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Authors: Lee, Doo-Hyung, Short, Brent D., Nielsen, Anne L., and Leskey, Tracy C.

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IMPACT OF ORGANIC INSECTICIDES ON THE SURVIVORSHIP AND MOBILITY OF *HALYOMORPHA HALYS* (STÅL) (HEMIPTERA: PENTATOMIDAE) IN THE LABORATORY

DOO-HYUNG LEE[1,3,*], BRENT D. SHORT[1], ANNE L. NIELSEN[2] AND TRACY C. LESKEY[1]
[1]USDA-ARS, Appalachian Fruit Research Station, 2217 Wiltshire Road, Kearneysville, WV 25430-2771

[2]Rutgers University, 121 Northville Rd, Bridgeton, NJ 08302

[3]Corresponding author; E-mail: dl343@gachon.ack.dk

*Current address: Department of Life Sciences, Gachon University Seongnam-si, Gyeonggi-do, Republic of Korea

ABSTRACT

The invasive brown marmorated stink bug, *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae) has become a major concern for specialty and row crop growers in the United States. Management tactics against this new pest are currently limited to repeated synthetic insecticide applications, thereby making this problem even more challenging for the organic grower community. This study evaluated the insecticidal efficacy of organically-approved insecticides (azadirachtin, potassium salts of fatty acids, spinosad, pyrethrins, and pyrethrins + kaolin) and experimental biopesticides (*Chromobacterium subtsugae* Martin et al. strain PRAA4-1^{T} [MBI-203], extract of *Eucalyptus* sp. [MBI-205], and *Burkholderia* sp. [MBI-206]). These materials were presented as 18-h old dried residues against adult *H. halys* in the laboratory. Nonlethal effect on horizontal walking mobility of *H. halys* was evaluated during a 4.5-h insecticide exposure period; vertical walking mobility was measured at 4.5 h and 7 d after the insecticide exposure. All treatments, except for azadirachtin, resulted in significantly higher mortality of *H. halys* over 7 d, compared with the untreated control. Pyrethrins + kaolin, MBI-203, and MBI-206 resulted in ≥80% of individuals moribund or dead after 7 d. Horizontal walking distance of *H. halys* was significantly greater immediately and 3 h after exposure to pyrethrins and MBI-203, respectively, compared with the untreated control. After the 4.5-h exposure to potassium salts, pyrethrins, and pyrethrins + kaolin, surviving *H. halys* climbed significantly shorter distances while those exposed to MBI-203 climbed significantly greater distances compared with the untreated control, in the vertical mobility bioassay. After 7 d, there was no measurable difference, in the vertical walking distance by surviving individuals, between any of the tested materials and the untreated control. The results of the study are discussed within the context of developing effective management strategies for *H. halys* in organic production systems.

Key Words: brown marmorated stink bug, invasive species, lethality, mobility, pesticide

RESUMEN

El chinche hediondo café marmolado invasivo, *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae) se ha convertido en una preocupación importante para los agricultores de los Estados Unidos. Actualmente, las tácticas de manejo en contra de esta nueva plaga se limitan a las aplicaciones repetidas de insecticidas sintéticos, lo que hace el problema aún más difícil para la comunidad de agricultores orgánicos. Este estudio evaluó la eficacia de productos seleccionados de insecticidas orgánicos aprobados (azadiractina, sales de potasio de ácidos grasos, spinosad, piretrinas y piretrinas + caolín) y biopesticidas experimentales (*Chromobacterium subtsugae* [MBI-203], extracto de *Eucalyptus* sp. [MBI- 205], y *Burkholderia* sp. [MBI-206]) presentados como residuos secos por 18 horas contra los adultos de *H. halys* en el laboratorio. Se evaluó el efecto no letal en la movilidad horizontal de caminar de *H. halys* durante un período de exposición a insecticidas de 4.5 horas; se midió la movilidad vertical de caminar a las 4.5 horas y 7 días después de la exposición al insecticida. Todos los tratamientos, menos la azadiractina, resultaron en una mortalidad significativamente mayor de *H. halys* durante los 7 dias, en comparación con el control sin tratar. Las piretrinas + caolín, MBI-203 y MBI-206 resultaron en ≥ 80% de los individuos moribundos o muertos después de 7 días. La distancia horizontal de caminar de *H. halys* fue significativamente mayor inmediatamente después de la exposición a las piretrinas y 3 horas después de MBI-203, en comparación con el control no tratado. En el bioensayo de la movilidad vertical, los *H. halys* que sobrevivieron después de la exposición por 4.5 horas a las sales de potasio, piretrinas, y piretrinas + caolín subieron distancias significativamente más cortas, mientras que los expuestos a MBI-203 subieron significativamente mayores distancias en comparación con el control no tratado. Después de 7 días, no hubo una diferencia medible en la distancia vertical de caminar entre los materiales probados y el control sin tratar. En este estudio se discuten los resultados en el contexto de un desarrollar de programas de manejo eficaces para esta especie invasora en la producción orgánica.

Palabras Clave: *Halyomorpha halys*, especies invasoras, letalidad, movilidad, plaguicidas

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Invasive species are major environmental and economic threats to agroecosystems in the United States (Pimentel 2005). Recently, the invasive brown marmorated stink bug, *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae), has become a serious nuisance and agricultural pest in the mid-Atlantic region of the United States, particularly in tree fruit, vegetables, and row crops (Leskey et al. 2012c). *Halyomorpha halys* was accidently introduced from Beijing, China in the mid-1990s (Hoebeke & Carter 2003; Xu et al. 2013) and as of 2013 has been officially detected in 40 states and the District of Columbia based on state records and BMSB Working Group assessments (Leskey & Hamilton 2013). *Halyomorpha halys* is a very mobile and polyphagous pest with >100 host plants identified in Asia (Lee et al. 2013a) and the U.S. (Bernon 2004).

When *Halyomorpha halys* populations increased dramatically in the mid-Atlantic region, the use of insecticides by growers rapidly changed in response to the immediate threat posed by this new stink bug species. *Halyomorpha halys* adults and nymphs feed on numerous crops causing direct feeding injury on fruit (Leskey et al. 2012c). Following the devastating crop losses in 2010 in this region due to *H. halys*, growers were forced to rely on broad-spectrum chemistries (e.g., pyrethroids and carbamates) thereby deviating from sustainable IPM programs. Some tree fruit growers in the region increased the number of insecticide applications nearly four-fold in 2011 (Leskey et al. 2012a). Natural enemy abundance has plummeted, leading to frequent secondary pest outbreaks (e.g., mites and aphids). This type of management program is not financially or ecologically sustainable for growers and does not meet the needs for organic growers.

Organic production utilizes a diverse array of cultural and biological control tactics as alternatives to synthetic insecticides to reduce the level of crop injury by arthropod pests (Zehnder et al. 2007). Few alternatives to synthetic insecticides are available to organic growers for management of *H. halys* (Lee et al. 2013a) and therefore, organic insecticides may play a key role until cultural and biological control tactics are developed and adopted. Organic insecticides may also continue being used in conjunction with other management tactics. To date, very little is known regarding the efficacy of insecticidal materials approved for use in organic farming against *H. halys* and fewer organic insecticides are available compared with conventional insecticides that have proven effective against other pentatomids (Durmusoglu et al. 2003; Trdan et al. 2006; Mahdian et al. 2007; Kamminga et al. 2009).

Along with the lethal effects of insecticides, conventional and organic materials may also affect fecundity, feeding, and dispersal of target or non-target insects (Haynes 1988; Desneux et al. 2007). Laboratory bioassays have documented changes in *H. halys* motor skills (e.g., climbing and walking) after exposure to synthetic insecticides (e.g., pyrethroids) (Leskey et al. 2012b; Lee et al. 2013b). Given that *H. halys* is considered a highly mobile pest, adults could disperse within and among plots and farms even after exposure to insecticide residues. Therefore, the impact of insecticides on *H. halys* mobility should be considered when developing management programs.

In the study reported here, we evaluated the lethality of organically-approved insecticides and experimental biopesticides against adult *H. halys* in laboratory bioassays. Organically-approved insecticides are natural or synthetic products that have been produced through approved methods that have met specific requirements and are generally regarded as safe and "do not contribute to the contamination of crops, soil or water" as specified by USDA National Organic Program Rule 7 under section 205.600. Other products evaluated included: biopesticides, which refer to certain types of pesticides derived from such natural materials as animals, plants, bacteria, and certain minerals (EPA 2013) and kaolin clay which forms a dry particulate film and is known to discourage insect foraging and oviposition (Leskey et al. 2010). In addition to lethal toxicity, we also determined whether insecticide exposure affected walking mobility of adults on horizontal and vertical surfaces. This information will ultimately assist in development of effective management programs for this invasive species in organic agricultural production.

Materials and Methods

Lethality Test

Insecticide lethality was evaluated based on guidelines published by the International Organization of Biological Control (Candolfi et al. 2000) and general methods described in detail in Leskey et al. (2012b). Wild overwintering *H. halys* adults were collected from man-made structures in Jefferson and Berkeley County, WV. The insects were maintained with food including potted soybean plants, peanuts, carrots and sunflower seeds, and water in a laboratory colony at ~25 °C, ~60% RH and 16:8 h L:D for ≥2 wk to break diapause.

Organically-approved insecticides were mixed in accordance with the label recommendations for tree fruit at a rate of 935 L of water per ha. In addition to registered materials, three experimental biopesticides, MBI-203 (*Chromobacterium subtsugae* Martin et al. strain PRAA4-1^{T}) (Martin et al. 2007), MBI-205 (extract of *Eucalyptus* sp.) and MBI-206 (*Burkholderia* sp.) (Marrone BioInnovations, Davis, California), were tested (Table 1). At the completion of this study, MBI-203 (trade name: Grandevo) and MBI-206 (trade name: Venerate) have been approved by the National Organic Program. With the exception of kaolin clay and the experimental biopesticides, all materials were tested at the highest recommended rate. For each bioassay arena, 505 µl of formulated material was atomized onto glass Petri dishes and lids (100 × 15 mm; Kimble Chase, Vineland, New Jersey) and then dried under the fume hood for 18 h prior to the start of the bioassays. A total of eight insecticide treatments were evaluated in this study and water alone was used as an untreated control.

Thirty *H. halys* adults (sex ratio = 1:1) were evaluated individually for response to each insecticide within a treated Petri dish arena. Dishes for the untreated controls were atomized with water. Two untreated control treatments were included over the course of the bioassays for a total of 60 individuals. Adults were exposed individually to the dried residues for 4.5 h in the arena. After the 4.5-h exposure period, *H. halys* were transferred individually into clean 30-ml plastic cups (Jetware, Hatfield, Pennsylvania) with peanuts, sun-dried tomatoes, and water. Thereafter, adults were monitored daily over 7 d for survivorship and assigned a physical condition (alive, affected, moribund or dead). Each individual represented a replicate. *H. halys* rated as 'alive' showed no signs of intoxication, could move horizontally and vertically, and appeared to feed normally. An 'affected' bug was capable of moving, but with irregular, lethargic motions. A 'moribund' bug was nearly immobilized, typically lying on its dorsum and only capable of slight movements of a leg or antenna. A 'dead' bug no longer exhibited any movement, even in response to probing. The insecticide lethality was calculated as the percentage of 'moribund' plus 'dead' individuals for each daily observation period, and this mortality rate of *H. halys* was used to compare insecticide efficacy with the untreated control. The data were analyzed using a generalized linear model with binomial distribution for each daily observation period (JMP Genomics 5.0, SAS Institute Inc., Cary, North Carolina). *P*-values were adjusted using the Bonferroni correction for multiple comparisons. Each individual *H. halys* was evaluated in the following mobility tests over the course of the 7-d experiment period.

Mobility Test

Walking mobility of *H. halys* adults was evaluated on horizontal and vertical surfaces in the laboratory. Methods used in this study are described in greater detail in Lee et al. (2013b). Horizontal movement of *H. halys* was evaluated directly on insecticide-treated glass Petri dish arenas during a 4.5-h exposure period. *Halyomorpha halys* movement in the Petri dish arena was recorded using a video visualizer camera (RE-350, Canon, Inc., Tokyo, Japan) and analyzed using Noldus EthoVision software (version 3.1.16, Noldus Information Technologies, Wageningen, The Netherlands). Individual *H. halys* were recorded for 10-min periods at 0.0, 1.5, 3.0, and 4.5 h after introduction into the test arenas. The software was used to analyze video images of *H. halys* movements and calculate total distance and duration

TABLE 1. INSECTICIDES TESTED AGAINST ADULT *HALYOMORPHA HALYS* IN THE LABORATORY BIOASSAYS.

Trade Name	Active Ingredient	Recommended field rate	Tested rate
Neemix (4.5 EC)	Azadirachtin (4.5%)	292.2 mL-1.2 L/ha	1.2 L/ha
M-Pede (SL)	Potassium salts of fatty acids (49%)	1.0-2.0% v/v	2.0% v/v
Entrust (80W)	Spinosad (80%)	104.9-209.8 g/ha	209.8 g/ha
Pyganic (1.4 EC)	Pyrethrins (1.4%)	4.1-8.2 L/ha	8.2 L/ha
Surround (WP)	Kaolin (95%)	28.0-112 kg/ha	14.0 kg/ha
Grandevo[1] (AF)	*Chromobacterium subtsugae* (strain PRAA4-1T)	N/A	5.0% v/v
MBI-205[1] (AF)	Extract of *Eucalyptus* sp.	N/A	5.0% v/v
Venerate[1] (AF)	*Burkholderia* sp.	N/A	5.0% v/v

[1]These materials were experimental biopesticides when this study was conducted. Grandevo and Venerate were named MBI-203 and MBI-206, respectively, when tested in this study.

of movement recorded during the 10-min period. Because the conditions of the insects (alive, affected, moribund, and dead) were not assessed until the 4.5-h exposure period was completed, data included movement distances from adults that became incapacitated or died during the exposure period. Total distance and duration of movement was square-root transformed to normalize the data and compared among treatments using Tukey-Kramer HSD (JMP Genomics 5.0, SAS Institute Inc., Cary, North Carolina).

Following the 4.5-h exposure period in Petri dishes, *H. halys* were removed from the dishes and evaluated for vertical mobility. Distance climbed by surviving *H. halys* (i.e., 'alive' or 'affected') on the interior surface of polycarbonate cylinders (30 cm tall × 7 cm diameter) was recorded at 30-s intervals in three consecutive 5-min trials. The cylinder arena was inverted at the end of the 30 s if the insect reached the top of the arena. This test was conducted immediately following the 4.5-h exposure period and after 7 d for surviving individuals. Total distance climbed over the 15-min period was compared among treatments. For the data sets collected at 4.5 h, the distance was log-transformed and analyzed using Tukey-Kramer HSD. The data sets collected at 7 d were compared using Wilcoxon rank sums test due to relatively small sample sizes (i.e., the number of surviving *H. halys* after 7 d) (JMP Genomics 5.0, SAS Institute Inc., Cary, North Carolina).

Results

Insecticidal Efficacy

Overall, there was a significant difference in the lethality of *H. halys* adults (i.e., the percentage of 'moribund' plus 'dead' individuals) between the untreated control and insecticide treatments over a 7-d experiment period ($P < 0.001$) (Fig. 1). In general, the insecticide lethality increased over time, suggesting there was no significant recovery of *H. halys* from the moribund state after exposure to the insecticide residues evaluated in this study. Pyrethrins and pyrethrins + kaolin resulted in significantly higher lethality rates compared with the untreated control immediately

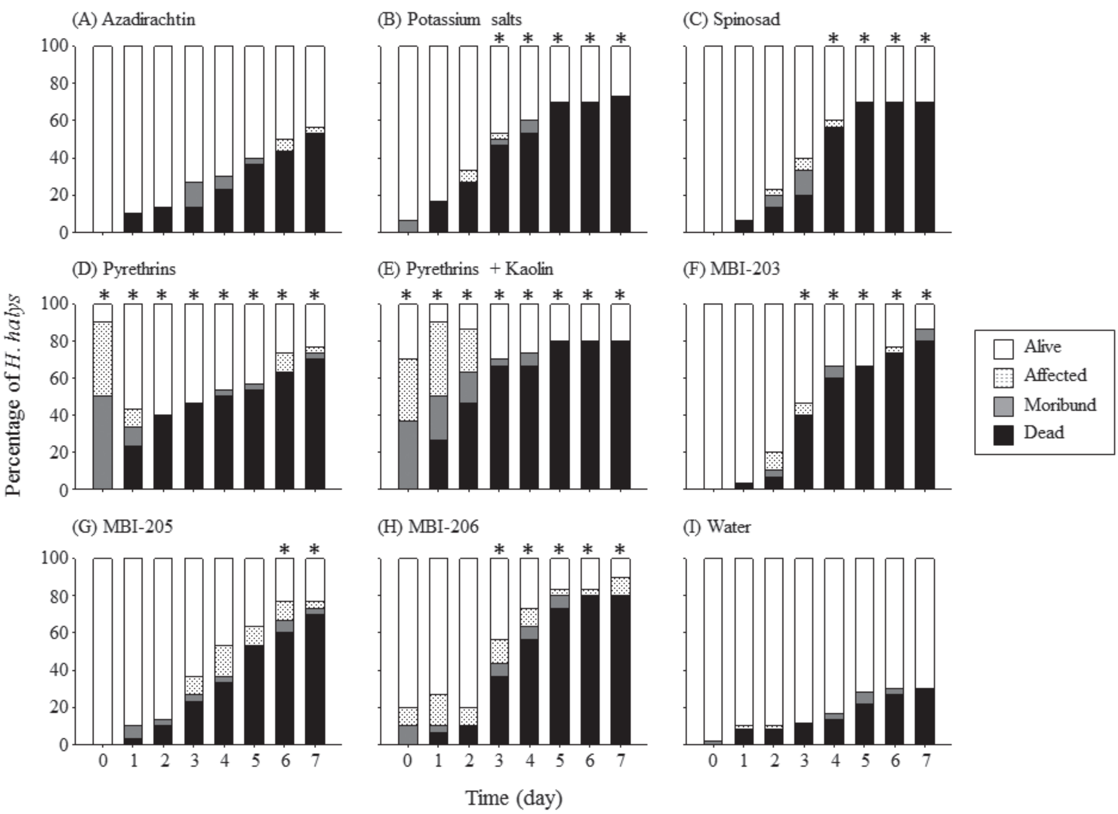

Fig. 1. Percentage of adult *Halyomorpha halys* by physical condition over 7 d following 4.5-h exposure period on insecticide-treated and untreated surfaces in the Petri dish arenas. Asterisk indicates that insecticide lethality (the percentage of 'moribund' plus 'dead' individuals) was significantly different from the untreated control ($P < 0.05$).

after 4.5-h insecticide exposure (pyrethrins: χ^2 = 29.520, df = 1, *P* < 0.001; pyrethrins + kaolin: χ^2 = 18.499, df = 1, *P* < 0.001). Other materials, except for azadirachtin, began to yield significantly higher lethality 3 d after the 4.5-h exposure to insecticide residues (P < 0.05). All materials, except for azadirachtin (χ^2 = 4.575, df = 1, *P* = 0.260), resulted in significantly higher rates of lethality of adults after 7 d, compared with the untreated control (*P* < 0.05) (Fig. 1). Among insecticide treatments, exposure to MBI-203 residues resulted in the highest lethality rate after 7 d.

Insect Mobility

In the Petri dish arenas treated with insecticides, *H. halys* adults exposed to pyrethrins moved significantly greater horizontal distances compared with the untreated control, during the first 10 min of insecticide exposure (*P* < 0.05) (Table 2). However, this elevated walking distance by pyrethrins was not observed during the first 10-min period when the material was applied with kaolin. At 1.5 h, horizontal distance moved by adults exposed to pyrethrins + kaolin was significantly less than the untreated control (*P* < 0.05). At 3.0 and 4.5 h, *H. halys* adults moved significantly longer distances and for longer periods of time compared with the untreated control when exposed to MBI-203 (*P* < 0.05).

For *H. halys* exposed to potassium salts, pyrethrins, and pyrethrins + kaolin, vertical distance climbed by surviving (i.e., 'alive' or 'affected') adults was significantly lower compared with the untreated control immediately after the 4.5-h exposure period (*P* < 0.05) (Table 3). Conversely, adults exposed to MBI-203 moved significantly greater distances compared with the control (*P* < 0.05) after the 4.5-h exposure period. At 7 d, there was no significant difference in the vertical distance moved by surviving *H. halys* compared with the untreated control for any of the treatments.

Discussion

Limited information is available for insecticidal efficacy of organically-approved materials against *H. halys*. Organically-approved materials and experimental biopesticides tested in this study had lethal effects on adult *H. halys* within the laboratory setting. With the exception of azadirachtin, exposure to insecticides resulted in significantly greater mortality of *H. halys* over a 7-d period compared with the untreated control. Pyrethrins and pyrethrins + kaolin resulted in knockdown effects on *H. halys* yielding signifi-

TABLE 2. MEAN HORIZONTAL MOVEMENT DISTANCE (CM) AND DURATION (S) OF ADULT *HALYOMORPHA HALYS* OVER A 10-MIN PERIOD AT 0.0, 1.5, 3.0, AND 4.5 H AFTER INTRODUCTION INTO THE PETRI DISH ARENAS.

	Distance ± SE (cm)[1]			
Active ingredient	0.0 h	1.5 h	3.0 h	4.5 h
Azadirachtin	73.60 ± 14.79 ab	96.24 ± 34.86 ab	156.87 ± 46.00 ab	117.44 ± 32.40 b
Potassium salts	83.48 ± 26.27 ab	65.49 ± 21.43 ab	53.25 ± 16.82 b	98.25 ± 26.24 b
Spinosad	22.88 ± 6.49 b	92.45 ± 33.85 ab	92.62 ± 33.47 b	90.45 ± 37.67 b
Pyrethrins	148.63 ± 33.55 a	99.42 ± 21.92 ab	95.35 ± 26.29 ab	124.89 ± 31.97 ab
Pyrethrins + Kaolin	59.53 ± 17.45 b	24.39 ± 8.96 b	33.01 ± 17.71 b	16.44 ± 6.06 b
C. subtsugae	60.44 ± 16.88 ab	222.78 ± 55.96 a	306.49 ± 67.44 a	351.35 ± 74.03 a
Eucalyptus sp.	40.24 ± 12.34 b	77.38 ± 17.35 ab	84.81 ± 25.19 ab	57.22 ± 29.99 b
Burkholderia sp.	28.23 ± 7.78 b	67.76 ± 21.99 ab	152.44 ± 43.83 ab	124.88 ± 28.48 ab
Water	63.27 ± 12.41 b	145.02 ± 26.19 a	91.53 ± 23.27 b	111.90 ± 25.16 b
	Duration ± SE (s)[1]			
	0.0 h	1.5 h	3.0 h	4.5 h
Azadirachtin	100.90 ± 20.91 ab	92.91 ± 29.88 ab	142.53 ± 33.31 ab	108.36 ± 25.23 ab
Potassium salts	87.74 ± 24.50 ab	73.73 ± 21.73 ab	61.42 ± 19.58 b	133.13 ± 35.03 ab
Spinosad	38.83 ± 12.50 b	87.16 ± 27.34 ab	92.05 ± 29.54 ab	81.28 ± 26.88 b
Pyrethrins	147.51 ± 26.78 a	108.84 ± 21.61 ab	98.51 ± 22.36 ab	128.50 ± 26.26 ab
Pyrethrins + Kaolin	77.60 ± 22.21 ab	38.52 ± 12.50 b	41.68 ± 18.86 b	32.07 ± 11.82 b
C. subtsugae	83.86 ± 21.26 ab	196.93 ± 42.04 a	240.87 ± 44.42 a	261.37 ± 43.39 a
Eucalyptus sp.	59.53 ± 20.08 b	101.25 ± 23.50 ab	103.38 ± 25.95 ab	56.60 ± 21.37 b
Burkholderia sp.	48.49 ± 14.76 b	79.60 ± 25.23 ab	150.47 ± 34.17 ab	148.57 ± 31.82 ab
Water	70.62 ± 12.48 ab	142.85 ± 22.89 ab	97.64 ± 21.64 b	108.46 ± 19.23 b

[1]Values in the same column followed by different letters are significantly different according to Tukey-Kramer HSD (*P* < 0.05).

TABLE 3. MEAN VERTICAL MOVEMENT DISTANCE (CM) OF ADULT *HALYOMORPHA HALYS* OVER A 15-MIN PERIOD AT 4.5 H AND 7.0 D AFTER EXPOSURE TO TREATMENTS.

	4.5 h[1]		7.0 d[2]	
Active ingredient	% surviving insects	Distance ± SE (cm)[3]	% surviving insects	Distance ± SE (cm)[3]
Azadirachtin	100	143.73 ± 33.81 b	47	46.86 ± 35.71 a
Potassium salts	93	2.96 ± 1.66 d	27	25.63 ± 14.84 a
Spinosad	100	148.07 ± 37.67 bc	30	12.33 ± 7.94 a
Pyrethrins	50	23.40 ± 17.94 cd	27	166.75 ± 87.19 a
Pyrethrins + Kaolin	63	3.74 ± 2.66 d	20	2.67 ± 0.92 a
C. subtsugae	100	365.90 ± 51.84 a	13	75.25 ± 40.61 a
Eucalyptus sp.	100	98.20 ± 33.13 bc	27	31.50 ± 19.96 a
Burkholderia sp.	90	155.85 ± 50.55 bc	20	1.83 ± 1.14 a
Water	98	107.56 ± 21.03 b	70	64.81 ± 23.83 a

[1]Data was log-transformed and analyzed using Tukey-Kramer HSD.
[2]Data was analyzed using Wilcoxon rank sums test.
[3]Values in the same column followed by different letters are significantly different ($P < 0.05$).

cantly higher lethality immediately after 4.5-h exposure to dried residues. Other materials generally resulted in significant insecticidal effects three or four days after the 4.5-h exposure period. There was virtually no recovery of *H. halys* from a moribund state after exposure to the organic compounds tested in this study. *H. halys* adults used in this study were older, overwintered bugs. Based on season-long trials examining the effect of residual activity of synthetic insecticides against *H. halys*, overwintered adults were much easier to kill with insecticides than new generation adults later in the season (Leskey et al. 2013). Thus, organic materials evaluated here may be more effective against overwintered adults, but less so against younger, new generation adults later in the season.

Other researchers have reported varying levels of efficacy of organic materials against other pentatomids. Pyrethrins, an organic insecticide group derived from *Chrysanthemum* spp. (Casida 1980), were effective against the green stink bug, *Chinavia hilaris* (Say), but not the brown stink bug, *Euschistus servus* (Say), in laboratory bioassays (Kamminga et al. 2009). We found that *H. halys* was susceptible to pyrethrins with 73% lethality after 7 d following 4.5-h exposure to dried residues. Trdan et al. (2006) recommended the use of potassium salts against cabbage stink bugs (*Eurydema* spp.) as a reduced toxicity insecticide, although its effectiveness was inferior to that of a synthetic insecticide such as malathion (organophosphate). A product containing fatty acid of the neem seeds and 25% potassium salt was effective on the southern green stink bug *Nezara viridula* (L.) nymphs but not adults (Durmusoglu et al. 2003). Here, we found that *H. halys* was susceptible to potassium salts but not to azadirachtin, a neem-based product. Spinosad has been tested and used for management of many insect pests (Sparks et al. 2012), such as Diptera (Burns et al. 2001), Lepidoptera (Zhao et al. 2002), and Thysanoptera (Eger et al. 1998). Kamminga et al. (2009) reported that spinosad was as effective as lambda-cyhalothrin in laboratory bioassays against *C. hilaris* and *E. servus*. Spinosad was also promising against *H. halys* in our studies, and this material has demonstrated selectivity against the predatory stink bug, *Picromerus bidens* (L.) (Mahdian et al. 2007).

Experimental biopesticides tested in this study exhibited insecticidal activity against *H. halys* at levels comparable with other organically-approved compounds (Fig. 1). MBI-203 is formulated from a strain of *Chromobacterium subtsugae* that has shown activity against Colorado potato beetle (*Leptinotarsa decemlineata* Say), yellowmargined leaf beetle (*Microtheca ochroloma* Stål), and southern green stink bug (*N. viridula*) (Martin et al. 2007; Balusu & Fadamiro 2012). MBI-205 is based on the extract of *Eucalyptus* sp. Eucalyptus essential oil has been demonstrated to possess a wide spectrum of biological activity including insecticidal and repellency effects on mosquitoes and flour beetles (Batish et al. 2008). MBI-206 consists of a new bacterial species of the genus *Burkholderia* isolated from soil with reputed broad insecticidal effects on chewing and sucking insects (Asolkar et al. 2013).

In addition to the lethal impact of insecticides, the tested materials were also evaluated for their effects on mobility of adult *H. halys*. Exposure to pyrethrins resulted in an immediate elevation in horizontal movement of *H. halys* compared with the untreated control. This activity waned after 1.5 h to levels observed in the untreated control. Pyrethroids, synthetic versions of pyrethrins, have been shown to cause similar immediate locomotive stimulation of *H. halys*, although synthetic pyrethroids typically yielded greater toxicity thereby leaving most individuals moribund within a 4.5-h exposure period (Leskey et al. 2012b; Lee et al. 2013b). There was also a significant increase in horizontal mobility in both distance and duration of *H. halys* movement after 3 h of exposure when exposed to MBI-203 indicating that the onset of insecticide effects was not as immediate as pyrethrins.

For vertical mobility, distances climbed by surviving *H. halys* after the 4.5-h exposure period was significantly less than the untreated control for potassium salts, pyrethrins, and pyrethrins + kaolin; however, the climbed distance was significantly greater for MBI-203. Changes in *H. halys* mobility are an important consideration in management programs in conjunction with insecticidal efficacy. For example, low initial knockdown but increased mobility of *H. halys* adults exposed to MBI-203 needs to be considered because the majority of surviving *H. halys* are likely to maintain the capacity to disperse from insecticide-treated areas. This may facilitate pest dispersals within/among crops. Alternatively, although speculative, MBI-203 could work as a repellent on crops. In contrast, pyrethrins + kaolin showed relatively rapid knockdown effects compared with other test materials and decreased the mobility of surviving *H. halys*, indicating that this treatment not only could result in high mortality, but also, perhaps, reduce the likelihood of surviving adults to escape from the treated area. Further studies are warranted to evaluate how these non-lethal effects would affect the overall management efficacy at larger scales in time and space.

Currently, organic growers have few options to effectively and sustainably manage *H. halys*. The results reported here indicate that some organically-approved insecticides and experimental biopesticides hold promise for management of *H. halys.* In general, the materials tested in this study yielded significantly higher mortality of *H. halys* and affected the insect mobility to varying degrees in the laboratory bioassays. The changes in mobility may have different implications for pest management depending on crop systems and pest pressure. This baseline information should be further validated in the field in order to develop appropriate treatment recommendations for organic growers.

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