, peppermint oil, and thyme oil), Cirkil (a.i.,neem oil) and CimeXa (a.i., silica gel) were compared with two pyrethorids Bonide Bedbug Killer (a.i.,permethrin) and D-Force (a.i.,deltamethrin) as positive controls, and water for direct contact spray knockdown and lethal effects in the laboratory over 4 days. Orange Guard, CedarCide, Essentria, EcoSmart, and Cirkil provided extensive knockdown within 15 min (recovery was, at most, negligible), and caused 80 to 100% mortality within a day making them as effective as the two pyrethroids. CimeXa did not cause appreciable knockdown, but nearly complete mortality was achieved within a day. Product effects in terms of active ingredients and factors that might increase and decrease product effectiveness, such as cimicid aggregation behavior and residual effects, are discussed.

KEY WORDS : Cedar oil, *d*-limonene, essential oils, eugenol, mode of action, neem oil, peppermint oil, rosemary oil, silica gel, sodium laurel sulfate

INTRODUCTION

The bed bug, *Cimex lectularius* (L.) (Cimicidae: Hemiptera), is a flightless obligatory hematophagous parasite of man, bats, poultry, and many domestic animals (Usinger, 1966; Ebeling, 1975). *Cimex lectularius* infestations cause emotional distress,

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sleeplessness, and anxiety (Potter, 2006). Public tolerance for *C. lectularius* bites in the United States is almost zero, and litigation, especially involving hotels, is becoming common (Potter, 2006, 2011). Over the last decade, pest control professionals have reported significant increases of *C. lectularius* infestations in the United States and in developed countries worldwide (Potter, 2006; Cooper, 2011). Explanations for this resurgence include reduction of baseboard spraying of synthetic pesticides for cockroach control following the introduction of effective baits in the early 1980s, resistance to insecticides, loss of efficacious organophosphates and carbamates as treatment options after enactment of the Food Quality Protection Act (1996), increased international travel, and lack of awareness by the public and pest management professionals (Silverman and Shapas, 1986; Shurdut*et al*., 1998; Potter, 2006; Romero *et al*., 2007; Cooper, 2011). *Cimex lectularius* has developed resistance against DDT, organophosphates, carbamates, and pyrethroids, the latter class of insecticide being most commonly used today (Romero *et al*., 2007; Davies *et al*., 2012; Koganemaru and Miller, 2013). The rapid resurgence of *C. lectularius* in the United States during the last decade has created one of the most difficult pest management challenges in a generation (Potter, 2006; Potter *et al*., 2008; Koganemaru and Miller, 2013) and there is a critical immediate need for new insecticides to achieve control.

As *C. lectularius* resistance to conventional insecticides increases, alternative control tactics, such as application of bioactive natural products that often involve multiple compounds with different modes of action warrant investigation and development. Different modes of action in the same nonconventional insecticide can reduce the risk of insecticide resistance. Botanical products that contain bioactive compounds are desirable for pest management when they are effective and benign to natural enemy populations (Schmutterer, 1990, 1995; Ascher, 1993). Many are considered to be minimum-risk pesticides and are exempt from Environmental Protection Agency (EPA) registration under section 25(b) of the Federal Insecticide and Rodenticide Act (Cloyd*et al*., 2009). While some claims of success using nonconventional insecticides against *C. lectularius* are anecdotal, a limited number of nonconventional insecticides, including botanically-based formulations and desiccating powders, have been scientifically assessed and were found to be efficacious against *C. lectularius* (Anderson and Cowles, 2012; Akhtar and Isman, 2013; Hinson *et al*., 2014; Wang *et al*., 2014; Goddard and Maschek, 2015). Because the need for assessing rapid effects of nonconventional insecticides is becoming more apparent as *C. lectularius* resistance to conventional insecticides continues to develop and *C. lectularius* infestations spread and intensify, we assessed the direct contact efficacy of eight nonconventional commercial insecticides, each with different active ingredients, for *C. lectularius* suppression by means of knockdown and mortality.

MATERIALS AND METHODS

Assays were conducted at Sierra Research Laboratories in Modesto, Stanislaus County, CA, during March and April 2014. Sierra Research Laboratories-WMB strain *C. lectularius* (L.), with moderate permethrin resistance (10×) were used. The treatment products were Orange Guard (EPA reg. no. 61887-1-AA, Orange Guard, Carmel Valley, CA) ready to use (RTU) emulsion with the active ingredient listed as being *d*-limonene (5.8%); Natria Home Pest Control (EPA reg. exempt, Bayer, Environmental Science, Research Triangle Park, NC) RTU emulsion with active ingredients soy bean oil (3%) and eugenol (0.25%); RestAsure (EPA reg. exempt, RestAsure, St. Louis, MO) RTU emulsion with active ingredients sodium laurel sulfate, sodium chloride, and potassium sorbate (proprietary mixture); CedarCide (EPA reg. exempt, CedarCide, Lewisville, TX) RTU emulsion with active ingredients cedar oil (5-20%) and hydrated silica (80-95%); Essentria Broadcast Insecticide (EPA reg. exempt, Envincio, Cary, NC) RTU aerosol with active ingredients 2-phenethyl propionate (3%), rosemary oil (1.5%), and peppermint oil (2%); EcoSmart Organic Home Pest Control (EPA reg. exempt, Alpharetta, GA) RTU emulsion with active ingredients 2-phenethyl propionate (2%), clove oil (1%), rosemary oil (1%), peppermint oil (1%), and thyme oil (0.5%); Cirkil RTU

(EPA reg. no. 88760-1, Terramera, Buena Park, CA) RTU emulsion with cold pressed neem oil as the active ingredient (5.5% cold pressed neem oil); CimeXa (EPA reg no. 73079-12, Rockwell Labs, Kansas City, MO) with silica gel dust as the active ingredient (100%); Bonide Bedbug Killer (EPA reg. no. 4-358, Bonide Products, Oriskany, NY) RTU emulsion with permethrin as the active ingredient (0.5%) as a positive control; and D-Force (EPA reg. no. 279-9554, FMC, Philadelphia, PA) RTU aerosol with deltamethrin as the active ingredient (0.6%) as another positive control to which the strain of *C. lectularius* used in this study was not known to be resistant. All of the treatments were obtained from various retail sources, and the control was tap water.

Treatment units were each comprised of 10 adult *C. lectularius* inside a 336-mL plastic cup (Kal-Clear KC12S, Fabri-Kal, Kalamazoo, MI) on a cone coffee filter at the bottom to absorb excess liquid. Plastic Kal-Clear domed lids to the cups each had a 2.5-cm diameter hole at the apex through which the treatment formulations were sprayed using a 710-mL Delta Orbital Sprayer (Delta Industries, King of Prussia, PA) or aerosol can in which the product was purchased. Application distance between the sprayer nozzle was 15 cm for all of the treatments. The amount of each product delivered by the sprayer varied based on the formulation but complete coverage was achieved in every instance. Orange Guard was delivered in the amount of 1.8 mL/replicate, CedarCide 2.2 mL/replicate, Essentria Broadcast Aerosol 0.9 mL/replicate, EcoSmart Home Pest Control 1.6 mL/replicate, Natria Home Pest Control 1.7 mL/replicate, RestAsure 0.84 mL/replicate, Cirkil 1.3 1.3 mL/replicate, CimeXa 0.1 g/replicate, D-Force Aerosol 0.7 mL/replicate, Bonide Bedbug Killer 2.4 mL/replicate, and the control was comprised of 1.6 mL of water. Five minutes after treatment, the insects in each cup were moved on to a 9.4-cm-diam, 1.5 cm deep plastic dish (Greiner Bio-One North America, Monroe, NC) with a 7.5-cm-diam #2 Whatman (VWR, Westchester, PA) filter paper disc inside as harborage and the dish was covered with a flat lid. This procedure was replicated five times for each of the 11 treatments, and the treatments were arranged in a completely randomized experimental design.

Knockdown (the inability of the bed bug to right itself or move in an upright deliberate manner) and recovery (process leading to restoration from knockdown) were determined by counting numbers of knocked down insects in each cup at 5, 15, 30, 45, 60, 120, and 240 min after treatment. Mortality (no movement on being probed) was assessed as numbers of dead insects at 1, 2, 3, and 4 days following treatment.

The knockdown, recovery, and mortality assays were each analyzed using one-way ANOVA and using repeated measures with treatment and time as factors and a treatment × time interaction (Analytical Software, 1998). Mean separations were accomplished with Tukey's HSD ($P < 0.05$) (Analytical Software, 1998). Because normality and homogeneity of variance assumptions were not violated, data were not log $(x + 1)$-transformed before analyses.

RESULTS

Knockdown effects were detected ($F = 21.95$, df = 76, 384, $P < 0.0001$). Within the first 5 min CedarCide, EcoSmart, and Bonide caused complete knockdown and similar results were obtained with Orange Guard, Natria, Cirkil, and D-Force (Fig. 1) (Table 1). RestAsure and Essentria achieved 52% and 48% knockdown, but CimeXa failed to cause more knockdown than the negative control throughout the assay (Fig. 1). The most potent knockdown-inducing products at 5 min maintained high efficacy levels for the rest of the 4-h-long knockdown assessment, and knockdown in the Essentria treatment increased from 48 to 92% by 15 min (Fig. 1). Although knockdown in the Natria treatment was not statistically different from complete knockdown, it declined from a peak of 66% at 5 min to 60% at 15 min and to ≈52% by 30 min (Fig. 1). Similarly, RestAsure did not statistically differ at each sampling time from the products that were>90% effective and knocked down only ≈60% of the cimicids (Fig. 1). Repeated measures detected a treatment effect ($F = 24.45$, df = 10, 384, $P < 0.0001$),a time effect ($F = 6.04$, df = 6, 384, $P < 0.0001$) occurred between 5 and 15 min, and a treatment × time interaction was detected ($F = 7.35$, df = 60, 384, P <

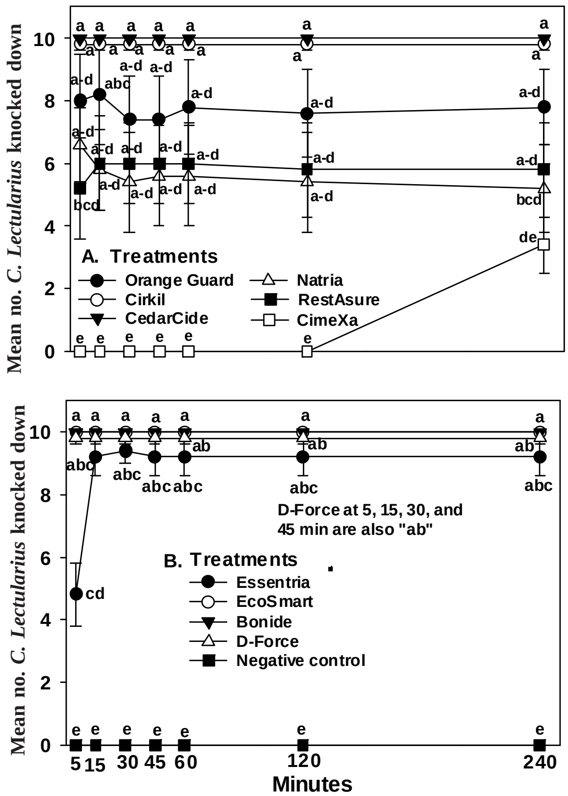

Fig. 1. Mean (± SE) *C. lectularius* knockdown at time intervals to 4 h (*n* = 5 replicates, one-way ANOVA, Tukey's HSD; a-d is abcd) for A) six nonconventional insecticides and B) two nonconventional insecticides, two pyrethroids, and a control comprised of water (A and B data analyzed together but presented separately to enhance clarity).

0.0001). Three nonconventional insecticides achieved > 90% knockdown within 5 min, one did so within 15 min, and Orange Guard maintained ≈78% knockdown throughout the 4-h-long assay (Table 1).

Recovery from knockdown did not occur in the CedarCide, Essentria, EcoSmart, and the two pyrethroid treatments, and it did not rise above 10% in any of the other treatments that caused knockdown (Fig. 1). Although treatment differences were detected (F = 2.03, df = 32, 164, P = 0.0029), Tukey's HSD did not identify which means were involved. Similarly, repeated measures detected treatment differences (F = 2.18, df = 10, 164, P = 0.0375) that were not clarified by Tukey's HSD. Time did not affect recovery and a treatment × time interaction was not detected.

Treatment influenced mortality (F = 17.55, df = 43, 219, P < 0.0001) during the 4-d sampling period after the insecticides were applied. All of the insecticides killed more cimicids than died in the negative control (Table 2), but only CedarCide caused 100% mortality and it did so by the end of the first day (Tables 1 and 2). Essentria, Cirkil, CimeXa, Bonide, and D-Force resulted in > 90% mortality on the first day, and EcoSmart and Orange Guard caused 88 and 76% mortality, respectively (Tables 1 and 2). Natria and RestAsure killed 42% and 46% of the cimicids on the first day, and neither of them killed more than 52% by the end of 4 day (Table 2). Mortality in the Orange Guard treatment increased by 18.4% during the 4 day, becoming 87.5 and 73.1% more effective than Natria and RestAsure, respectively (Table 2). Repeated measures detected treatment differences (F = 19.42, df = 10, 219, P < 0.0001) resulting from the relatively low mortality in the Natria and RestAsure treatments, and in the negative control. Time effects (F = 11.89, df = 3, 219, P < 0.0001) occurred between the second and third day when overall mortality increased by 3.9%. A treatment × time interaction was detected (F = 2.43, df = 30, 219, P = 0.0003).

DISCUSSION

Desirable insecticides for cimicid control in the home, hotels, and other locations where humans are likely to encounter them will rapidly (within minutes) halt biting activity and, possibly more slowly, eliminate the pest. The two goals, knockdown and elimination, can be accomplished separately and by different means, or at the same time using one or more insecticide. Elimination can occur in hours, days, or weeks depending on the scale and complexity of the infestation, and it can be achieved by repellency (mainly aims to completely avert biting) or mortality. Although neurotoxic pyrethroid insecticides (Vijverberg and van den Bercken, 1990), such as permethrin, are known for achieving rapid knockdown and for their lethality to *C. lectularius*, resistance has become increasingly problematic

(Romero *et al*., 2007; Davies *et al*., 2012; Koganemaru and Miller, 2013). When treating structures and surfaces, effective cimicid control products should also provide sufficient residual effects to continue eliminating the pest over a substantial period of time (weeks, months) following application (Hinson *et al*., 2014) because cimicids are difficult to locate and eliminate with low-residual direct sprays (Romero *et al*., 2009). Commercial nonconventional insecticides are available for purchase but few have been compared in terms of efficacy, particularly products with different modes of action.

The insecticides we tested contain different active ingredients, some have different modes of action, and a few have different active ingredients and modes of action within the same product. Neem-based products, such as Cirkil, often involve a variety of bioactive compounds (*e.g.*, salannin, salannol, nimbinen, gedunin, and dirachtin derivatives)that can induce a variety of insecticidal effects (*e.g.*, growth regulation, repellency, mortality from direct contact and exposure to volatiles, sublethal reproductive inhibition) against arthropods (Jones *et al*., 1989; Schmutterer, 1990, 1995; Walter, 1999; Showler *et al*., 2004; Greenberg *et al*., 2005). A commercial product containing 70% clarified hydrophobic extract of neem oil, however, was found to have negligible efficacy against cimicids (Hinson *et al*., 2014). The strong efficacy of neem-based Cirkil suggests that it has a different blend of bioactive components.

RestAsure's proprietary mixture of active ingredients sodium laurel sulfate, sodium chloride, and potassium sorbate are intended to repel, desiccate, and kill, respectively. The active ingredients have not been well established as insecticides and potassium sorbate is best known as an antibacterial and antifungal agent for preserving food (Nikolov and Ganchev, 2011), and sorbic acid was reported to have an insecticidal effect in stored products (Dunkel*et al*., 1984; Dunkel and Read, 1991).

A variety of essential oils have shown pest control properties (Koul *et al*., 2008). Essentria's 2-phenethl propionate and two botanically-based essential oils are indicated by the label as being an octopamine blocker and repellent, and EcoSmart contains 2-phenethyl propionate and four botanically-based essential oils. The precise modes of action of the various essential oils are not always clear, but most essential oils are neurotoxic, involving

Table 1. Mean (± SE) peak percentage knockdown and mortality and time at which the peak was first observed

Treatment[a]	Knockdown (%)	Minutes	Mortality (%)	Hours
Orange Guard	82.0 ± 11.9	15	72.0 ± 16.2	96
CedarCide	100	5	100	24
Essentria	92.0 ± 5.8	15	94.0 ± 6.0	24
EcoSmart	100	5	96.0 ± 2.2	72
Natria	66.0 ± 15.1	5	42.0 ± 12.8	24
RestAsure	60.0 ± 15.1	15	56.0 ± 16.3	72
Cirkil	98.0 ± 2.0	5	98.0 ± 2.0	24
CimeXa	34.0 ± 8.7	240	98.0 ± 2.0	24
Bonide	100	5	78.0 ± 17.4	24
D-Force	98.0 ± 2.0	5	98.0 ± 2.0	24
Control	0	n/a	0	n/a

[a]Orange Guard, a.i.,*d*-limonene (5.8%); Natria Home Pest Control a.i., soy bean oil and eugenol (0.25%); RestAsure a.i., sodium laurel sulfate, sodium chloride, and potassium sorbate (proprietary mixture); CedarCide a.i., cedar oil (5-20%) and hydrated silica (80-95%); Essentria Broadcast Insecticide a.i., 2-phenethyl propionate (3%), rosemary oil (1.5%), and peppermint oil (2%); EcoSmart Organic Home Pest Control a.i., 2-phenethyl propionate (2%), clove oil (1%), rosemary oil (1%), peppermint oil (1%), and thyme oil (0.5%); Cirkil a.i.,neem oil (5.5% cold pressed neem oil); CimeXa a.i., silica gel (100%); Bonide Bedbug Killer a.i., permethrin (0.5%) positive control; D-Force a.i., deltamethrin (0.6%) positive control; water, negative control.

acetylcholinesterase inhibition, competitive obstruction of octopaminergic receptors, or interference with GABA-gated chloride channels (Mann and Kaufamn, 2012). Eugenol, from cloves and other botanical sources, in Natria acts on octopaminergic receptors (Khanikor *et al*., 2013) and it has repellent knockdown and lethal effects on a variety of herbivorous and phlebotomous arthropods (Bhatnagar*et al*., 1993, Cornelius *et al*., 1997, Lee *et al*., 1997, Obeng-Ofori and Reichmuth, 1997; Isman, 2000; Hummelbrunner and Isman, 2001; Thorsell *et al*., 2006; Hieu*et al*., 2010; Velazquez *et al*., 2011b). Peppermint, another essential oil, is mainly used in arthropod control as a repellent (Thorsell *et al*., 2006; Mkolo *et al*., 2011; Hieu *et al*., 2012), and rosemary has been reported as being toxic to arthropods (Velazquez *et al*., 2011a). Orange Guard's *d*-limonene, from citrus oil, destroys the wax coating of arthropod respiratory systems and has been shown to kill a variety of arthropods and to inhibit egg hatching in some, including ticks (Coates *et al*., 1991; Lee *et al*., 1997; Hummelbrunner and Isman, 2001; Raina *et al*., 2007; Ferrarini *et al*., 2008). A commercial cimicid control product with active ingredients clove oil, peppermint oil, and sodium lauryl sulfate produced 100% cimicid mortality in 7–14 days depending on the insect strain (Hinson *et al*. 2014). Another commercial product with geraniol, cedar oil, and sodium lauryl sulfate caused 92.5% cimicid control in apartment buildings (Wang *et al*., 2014). A different commercial product with phenethyl propionate, soybean oil, and clove oil only provided 45% control in a chicken house (Goddard and Mascheck, 2015). Cedar oil in CedarCide blocks respiration and has neurological effects, including toxicity and repellency (Panella *et al*., 1997; Dolan *et al*., 2007), and some other essential oils, if delivered in sufficient doses, can in the same way affect respiration. Another commercial product containing 10% cedar oil, also provided 100% cimicid mortality, within 1 h (Hinson *et al*., 2014). Soybean oil in Natria, like most oils on arthropods, can also block respiration (Bográn *et al*., 2006).

CimeXa, a dust formulation, destroys the waxy

Table 2.Mean (± SE) numbers of C. *lectularius* killed by contact (spray) application of eight natural product-based and two pyrethroid insecticides after 1–4 days

Treatment[a]	Mortality[b] Days post treatment			
	1	2	3	4
Orange Guard	7.6 ± 1.2a-e	8.0 ± 1.0a-e	8.2 ± 0.9a-e	9.0 ± 0.5a-c
CedarCide	10a	10a	10a	10a
Essentria	9.4 ± 0.6a,b	9.4 ± 0.6a,b	9.4 ± 0.6a,b	9.4 ± 0.6a,b
EcoSmart	8.2 ± 0.4a-d	8.8 ± 0.4a-d	9.6 ± 0.2a,b	9.6 ± 0.2a,b
Natria	4.2 ± 1.3e,f	4.2 ± 1.3e,f	4.6 ± 1.2e	4.8 ± 1.4e,f
RestAsure	4.6 ± 0.6e	4.8 ± 1.5d,e	5.6 ± 1.6b-e	5.2 ± 1.6c-e
Cirkil	9.8 ± 0.2a	9.8 ± 0.2a	9.8 ± 0.2a	9.8 ± 0.2a
CimeXia	9.8 ± 0.2a	9.8 ± 0.2a	9.8 ± 0.2a	9.8 ± 0.2a
Bonide	9.6 ± 0.4a,b	9.4 ± 0.4a,b	9.4 ± 0.4a,b	9.4 ± 0.4a,b
D-Force	9.8 ± 0.2a	9.8 ± 0.2a	9.8 ± 0.2a	9.8 ± 0.2a
Control	0g	0g	0.4 ± 0.4fg	0.4 ± 0.4fg

[a]Orange Guard, a.i., *d*-limonene (5.8%); Natria Home Pest Control a.i., soy bean oil and eugenol (0.25%); RestAsure a.i., sodium laurel sulfate, sodium chloride, and potassium sorbate (proprietary mixture); CedarCide a.i., cedar oil (5-20%) and hydrated silica (80-95%); Essentria Broadcast Insecticide a.i., 2-phenethyl propionate (3%), rosemary oil (1.5%), and peppermint oil (2%); EcoSmart Organic Home Pest Control a.i., 2-phenethyl propionate (2%), clove oil (1%), rosemary oil (1%), peppermint oil (1%), and thyme oil (0.5%); Cirkil a.i.,neem oil (5.5% cold pressed neem oil); CimeXa a.i., silica gel (100%); Bonide Bedbug Killer a.i., permethrin (0.5%) positive control; D-Force a.i., deltamethrin (0.6%) positive control; water, negative control.

[b]Values followed by different letters are significantly different ($P < 0.05$), one-way ANOVA, Tukeys HSD.

cuticle of the cimicid, resulting in dehydration (Akhtar and Isman, 2013; Goddard and Maschek, 2015). Although cimicid control in a chicken house reached only 46% when diatomaceous earth mixed with the neonicotinoid insecticide dinotefuran was used, CimeXa provided 100% control within 24 h (Goddard and Mascheck, 2015). Because effective dust-based desiccant products are not affected by residue aging, Anderson and Cowles (2012) concluded that they were superior to sprayable pyrethroid products for cimicid control.

We found that Cirkil, CedarCide, Orange Guard, Essentria, EcoSmart were as effective or nearly as effective as the two pyrethroids, Bonide and D-Force, in terms of achieving > 80% knockdown within 15 min and maintaining that level for the 2-h duration of the knockdown assay. The same five nonconventional insecticides achieved > 90% cimicid mortality within 4 days, hence, all five were as effective for knockdown and elimination as the pyrethroid positive controls. The five nonconventional products involved neem oil, cedar oil, *d*-limonene, 2-phenethyl propionate, rosemary oil, peppermint oil, clove oil, and thyme oil. Hence, certain essential oils, neem constituents, and 2-phenethyl propionate, which have a variety of modes of action (*e.g.*, octopamine receptor inhibition, possibly other neurotoxic effects, and respiratory interference or blockage can induce rapid knockdown and relatively high mortality within days). Natria's and RestAsure's moderate knockdown (50–60% with relatively great variability) and 40–50% lethality indicates that the eugenol, soybean oil, sodium lauryl sulfate, sodium chloride, and potassium sorbate were not sufficient for adequate knockdown and mortality at the dosages and in the formulations used. Repeated measures showed that in terms of knockdown, Natria and RestAsure averaged 32 to 42.5% less, and mortality averaged 46.3 to 50% less, than the more efficacious conventional and nonconventional products, and that knockdown for most products occurred within the first 15 min. While CimeXa only caused negligible knockdown, it was highly effective for killing bedbugs within 24 h. Similarly, repeated measures showed that mortality mainly occurred within 24 h and that there was a slight (4%) average increase between the second and third post-treatment days. Within the parameters of our study, Cirkil, CedarCide, Orange Guard, Essentria, and EcoSmart were best for rapid knockdown and elimination, but CimeXa provided effective control in one day absent rapid knockdown.CimeXa, and other similarly effective dust-based products, might gain a rapid knockdown effect by combining it with another insecticide with strong knockdown capability.

Because this study involved contact knockdown and lethal effects within a maximum of 4 days, the full extent of possible effects of the tested products were not measured. Neem, for example, can contain many bioactive compounds (Jones *et al*., 1989; Schmutterer, 1990, 1995; Walter, 1999) whose effects were not observed in the context of the study. Azadirachtin, the most widely recognized active ingredient of neem-based insecticidal products, is mostly regarded as an insect growth regulator that affects insects during molts or other transitions in developmental stages (Schmutterer, 1990, 1995; Kraiss and Cullen, 2008), hence, Cirkil might not have shown its full potential for eliminating cimicids. Residual effects from contact with treated surfaces were also not measured, nor was the contribution of repellency to control, and horizontal transmission of powder and botanical-based nonconventional insecticides at aggregations has been shown to occur in cimicids (Akhtar and Isman, 2013). Finally, sublethal effects that might hinder reproduction (*e.g.*, reduce fecundity, decrease egg hatch from treated parent insects) were not considered. Some factors that might have negatively influenced efficacy under natural conditions were also not tested. As examples, aggregation can reduce mortality from some insecticides (Benoit *et al*., 2007), and long-term effects of population dynamics can rekindle and reintroduce problematic infestations (*e.g.*, infestations can originate from a single mated female) (Booth *et al*., 2012; Hinson *et al*., 2014).

The nonconventional products Orange Guard, CedarCide, Essentria, EcoSmart, and Cirkil, displayed the knockdown and elimination capabilities of a desirable cimicid insecticide when applied as direct contact sprays. Based on the active ingredients of each product, *d*-limonene, cedar oil, and cold pressed neem oil were each effective. Because Essentria and EcoSmart are blends of essential oils and specific bioactive chemicals, the relative contributions of 2-phenethyl propionate, rosemary oil, peppermint oil, clove oil, and thyme oil to knockdown and mortality were not established. A sixth nonconventional product, CimeXa, comprised of silica gel, was effective at eliminating the pest within a single day. It is possible that the multiple modes of action of most of the nonconventional products we tested, some sufficiently benign to be exempt from EPA registration, will delay or prevent the development of resistance commonly associated with conventional insecticides.

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