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## EFFICACIES OF COMMON READY TO USE INSECTICIDES AGAINST *HALYOMORPHA HALYS* (HEMIPTERA: PENTATOMIDAE)

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### ABSTRACT

Efficacies of topical applications and dry residues of 9 common ready-to-use (RTU) insecticides were evaluated against brown marmorated stink bug, *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae) at intervals of exposure of 1 and 48 h. Permethrin and acetamiprid, were further evaluated to determine if *H. halys* recovered after an initial exposure. Topical applications of carbaryl, permethrin, insecticidal soap, petroleum oil, and acetamiprid, and residues of permethrin and acetamiprid increased mortality of adults. Topical applications of spinosad, essential oils, carbaryl, permethrin, insecticidal soap, petroleum oil, and acetamiprid, and residues of carbaryl, permethrin, and acetamiprid increased mortality of nymphs. Topical applications of carbaryl, neem oil, insecticidal soap, and acetamiprid increased egg mortality. In general, nymphs were more susceptible to insecticides than adults. Adult *H. halys* recovered after exposure to topical applications, but not dry residues of permethrin. Clearly, several RTU insecticides in the marketplace demonstrated potential to help gardeners manage *H. halys*.

Key Words: ready-to-use, brown marmorated stink bug, insecticide efficacy, IPM

### RESUMEN

La efectividad de aplicaciones topicales y residuos de 9 insecticidas comunes listos para usar disponibles en el mercado, fueron evaluados para controlar el chinche hediondo marrón mármol, *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae) a intervalos de exposición de 1 y 48 h. Permethrin y acetamiprid, fueron adicionalmente evaluados para determinar si *H. halys* se recobraba después de la exposición inicial. Aplicaciones topicales de aspersiones de carbaryl, permethrin, jabones insecticidas, aceites de petróleo, y acetamiprid, y residuos de permethrin y acetamiprid, aumentaron significativamente la mortalidad de adultos comparados con los adultos tratados solo con agua destilada. Las aplicaciones topicala de aspersiones de spinosad, aceites esenciales, carbaryl, permethrin, jabones insecticidas, aceite de petróleo, y acetamiprid, y residuos de carbaryl, permethrin, y acetamiprid aumentaron significativamente la mortalidad de ninfas comparados con ninfas tratadas solamente con agua destilada. Las aspersiones aplicadas topicalmente y la exposición a residuos secos causó una mayor mortalidad de ninfas en comparación a los adultos. Las aplicaciones topicales de aspersiones de carbaryl, aceite de neem, jabones insecticidas, y acetamiprid aumentaron significativamente la mortalidad de huevos. Los adultos de *H. halys* se recobraron después de ser expuestos a aspersiones topicales, pero no a residuos secos de permethrin. Los adultos que invernaron fueron más susceptibles a los insecticidas que los adultos recién emergidos. Es evidente, que varios insecticidas 'listos para usar' disponibles comercialmente demostraron potencial para ayudar a los agricultores orgánicos a controlar *H. halys*.

Palabras Clave: Insecticidas listos para usar, chinche hediondo marrón mármol, eficacia de insecticidas, MIP

Stink bugs (Hemiptera: Pentatomidae) are important pests of agricultural crops and ornamental plants in the United States (McPherson & McPherson 2000). Previous studies have demonstrated that stink bug damage can be significant to crops including tomato, soybean, peach, and apples through feeding or the introduction of pathogens (Underhill 1934; Emfinger et al. 2001; Nault & Speese 2002; Funayama 2004; Medrano et al. 2007; Nielsen & Hamilton 2009b; Rucker

& Hamilton 2011; Leskey et al. 2012ac). Furthermore, management of stink bugs can be challenging with injury resulting despite the application of broad-spectrum insecticides (Chyen et al. 1992; Leskey et al. 2012a).

*Halyomorpha halys* is native to China, Japan, Korea, and Taiwan, but it has now been detected in 40 states and the District of Colombia since it was first discovered in North America near Allentown, PA in the late 1990's (Hoebeke & Cart-

er 2003; Leskey et al. 2012c). Unfortunately, *H. halys* is polyphagous with over 300 reported host plants ranging from agricultural crops to ornamental plants (Hoffman 1931; Hoebeke & Carter 2003; Bernon 2004; Nielsen & Hamilton 2009b). Furthermore, *H. halys* is a nuisance pest in residential settings due to its predilection to use human-made structures such as houses as overwintering sites where infestations can exceed 20,000 individuals (Watanabe et al. 1994; Hamilton et al. 2008; Sargent et al. 2011; Inkley 2012).

Several recent studies conducted in the field and laboratory in the United States provide insights into the utility of different classes of insecticides to kill stink bugs and to mitigate their damage. Kamminga et al. (2009) focused on the organic insecticides azadirachtin, pyrethrins, and spinosad applied alone and in combination to modify behavior, and to reduce feeding, survival, abundance, and damage caused by *Chinavia hilaris* (Say) and *Euschistus servus* (Say) in tomatoes and soybeans. Nielsen et al. (2008b) were among the first to evaluate organophosphate, pyrethroid, and neonicotinoid insecticides against different life stages of *H. halys* and found high levels of toxicity in several pyrethroids and neonicotinoids. Leskey et al. (2012b) tested the lethality of 37 insecticides to adult *H. halys* under controlled laboratory conditions. Several classes of insecticides including carbamates, organophosphates, organochlorines, pyrethroids, and neonicotinoids were highly lethal to *H. halys* after 7 days. Unfortunately, 8 compounds most of which were pyrethroids declined in lethality over 7 days (Leskey et al. 2012b). In a series of field trials, Leskey et al. (2013) demonstrated that overwintered *H. halys* adults were more susceptible to insecticides than new adults of the summer generations and efficacies of insecticide residues were less effective and declined with time relative to freshly applied insecticides. Lee et al. (in press) recently evaluated the efficacies of several insecticides approved for organic production of specialty crops and found dry residues of several including potassium salts of fatty acids, spinosad, pyrethrins, pyrethrins + kaolin, and three experimental compounds to significantly increase mortality of *H. halys* relative to water controls.

In addition to the growing recognition that *H. halys* poses a serious threat to many crops, inquiries and complaints from the general public confirm its role as a serious pest in residential vegetable gardens and landscapes (Sargent et al. 2011; Inkley 2012). Homeowners regularly apply premixed ready-to-use (RTU) insecticides to vegetables, fruits, shrubs, and trees to control insect pests (Baldwin et al. 2008; Matheny et al. 2009) and consumer interest and demand are high for methods of stink bug control including the use of insecticides for *H. halys* (J.H. Traunfeld, University of Maryland Extension, personal communi-

cation). Recent studies examined toxicities and efficacies of several insecticides used in agronomic systems for controlling stink bugs including *H. halys* (Nielsen et al. 2008b; Kamminga et al. 2009; Rucker & Hamilton 2011; Leskey et al. 2012ab; Leskey et al. 2013, Lee et al. in press). However, there is no published account of the efficacy of common consumer-based RTU insecticides to control *H. halys* to date. The objectives of this study were as follows. First, effects of topical applications and residues of RTU insecticides on the mortality of *H. halys* nymphs and adults exposed for short (1 hour) and long (48 hour) intervals were evaluated. The effects of topical applications of RTUs to *H. halys* eggs were also evaluated. Previous reports of insecticidal activity against *H. halys* noted adult stink bug recovery after an initial exposure to insecticides (Nielsen et al. 2008b; Leskey et al. 2012b). Two of the active ingredients found in the RTUs in this study, permethrin and acetamiprid, were among those observed in previous studies of *H. halys* recovery (Nielsen et al. 2008b; Leskey et al. 2012b). An additional trial evaluated the ability of *H. halys* adults to recover from exposure to topical applications of permethrin and acetamiprid. Information from these studies will be useful in assisting consumers in their selection of RTU insecticides to be used against *H. halys* in home vegetable gardens.

## MATERIALS AND METHODS

### Insect Source

Wild adults of *H. halys* were collected from wheat, *Triticum aestivum* L., peach, *Prunus persica* (L.), and sweet corn, *Zea mays saccharata* L., from Jun 2011 through Oct 2012 in Central Maryland. Before use in bioassays, insects were placed in plastic containers (30 × 19 × 20 cm, All Living Things Critter Totes®) and fed organic nuts, fruits, and vegetables including: raw peanut, *Arachis hypogaea* L. (always provided) and carrots, *Daucus carota* L.; green beans, *Phaseolus vulgaris* L.; sweet corn, tomato, *Solanum lycopersicum* L. (individually based on seasonal availability). Moistened sponges were placed in small Petri dishes (Fisherbrand® 100 × 15 mm) as water sources. Food and water were changed twice weekly. Filter paper (Double Rings® #102, 12.5 cm diam) attached to one side of each container served as an oviposition substrate. Egg masses were removed daily and placed into separate Petri dishes (Fisherbrand®, 100 × 15 mm) until they hatched. Once hatched, nymphs were placed into plastic containers described previously. Nymphs and adults were fed and watered, as previously described. Containers were maintained in growth chambers kept at 16:8 h L:D, 25 °C ± 1 °C, and 60 ± 10% RH. Second instar nymphs and egg masses were collected from the colonies for use in insecticide trials.

## Topical Application Trials

Between Jun 2011 and Sep 2012 we investigated the effects of RTU insecticides on *H. halys* adults, second instar nymphs, and eggs. The sex ratio of *H. halys* adults used in all studies was 1:1. RTU insecticides were purchased from retail garden centers in metropolitan Washington, DC during the first week of Jun in 2011. Each product had a label indicating its use in controlling insect pests of vegetables, fruits, shrubs, and trees. We chose insecticides representing several different classes of compounds with different modes of action. Common names, brand names, and concentrations of active ingredients are listed in Table 1. Two of the 9 compounds, one containing acetamiprid and one containing carbaryl, identified stink bugs as a target pest, but none specifically mentioned *H. halys* on the label. To determine the volume applied of each formulated RTU product used in our trials, before application, the applicator handle on each spray bottle was fully compressed 30 times and the spray was collected in a graduated cylinder. After allowing the droplets to settle, the volume of insecticide was measured to the nearest mL, and the average volume delivered at each compression was calculated by dividing the total volume by 30. This procedure was repeated by 3 people and an average volume per compression for these 3 people was calculated for each spray bottle. Each topical application consisted of 3 compressions and the volumes of each product applied are reported in Table 1.

In separate experiments, one for adults and one for nymphs, 500 adults and 500 second instar nymphs were randomly assigned to 1 of 10 treatments in cohorts of 5. Each treatment was replicated 10 times. Products tested at all dates came from the same bottles. Methods of application and post-application care were the same for all subjects irrespective of date. All subjects were held at a temperature of  $21\text{ }^{\circ}\text{C} \pm 2\text{ }^{\circ}\text{C}$  and ambient light levels during the course of the studies. Cohorts were placed into 355 mL cups (Solo® top diam 9.2 cm, bottom diam 7.3 cm, height: 8.6 cm,) with clear plastic lids that served as assay arenas. Each arena was lined with a filter paper (Fisherbrand® P8, diam 7 cm) placed at the bottom. Twelve holes were punched in each cup with a dissecting probe to allow ventilation and drying of liquid sprays over the course of the trials. Treatments consisted of topical applications of distilled water; spinosad; a mixture of essential oils (rosemary – 0.25%, peppermint – 0.25%, thyme – 0.25%, and clove oil – 0.25%); carbaryl; permethrin; insecticidal soap; capsaicin, horticultural (petroleum) oil; neem oil; and acetamiprid. The distance from the arena containing the stink bugs to the tip of the spray bottle was standard-

TABLE 1. BRAND NAME, ACTIVE INGREDIENTS, AND VOLUMES OF READY TO USE PESTICIDE PRODUCTS APPLIED TO ADULTS, NYMPHS, AND EGGS OF *HALYOMORPHA HALYS*.

Brand name	Active ingredient (AI)	AI concentration (%) <sup>1</sup>	Volume applied (ml) (Average $\pm$ SE)
Distilled water	N/A	100	4.0 $\pm$ 0.1
Captain Jack's Deadbug	Spinosad (A & D)	0.001	4.1 $\pm$ 0.2
EcoSmart: Organic Garden Insect Killer	Rosemary, peppermint, thyme, & clove oil	0.25 (each oil)	4.2 $\pm$ 0.1
Sevin	Carbaryl	0.126	4.0 $\pm$ 0.0
Eight: Garden & Home	Permethrin	0.02	4.1 $\pm$ 0.2
Insecticidal Soap	Potassium salts of fatty acids	1.0	4.1 $\pm$ 0.0
Hot Pepper Wax	Capsaicin & other capsaicinoids	0.00001125	4.0 $\pm$ 0.1
All Seasons Horticultural Spray Oil	Petroleum oil	2.0	4.2 $\pm$ 0.2
Fungicide 3	Clarified hydrophobic extract of neem oil	0.9	4.1 $\pm$ 0.1
Ortho: Flower, Fruit, & Vegetable	Acetamiprid	0.006	4.8 $\pm$ 0.2

<sup>1</sup>AI concentrations are from the ingredient statement on the insecticide label.

ized at 30 cm. To apply the insecticides to the insects, the applicator handle was compressed 3 times for each RTU product and the distilled water control for each of the cups used in the trial. One day after treatment all arenas were provisioned with 2 cherry tomatoes, *S. lycopersicum* L., as a food source for *H. halys*.

To determine the effects of topical applications, *H. halys* adults and nymphs were observed 48 h after treatment. In each arena, each stink bug was evaluated and placed in 1 of 2 categories, alive, designated as the ability to move in response to a stimulus (touch with a probe) or dead, showing no movement in response to a stimulus. To determine effects of topical applications on egg mortality, one hundred egg masses were randomly assigned to one of the ten treatments. Insecticides or water were applied topically using the methods described previously. Each egg mass was observed daily for a period of 8 days. This interval was determined previously to exceed the average developmental period for eggs (Nielsen et al. 2008a). To quantify egg mortality, we recorded the number of nymphs both living and dead that hatched from each egg mass during the 8 day observation period. The number of nymphs that hatched was subtracted from the number of eggs in each egg mass. Therefore, only eggs that failed to hatch were used to estimate egg mortality.

In addition to the 48 h period of exposure to topical applications and their residues, a shorter interval of exposure to the RTUs of 1 h was investigated. Between Jun and Sep 2012, assays with 250 second instar nymph and 250 adults were repeated using methods described previously. After exposure to topical sprays, cohorts of *H. halys* were transferred to pristine cups and observed for 48 h at which time each insect was evaluated as described previously.

#### Dry Residue Trials

From Aug 2011 to Sep 2012, trials were conducted with 500 nymphs and 500 adult *H. halys* testing the dry residues of the 9 insecticides used in the topical spray trials. Nine insecticides and distilled water were applied to the inside of each container and the container's lid using the methods described previously. Containers and lids were allowed to dry for 48 h before cohorts of 5 adults and 5 nymphs were placed in each arena. Ten replicate cohorts were evaluated for each treatment. At 48 h after placement in the arena, all adults and nymphs were evaluated as in the topical spray trial. This study was repeated with an exposure interval of 1 h rather than 48 h using 250 nymphs and 250 adults assigned in cohorts of 5 to 10 treatments. All other procedures were followed as described previously.

#### Adult Recovery Trials

To investigate the phenomenon of adult recovery following exposure to permethrin and acetamiprid, 2 trials were performed with *H. halys* adults. One used topical sprays and the other insecticidal residues of permethrin and acetamiprid. For each method of application, 150 adults were assigned to one of three treatments in cohorts of 5. Ten cohorts of 5 adults served as controls and were treated with distilled water. Ten cohorts of 5 adults were treated with topical sprays of permethrin and 10 cohorts of 5 adults were treated with topical sprays of acetamiprid. Food was provided as in the trials described above and at intervals of 24 and 96 h after treatment, mortality was evaluated by criteria described previously.

#### Statistical Analyses

The response variable analyzed was mortality expressed as percent. Data that did not conform to assumptions of normality and homogeneity of variances after arcsine and square root transformations were subjected to non-parametric tests. To examine effects of different insecticides on mortality of *H. halys* eggs, nymphs, and adults, Kruskal - Wallis Analyses were used to detect differences among treatments (Zar 1999; Analytical Software 2003).

To evaluate recovery of *H. halys* adults following exposure to topical sprays and dry residues of acetamiprid and permethrin, Abbott's correction (Abbott 1925) was applied to mortality observed at 24 and 96 h post treatment. For each compound and both methods of application (topical sprays and dry residues) mortality was compared between time intervals (24 vs. 96 h) with a Wilcoxon Signed Rank Test (Zar 1999; Analytical Software 2003).

## RESULTS

#### Topical Spray Trials

After 1 h of exposure, mortality of *H. halys* nymphs differed significantly among insecticidal treatments ( $H = 40.8$ ;  $df = 9$ ;  $P < 0.0001$ ). Insecticidal mortality was least in nymphs treated with spinosad and essential oils. All other materials produced relatively high (> 90%) mortality (Fig. 1). Adults exposed for 1 h experienced significantly different mortality among treatments ( $H = 38.5$ ;  $df = 9$ ;  $P < 0.0001$ ) (Fig. 1) with spinosad, horticultural oil, and capsaicin causing the least mortality and carbaryl, acetamiprid, and permethrin causing the most.

After 48 h of exposure, mortality of *H. halys* nymphs and adults differed significantly among insecticidal treatments (nymphs:  $H = 58.4$ ;  $df = 9$ ;  $P < 0.0001$ ) (adults:  $H = 60.7$ ;  $df = 9$ ;  $P < 0.0001$ ).

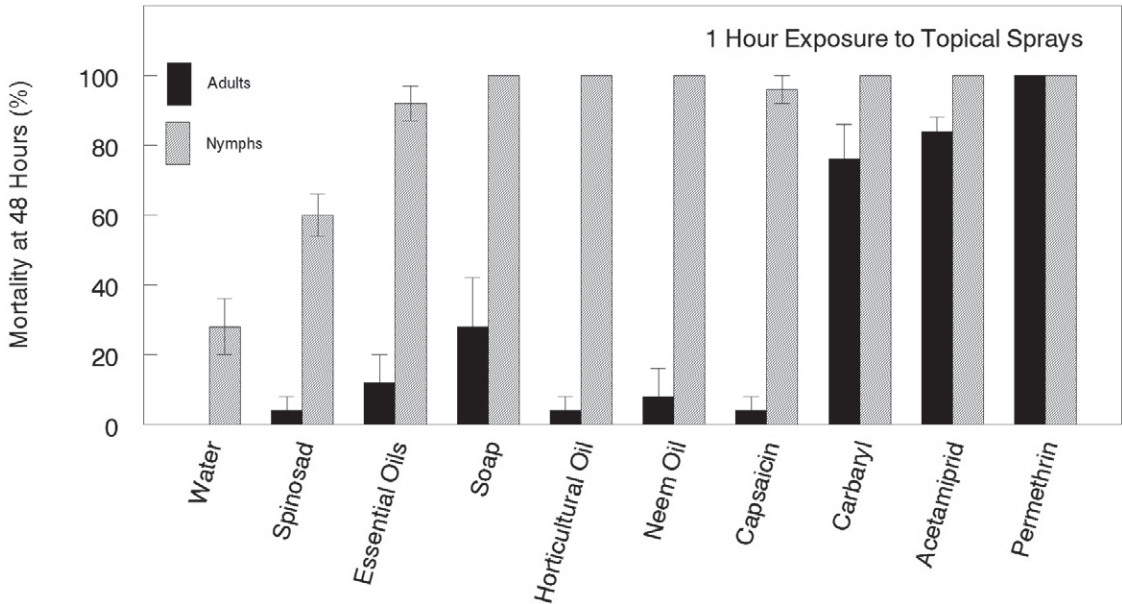


Fig. 1. Percentage mortality at 48 h post exposure of *H. halys* adults (black bars) and nymphs (gray bars) exposed to topical sprays of insecticides for 1 hour. Bars represent means and vertical lines are standard errors. Treatments differed significantly within each life stage (Kruskal - Wallis Analyses,  $P < 0.0001$ ). Comparisons were not made between life stages.

Insecticides producing the least mortality for adults were neem oil, capsaicin, and spinosad and those producing the greatest mortality were carbaryl, acetamiprid, and permethrin (Fig. 2).

In the egg mortality trial, the average number of eggs per egg mass was  $26.7 \pm 0.27$  (SEM) and did not differ among treatments ( $F_{9,90} = 0.19$ ,  $P < 0.99$ ). Mortality of eggs in response to topical applications differed significantly among treatments ( $H = 68.2$ ;  $df = 9$ ;  $P < 0.0001$ ). Applications of spinosad, permethrin, horticultural oil, and capsaicin produced the least mortality and neem oil, carbaryl, and acetamiprid produced the greatest mortality (Fig. 3).

#### Dry Residue Trials

Exposure to dry insecticide residues for 1 h resulted in significant mortality to nymphs ( $H = 33.8$ ;  $df = 9$ ;  $P < 0.0001$ ) and adults ( $H = 24.3$ ;  $df = 9$ ;  $P < 0.004$ ) (Fig. 4). Mortality of nymphs and adults was the least when exposed to dry residues of soap, horticultural oil, neem oil, and capsaicin. The greatest mortality of nymphs was observed following exposure to dry residues of carbaryl, acetamiprid, and permethrin (Fig. 4), while only permethrin produced high levels of mortality in adults (Fig. 4).

After 48 h of exposure, mortality of *H. halys* nymphs to dry residues differed significantly among insecticidal treatments ( $H = 43.0$ ;  $df = 9$ ;

$P < 0.0001$ ). Insecticides producing the least mortality were capsaicin, spinosad, and essential oils and those producing the most mortality were carbaryl, acetamiprid, and permethrin (Fig. 5). After 48 h of exposure, mortality of *H. halys* adults differed significantly among insecticidal treatments ( $H = 60.7$ ;  $df = 9$ ;  $P < 0.0001$ ) and, as with the 1 h exposure, permethrin produced the greatest levels of mortality (Fig. 5).

#### Adult Recovery Trials

Exposure of adult *H. halys* to topical sprays of permethrin resulted in an estimated mortality of  $100 \pm 0$  (SEM)% at 24 h. However, at 96 h mortality was  $66.0 \pm 7.3$  (SEM)%. This reduction in mortality was significant ( $T = 0$ ;  $n = 10$ ;  $P < 0.01$ ). Exposure to dry residues of permethrin resulted in mortality of  $6.0 \pm 3.1$  (SEM)% after 24 h, but at 96 h this increased significantly ( $T = 0$ ;  $n = 10$ ;  $P < 0.01$ ) to  $38.0 \pm 8.1$  (SEM)%. Exposure to topical sprays and dry residues of acetamiprid did not result in differences in mortality between 24 and 96 h ( $P > 0.05$ ), hence there was no indication of recovery or increasing mortality following exposure to acetamiprid.

#### DISCUSSION

The practical implication of these findings is that several RTU products killed *H. halys* adults,

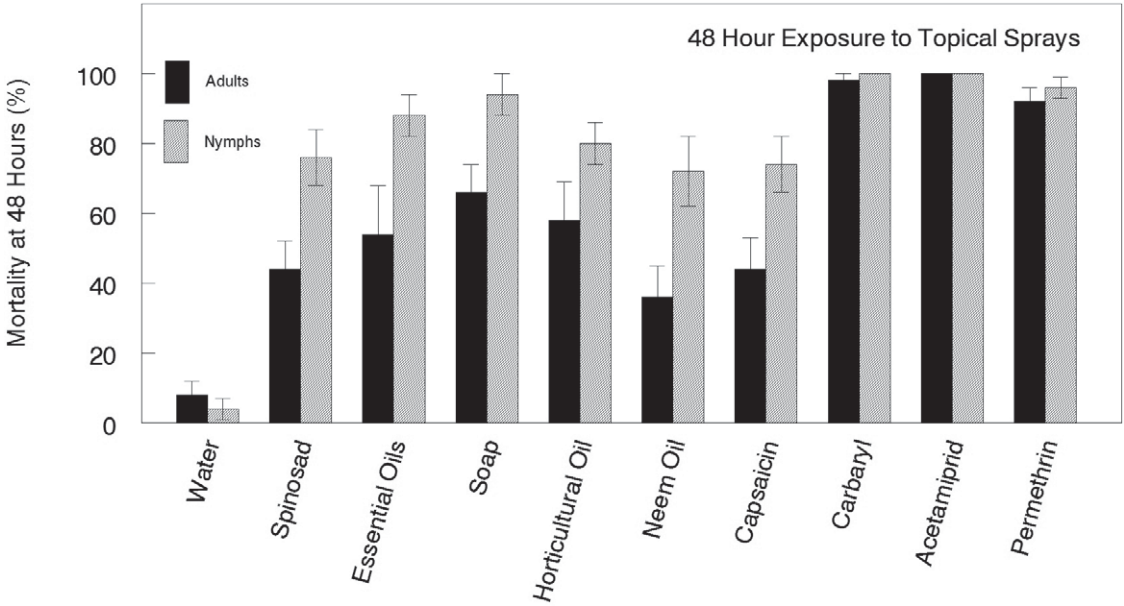


Fig. 2. Percentage mortality at 48 h post exposure of *H. halys* adults (black bars) and nymphs (gray bars) exposed to topical sprays of insecticides for 48 h. Bars represent means and vertical lines are standard errors. Treatments differed significantly within each life stage (Kruskal - Wallis Analyses,  $P < 0.0001$ ). Comparisons were not made between life stages.

nymphs, and eggs. In general, nymphs were more sensitive than adults to both topical applications of insecticides and their dry residues. In 34 of 36 cases where insecticides were applied to both

life stages, mortality in nymphs numerically exceeded that of adults. This pattern has been observed in studies involving *H. halys* (Nielsen et al. 2008b; Kuhar et al. 2012) and a variety of other

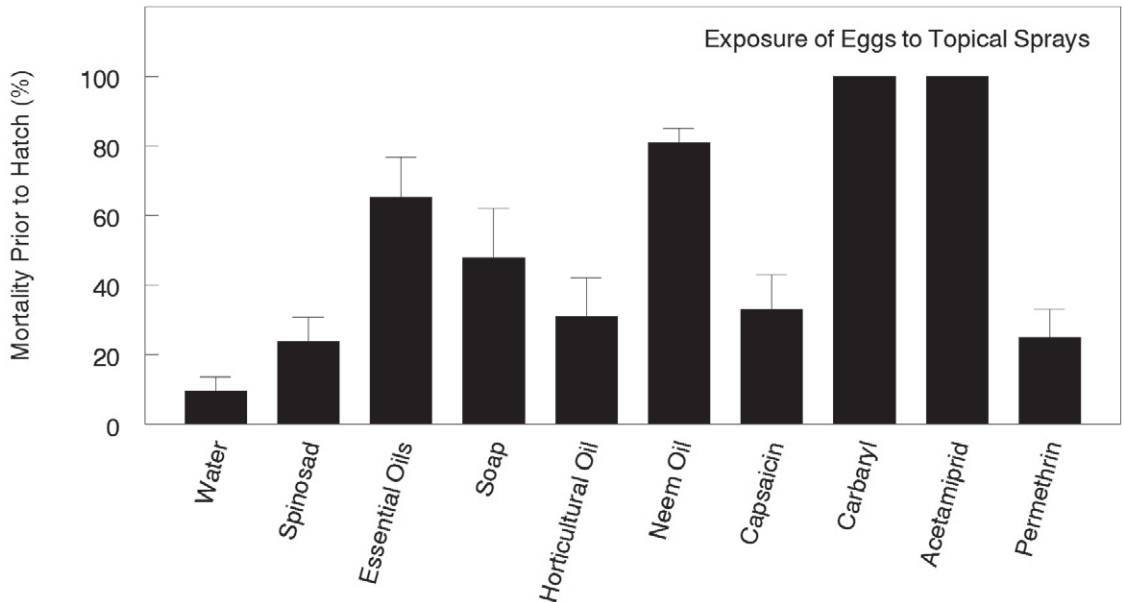


Fig. 3. Percentage mortality at 192 h post exposure of *H. halys* eggs exposed to topical sprays of insecticides. Bars represent means and vertical lines are standard errors. Treatments differed significantly (Kruskal - Wallis Analyses,  $P < 0.0001$ ).

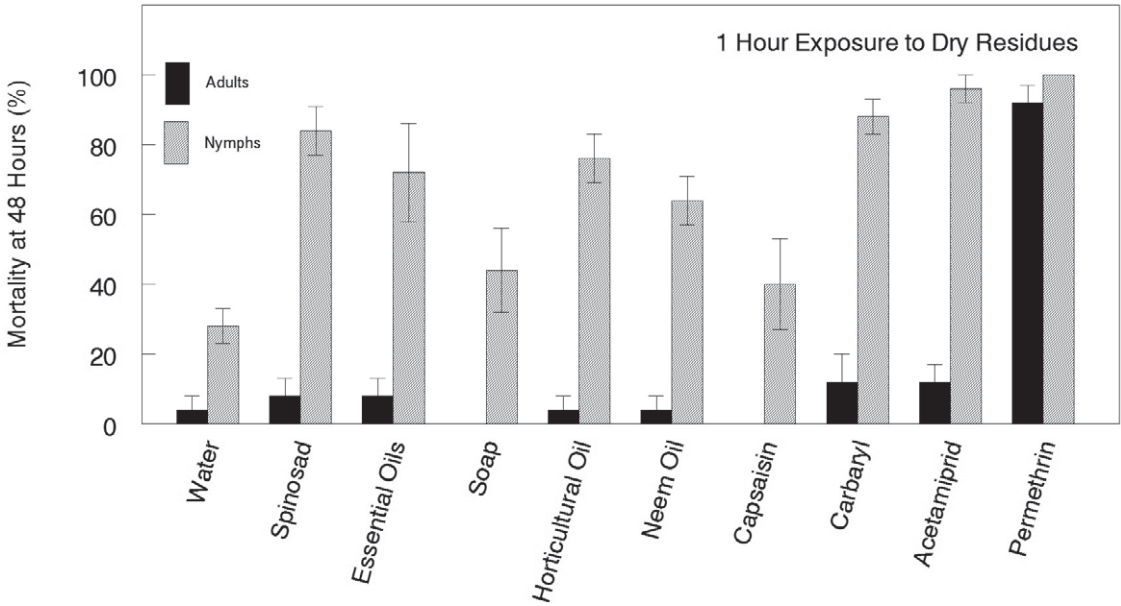


Fig. 4. Percentage mortality at 48 h post exposure of *H. halys* adults (black bars) and nymphs (gray bars) exposed to dry residues of insecticides for 1 hour. Bars represent means and vertical lines are standard errors. Treatments differed significantly within each life stage (Kruskal - Wallis Analyses,  $P < 0.0001$ ). Comparisons were not made between life stages.

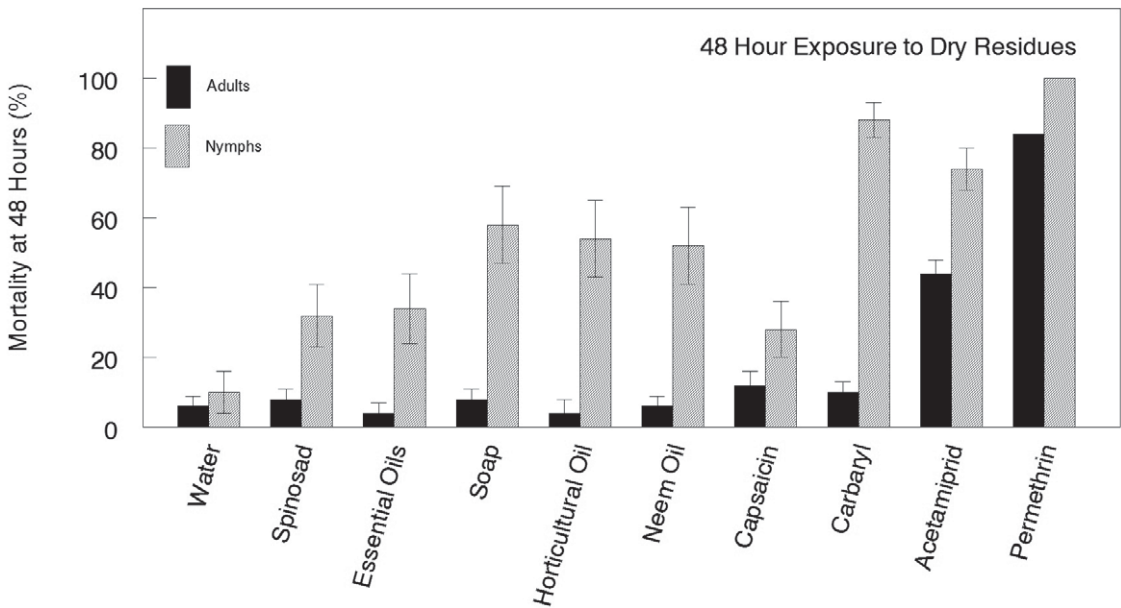


Fig. 5. Percentage mortality at 48 h post exposure of *H. halys* adults (black bars) and nymphs (gray bars) exposed to dry residues of insecticides for 48 h. Bars represent means and vertical lines are standard errors. Treatments differed significantly within each life stage (Kruskal - Wallis Analyses,  $P < 0.01$ ). Comparisons were not made between life stages.



phytophagous pentatomids including *C. hilare* Say, *N. viridula* L., and *E. servus* Say (Willrich et al. 2003). One unprecedented result of this study was the discovery of ovicidal activity of several RTU products including carbaryl, neem oil, and acetamiprid. Our assessment of their efficacies as ovicides is based on the failure of nymphs to hatch from eggs treated with these insecticides rather than an observation that nymphs hatched and were subsequently exposed to insecticides and died. Isman (2006) noted the toxicity of neem oil to a wide variety of soft-bodied insects and attributed its activity to physical effects and disulfides found in the oil. Davidson et al. (1991) and Caldwell (2005) noted the ovicidal activity of oils against a wide range of insects and mites. Bográn et al. (2006) list disruption of gas exchange and cell membrane structure and function as lethal attributes of oil-bases insecticides. In addition to their physical properties, plant essential oils are believed to have neurotoxic modes of action including disruption of interference with neuro-modulators and GABA-gated chloride channels (Isman 2006). Other insecticides showing high levels of ovicidal activity were well-known nerve poisons that bind to nicotinic receptors (acetamiprid) or inhibit acetylcholinesterase (carbaryl). We do not know the mode of action of any of these compounds as ovicides for eggs of *H. halys* and we suggest that this is a rich area for further study.

Topical applications and residues of the reduced risk insecticide spinosad demonstrated a trend for increased mortality of nymphs, but less so for adults. These results contrast with those of Kamminga et al. (2009) who found that adult *C. hilare*, and *E. servus* tended to be more susceptible to residues of spinosad than nymphs. Lee et al. (in press) also found significant mortality of *H. halys* adults exposed to spinosad. Three compounds, carbaryl, acetamiprid, and permethrin, exhibited relatively high levels of mortality. Carbaryl's performance was best as a topical spray increasing mortality in adults and nymphs. Residues of carbaryl were also effective in killing nymphs. Dry residues of carbaryl showed little effect on adults, a result consistent with those of Leskey et al. (2012b) who found the lethality of carbaryl residues to *H. halys* adults to be among the lowest of many compounds evaluated.

Acetamiprid elevated mortality of nymphs and adults relative to distilled water in topical spray trials at exposures of 48 h and to nymphs in residue trials of 48 and 1 h. Adults exposed to residues of acetamiprid for 1 or 48 h exhibited no greater mortality than adults exposed to distilled water controls. This result is consistent with the work of Kuhar et al. (2012) who found third instar nymphs to be highly susceptible to acetamiprid and adults less so. Acetamiprid provided moderate levels of control in field trials involving pep-

pers (Kuhar et al. 2012). Mortality of nymphs and eggs observed in trials reported here contrast with those of Leskey et al. (2012b), who found high initial lethality of *H. halys* adults to residues of acetamiprid that declined dramatically over 7 d. This disparity could be attributed to the fact that exposure time of *H. halys* to pesticides used were 4.5 h in the laboratory (Leskey et al. 2012b) and 24 h in the field (Leskey et al. 2013) whereas exposure times to topical sprays and their residues in trials reported here were continuous and lasted 48 h. Another potential limitation to the use of acetamiprid arises from the ability of stink bugs to recover from exposure to this compound (Leskey et al. 2012b). However, within 96 h no evidence of this phenomenon was found in the topical spray and dry residue trials reported here.

A further limitation regarding the efficacy of acetamiprid comes from the work of Tillman & Mullinix (2004) who observed intermediate levels of mortality of *E. servus* nymphs (40%) and adults (35%) exposed to residues of acetamiprid for 24 h. Field evaluations by Greene & Capps (2002) and Ngo et al. (2002) for *E. servus* found minimal efficacy of acetamiprid applications. By contrast, Rucker & Hamilton (2011) examined the efficacies of acetamiprid and several other compounds and found that acetamiprid alone or in combination with the growth regulator methoxyfenozide reduced the amount of cat-facing on apples caused by a complex of hemipterans consisting of *E. servus*, *E. tristigmus* Say, *C. hilare*, *H. halys*, and *Lygus lineolaris* Palisot de Beauvois. The variability of responses to acetamiprid indicates a strong need for further efficacy studies of this compound for control of *H. halys*.

Permethrin also dramatically increased mortality relative to water of nymphs and adults, but not eggs, as topical sprays and dry residues after exposure times of 1 and 48 h. These results are consistent with other laboratory assays that demonstrate high levels of mortality and lethality following the application of synthetic pyrethroids including permethrin (Nielsen et al. 2008b; Kuhar 2012; Leskey et al. 2012b). Unlike a study by Leskey et al. (2012b) that demonstrated no decline in efficacy of permethrin with time, the recovery trial reported herein indicated a decrease in apparent mortality at 96 h compared with 24 h. Clearly, these results are suggestive of knock-down recovery, and certainly deserve further attention.

Neem oil and its active ingredient azadiractin are insecticides popular amongst home vegetable growers and IPM practitioners (Isman 2006; Lee et al. in press). It is not surprising that topical sprays of neem oil failed to increase mortality of *H. halys* adults as the clarified hydrophobic extract of neem oil used in this study likely lacked azadiractin. Related studies of neem products containing azadiractin also found a lack of signifi-

cant mortality in *C. hilare* or *E. servus* nymphs and adults (Kammaing et al. 2009) and adults of *H. halys* (Lee et al. in press). However, results of the topical neem oil spray, 1 h exposure with second instar nymphs, demonstrated mortality exceeding 80%.

The other botanically-based insecticides, capsaicin and a mixture of essential oils, produced high levels of mortality as topical sprays to nymphs in 1 h exposure trials and slightly less so in 48 h topical spray studies. Lee et al. (in press) also reported activity of extracts of *Eucalyptus* sp. against adult *H. halys* in a recent study of insecticides used in the production of organic vegetables.

Horticultural oils and insecticidal soaps (potassium salts) are 2 groups of compounds often recommended for use in vegetable gardens due to their short period of residual activity, low mammalian toxicity, and general compatibility with integrated pest management programs (Davidson et al. 1991; Caldwell 2005). Potassium salts have been recommended as low toxicity insecticides for use against cabbage stink bugs, *Eurydema* spp. Indeed (Trdan et al. 2006) and Lee et al. (in press) recently demonstrated the susceptibility of *H. halys* adults to potassium salts. Horticultural oil performed well as a topical spray to *H. halys* nymphs with mortality ranging from 80 to 100%. As expected, oil residues had no significant effect on survival of nymphs or adults. Similarly, topical sprays of insecticidal soap killed from 80 to 100% of nymphs and produced surprisingly high mortality of eggs (87%). These findings are consistent with those of Lee et al. (in press) who reported significant mortality, more than 60%, of adult *H. halys* exposed to insecticidal soap (potassium salts of fatty acids). Egg mortality was unanticipated, as insecticidal soaps are not generally considered to be effective ovicides (Caldwell 2005). However, the efficacy of topical sprays is encouraging as horticultural oils and insecticidal soaps are readily available in many RTU formulations and are among the most common insecticides offered for use in home vegetable gardens.

In summary, these studies demonstrated the efficacy and lack thereof of several RTU insecticides in killing *H. halys* in controlled laboratory trails. Several compounds including carbaryl, permethrin, insecticidal soap, horticultural oil, and acetamiprid were active as topical sprays, dry residues, or both to one or more stages of *H. halys*. Mixtures of essential oils and the active ingredient capsaicin exhibited little activity against adults and variable efficacy against nymphs. Potential recovery of *H. halys* following applications of pyrethroids like permethrin and neonicotinoids like acetamiprid deserve further attention. Finally, before RTU insecticides can be confidently recommended to home gardeners for control of *H. halys*, the efficacy of these products as crop protectants should be evaluated in controlled trials

conducted under greenhouse and field conditions as efficacy under actual field conditions often lags dramatically behind efficacy observed under laboratory conditions (Leskey et al. 2013).

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