Factors Affecting Captures of Brown Marmorated Stink Bug, *Halyomorpha halys* (Hemiptera: Pentatomidae), in Baited Pyramid Traps[1]

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Abstract Trapping experiments targeting brown marmorated stink bug, *Halyomorpha halys* (Stål), addressed the effects of: (1) a modification to the trap container of a commercial trap, (2) the age of methyl (2*E*,4*E*,6*Z*)-decatrienoate lures, and (3) the age of dichlorvos-impregnated kill strips on bug captures. In the trap modification study, ventilation holes in the containers atop standard, commercial AgBio™ traps were modified to resemble a USDA prototype trap. Captures were compared among the standard traps, modified commercial traps, and prototype traps. *Halyomorpha halys* captures were significantly greater in the prototype trap than in standard commercial traps, whereas captures in modified commercial traps were intermediate between but not significantly different from AgBio or prototype traps. Traps baited with kill strips that were fresh or that had been field-aged for 1, 2, 3 or 4 wk showed no significant differences in the total number of *H. halys* captured over a 15-d trapping interval, although the percentage of dead bugs was significantly greater in traps containing fresh kill strips than in those with 3- or 4-wk-old kill strips. In the aged lure experiment, captures were not significantly different among traps baited with fresh, 1- and 2-wk-old lures or among those baited with 2-, 3- or 4-wk old lures or unbaited. Most (64.8%) bugs were captured during the first 3-d sample interval, during which traps with fresh lures captured more *H. halys* than those with each aged lure treatment. Weekly gravimetric measurements to determine the release of methyl (2*E*,4*E*,6*Z*)-decatrienoate from lures over 4 wk showed a sharp decrease in lure weight during the first 3-d interval at 20 and 25°C.

Key words monitoring, trapping, methyl (2*E*,4*E*,6*Z*)-decatrienoate, kill strip

The brown marmorated stink bug, *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae), has recently become a serious threat to a variety of field crops, vegetables, small fruits, and tree fruits in the midAtlantic region of the U.S. (Nielsen and Hamilton 2009, Nielsen et al. 2011). Native to northeastern Asia, *H. halys* was detected near Allentown, PA, in 1996 (Hoebeke and Carter 2003) and has subsequently been detected or established in 36 states and the District of Columbia (A. Dowdy, pers. comm.). *Halyomorpha halys* undergoes 2 overlapping generations in northern Virginia and West Virginia (Leskey et al. 2012) and in 2010 its economic impact on the eastern apple crop was estimated at US$37 million (American/Western Fruit Grower 2011).

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The development and refinement of effective monitoring tools for *H. halys* will be essential to determine its range expansion and rate of establishment in new areas, its population density and distribution in areas where it is established, and to optimize management tactics and strategies. Leskey and Hogmire (2005) used yellow pyramid traps baited with methyl (2*E*,4*Z*)-decadieonate, the aggregation pheromone of *Euschistus* spp. (Aldrich et al. 1991), to monitor native stink bug species in West Virginia. Methyl (2*E*,4*E*,6*Z*)-decatrienoate is the aggregation pheromone of the brown-winged green bug, *Plautia stali* Scott (Sugie et al. 1996), is cross attractive to other stink bug species, including *H. halys* (Aldrich et al. 2007, Khrimian et al. 2008) late in the season, and is currently the only semiochemical-based monitoring option for *H. halys*. From studies in 2010 using black pyramid traps, Leskey et al. (2012) reported that those baited with methyl (2*E*,4*E*,6*Z*)-decatrienoate captured more *H. halys* than baited and unbaited traps of other colors and that ground-deployed black pyramid traps collected more bugs than other commercially available trap types from Asia.

In spring 2011, numerous investigators deployed black pyramid traps (AgBio Development Inc., Westminster, CO) containing half of a dichlorvos-impregnated kill strip and a 66 mg methyl (2*E*,4*E*,6*Z*)-decatrienoate lure in various agricultural and nonagricultural settings. By midsummer, all investigators reported that *H. halys* captures were very low despite using ~10-fold higher rates than were used in previous studies (Aldrich et al. 2007, Khrimian et al. 2008) and that *H. halys* was not attracted to methyl (2*E*,4*E*,6*Z*)-decatrienoate early in the season. This finding prompted us to examine several potential factors related to the attraction and retention of bugs in pyramid traps. Whereas the prototype collection container used by Leskey et al. (2012) was ventilated via 4 sets of 3 holes (2.54 cm diam) covered by screen (Fig. 1a), the standard AgBio trap container was perforated with small holes (1 mm diam) (Fig. 1b), leading us to question whether differences in ventilation affected attractant release and bug captures. Leskey et al. (2012) showed that black pyramid traps baited with a

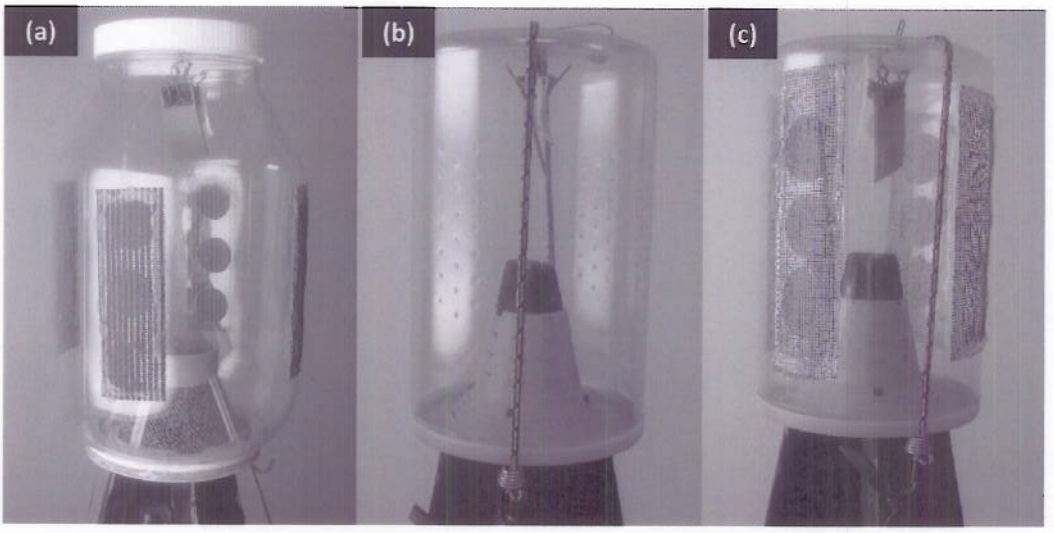

Fig. 1. Black pyramid trap types with (a) prototype, (b) unmodified commercial, and (c) modified commercial containers.

50 mg methyl (2*E*,4*E*,6*Z*)-decatrienoate lure captured more *H. halys* per week than unbaited traps. Furthermore, Leskey et al. (2012) reported that inclusion of a kill strip in lure-baited pyramid traps increased *H. halys* captures by 250%. Although the effects of lure and kill strip age on *H. halys* have not been examined specifically, previous studies have relied on replacement of these essential trap components at 4-wk and 2-wk intervals, respectively, assuming that this would mitigate potential problems with bug attraction to and retention in traps as lures and kill strips aged (Leskey et al. 2012). In this study, we addressed the effects of 3 fundamental mechanistic factors, trap ventilation, lure age, and kill strip age on *H. halys* captures in pyramid traps.

Materials and Methods

Traps. Black pyramid traps constructed from plywood were obtained from AgBio, Inc. (Westminster, CO) and compared with the USDA prototype trap used by Leskey et al. (2012). The dimensions of the pyramidal base of both traps were similar, 1.1-m tall and ~51 cm diam at the bottom. The bug collection device mounted atop the prototype trap consisted of a clear, plastic container (1.9 L) within which an inverted, screened boll weevil funnel was attached to the apex of the base (Fig. 1a). The opening in the funnel (~0.75 cm diam) was fringed; this design was effective at reducing escape of native stink bugs (Hogmire and Leskey 2006) but not *H. halys* (Leskey et al. 2012). Four sets of three 2.54 cm diam holes around the container were covered with vinyl-coated, woven, fiberglass screen (70% sun block, McMaster-Carr, Elmhurst, IL) for ventilation. The collection container on the standard AgBio traps also topped with a removable, inverted clear plastic container (1.9 L) snap to an inverted yellow plastic funnel with a 2.5-cm diam opening attached to the trap base (Fig. 1b, c). There were 4 sets of 23, 1-mm diam holes around the unmodified AgBio trap containers, spaced 1 cm apart over 14 cm^2 (Fig. 1b). Modified AgBio trap containers had ventilation holes that matched those in the prototype trap (Fig. 1c). Each trap was baited with a 66 mg methyl (2*E*,4*E*,6*Z*)-decatrienoate lure (AgBio Inc., Westminster, CO) and one half of a 2.5 × 9.5 cm (2.5 × 4.7 cm) kill strip (Hercon® Vaportape II, Hercon Environmental, Emigsville, PA) suspended from the top of the container. Half pieces of the 2.5 × 9.5 cm kill strips have been shown to kill stink bugs effectively (Leskey et al. 2012).

Effect of trap container modification. In VA, traps were deployed along the edge of a wooded area adjacent to a commercial apple orchard near Winchester, whereas traps in WV were deployed in the 4 m wide zone between a 65 ha corn field and a woodlot near Kearneysville. The orchard site had been severely impacted by hail early in the growing season and had received minimal insecticide applications subsequently, none of which specifically targeted *H. halys*. In VA, traps were deployed in a randomized block design, with 1 replicate of each treatment in each of 5 blocks. Traps within each block were rotated among positions at weekly intervals for 4 wk from 1 - 29 September; each treatment was represented at least once at each position. In WV, traps were placed at locations at which large numbers of *H. halys* had been observed, were not rotated during the study, and were sampled 3 × weekly from 29 July to 19 August. At both locations, traps within replications and between blocks were spaced at 50 m intervals.

Effect of aged lures and kill strips. The effects of lure and kill strip age on bug captures were evaluated in separate experiments in which the modified commercial traps were deployed along the edge of a wooded area adjacent to a commercial apple orchard near Winchester, VA. This orchard had received minimal insecticide applications,

none of which specifically targeted *H. halys*. Each experiment was arranged in a randomized block design, with 1 replicate of each treatment in each of 4 blocks. For the aged kill strip study, traps within blocks were spaced at 50 m intervals, with 100 m between adjacent blocks. Due to space constraints associated with an additional treatment in the aged lure study, traps were spaced at 50 m intervals within blocks, with 50 m between adjacent blocks. In preparation for each experiment, half pieces of 2.5 × 9.5 cm kill strips or lures containing 66 mg of methyl (2*E*,4*E*,6*Z*)-decatrienoate were field-aged for 0, 1, 2, 3, and 4 weeks (treatments) by hanging them from the branches of trees at the edge of a forested area at the Virginia Tech Alson H. Smith, Jr. Agricultural Research and Extension Center, Winchester, VA. Treatments were deployed in traps by suspending them from the top of the container and, depending on the experiment, paired with either a fresh lure or a fresh kill strip. For the aged lure study, a 5th treatment included traps with a kill strip but no lure.

Based on trapping data from 2010, showing that peak captures in these traps occurred from late July through September, the kill strip and lure experiments were conducted from 22 August to 6 September and from 12 - 30 September, respectively. Bug captures were recorded and traps were rotated among positions within each block at 3-d intervals, so that each treatment was represented at least once at each location. At each sample date, bugs were removed from the traps and the number of live and dead adult and nymphal *H. halys* was recorded. Adult gender was determined and nymphal instars were identified following Hoebeke and Carter (2003). Bug count data were square root-transformed; whereas, all proportion data were arcsine square root-transformed to reduce heteroscedasticity and analyzed using the general linear model (GLM) procedure of SAS Institute (2008). Means were separated using Tukey's HSD method, and all statistical comparisons were considered significant at $\alpha < 0.05$.

Gravimetric analyses were performed on 66 mg methyl (2*E*,4*E*,6*Z*)-decatrienoate lures (AgBio Inc., Westminster, CO). Fresh lures were purchased and held in a freezer at -23°C until the study began. Five lures were held individually in open 29.6-mL cups in a fume hood (Hamilton Industries Two Rivers, WI, Model PL-183) at 20 ± 1°C and in a controlled environment chamber (Percival Scientific, Inc., Perry, IA, Model 136VL) at 25 ± 0.5°C. The initial weight of each lure was measured 20 min after removal from the freezer, using a LECO-250 Balance (LECO Corporation, St. Joseph, MI). Subsequently, each lure was weighed at 3-d intervals for 4 wk from 10 January to 3 February 2012.

Results and Discussion

Effect of trap container modification. In the experiment comparing prototype, standard commercial and modified commercial traps, total *H. halys* captures were 1,809 and 1,643 at the Kearneysville and Winchester sites, respectively. Captures at Kearneysville were predominantly nymphs (92.3%); whereas, adult captures predominated (73.4%) at Winchester. The different proportions of nymphal and adult bugs captured in the 2 studies reflect the periods during which traps were deployed, and conform to the results from previous studies (Leskey et al. 2012, Bergh, unpubl. data) showing that nymphal and adult captures predominated in late July through early September and through the rest of September, respectively. Significantly more *H. halys* were captured in the prototype traps compared with standard commercial traps at Kearneysville ($F = 7.7$; df = 2, 85; $P < 0.001$) (Fig. 2a) and Winchester ($F = 3.9$; df = 2, 53; $P = 0.026$) (Fig. 2b), whereas bug captures in modified commercial traps were

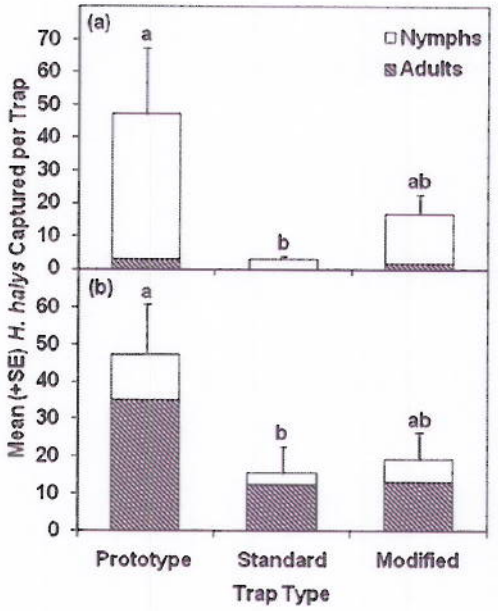

Fig. 2. Captures of *H. halys* adults and nymphs in prototype, standard commercial, and modified commercial traps at (a) Kearneysville, WV (29 July – 19 August, 2011) and (b) Winchester, VA (1 - 29 Sept. 2011). Bars with the same letter are not significantly different (Tukey's HSD Test: $\alpha < 0.05$).

intermediate between but not significantly different from the prototype or standard commercial traps. It appears that creating larger ventilation holes in the container of commercial traps, resembling those in the prototype trap, did not increase *H. halys* captures compared with the unmodified commercial traps, and that other physical features of the trap base or trap containers affected the attraction and/or retention of bugs.

Effect of aged lures and kill strips. Of 3,228 *H. halys* captured in the aged kill strip experiment, 75.7% were nymphs (93.1% fourth and fifth instars), and the remainder adults (~1:1 sex ratio) (Fig. 3), again conforming to previous results with respect to the relative proportions of life stages captured during that trapping period. The average total number of *H. halys* collected per trap over the 15-d trapping interval did not differ among kill strip treatments ($F = 0.5$; df = 4, 92; $P = 0.736$), but the percentage of dead bugs was significantly greater in the 0-wk-old treatment ($F = 4.1$; df = 4, 92; $P = 0.004$) than in the 3- and 4-wk-old treatments (Fig. 3). Although the percentage of dead bugs was slightly lower in traps with 3- or 4-wk-old kill strips than with fresh kill strips, total captures were not affected by kill strip age. This suggests that one half of a 2.5 × 9.5 cm Hercon Vaportape II kill strip should kill bugs or intoxicate them sufficiently to reduce their escape from traps for at least 4 wk. Alternatively, new *H. halys* may enter the trap, whereas others leave, masking the effect of kill strip age. Leskey and Wright (unpubl. data) recently found that in laboratory trials, retention rates in collection containers provisioned with fresh kill strips averaged ~80%. Perhaps, another method for conducting this study would be to age kill strips and then release known numbers of *H. halys* into collection containers to examine overall retention rates.

In the aged lure experiment, a total of 508 *H. halys* were captured, which were mostly (77.9%) adults (~1:1 sex ratio) (Fig. 4a), as would be expected based on the

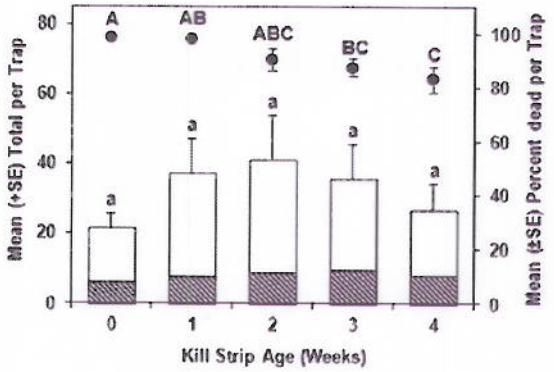

Fig. 3. Captures of *H. halys* in traps with half pieces of aged, dichlorvos-impregnated kill strips and percentage dead *H. halys* (22 August–6 September, 2011). Hatched and unhatched portions of bars represent adults and nymphs, respectively. Solid circles represent percentage dead bugs. Bars and circles with the same letter are not significantly different (Tukey's HSD Test: $\alpha < 0.05$).

12 - 30 September trapping period. Overall, there was a significant effect of lure age on captures ($F = 7.9$; df = 5, 135; $P < 0.001$) (Fig. 4a). Captures in traps baited with 0-, 1- and 2-wk-old lures were not significantly different. As well, captures did not differ significantly among unbaited traps or those containing 2-, 3- or 4-wk old lures. Most (64.8%) bugs were caught during the first 3-d sample interval, during which there was a significant or numerical separation among treatments ($F = 16.8$; df = 5, 15; $P < 0.001$) (Fig. 4b). Captures declined markedly during subsequent sample intervals. This result was consistent with and may be at least partially explained by the gravimetric analyses. At 20 and 25°C, the dispensers showed a high release rate of methyl (2*E*,4*E*,6*Z*)-decatrienoate during the first 3-d interval, followed by a relatively constant release at a much lower level over the following ~3.5 wk (Fig. 5), suggesting that the high captures recorded during the first 3-d interval may have been largely in response to this initial burst of attractant. The large reduction in captures during the subsequent 3-d sample intervals may have been a behavioral response to the lower release rate, demonstrated by the gravimetric analysis, and also to other potentially confounding factors. A 4-d period of cooler weather following the first 3-d sample interval (Fig. 4c) may have contributed to the reduced captures by simultaneously affecting attractant release rate and bug activity, although captures did not rebound after daily temperatures returned to levels equivalent to those during the first 3-d interval (Fig. 4c). Because this compound may be considered unstable in the field conditions, this also may have influenced the temporal changes in bug captures that we recorded.

In conclusion, our study illustrated the need for additional research on the physical features of pyramid traps and on the other trap components required to monitor *H. halys*, especially those that influence bug movement to the trap, into the trap container, and subsequent intoxication and retention. It is evident that further work to address the release rate and longevity of the attractant dispenser is required. In the absence of a species-specific aggregation pheromone for *H. halys,* traps baited with methyl (2*E*,4*E*,6*Z*)-decatrienoate remain the only current semiochemical-based

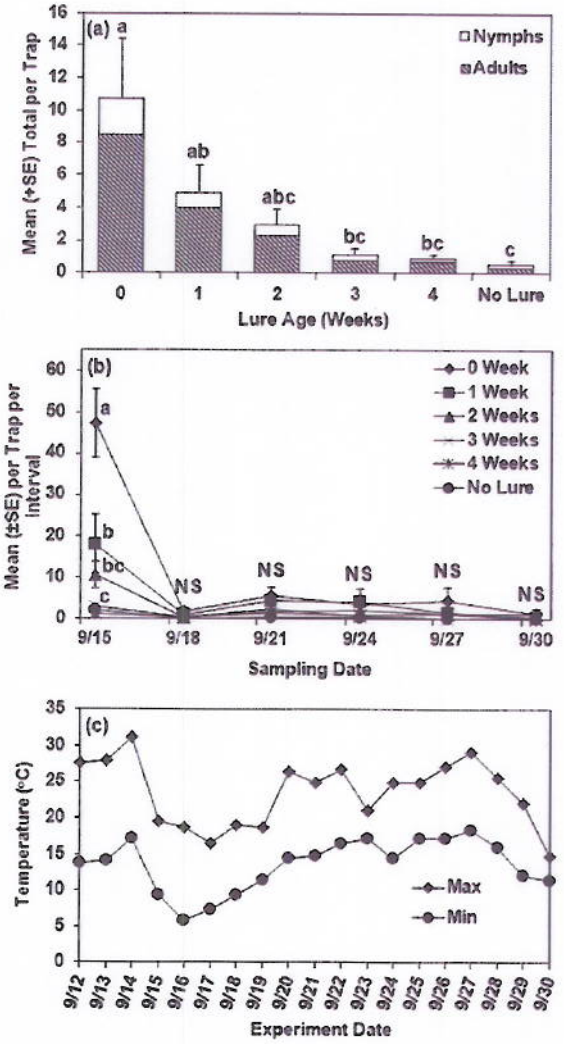

Fig. 4. Captures of *H. halys* in traps with aged, methyl (2*E*,4*E*,6*Z*)-decatrienoate lures during (a) the entire trapping period (12 - 30 September, 2011) and (b) per 3-d interval. Daily high and low temperatures during the experiment are shown in (c). Bars (a) or lined data-points (b) (within same sampling date) with the same letter are not significantly different (Tukey's HSD Test: $\alpha < 0.05$).

monitoring option for this pest. Given that the *H. halys* aggregation pheromone will ultimately be identified and commercially available, its use in a refined and optimized trapping system should tremendously improve the ability of researchers and growers to respond to this serious on-going threat.

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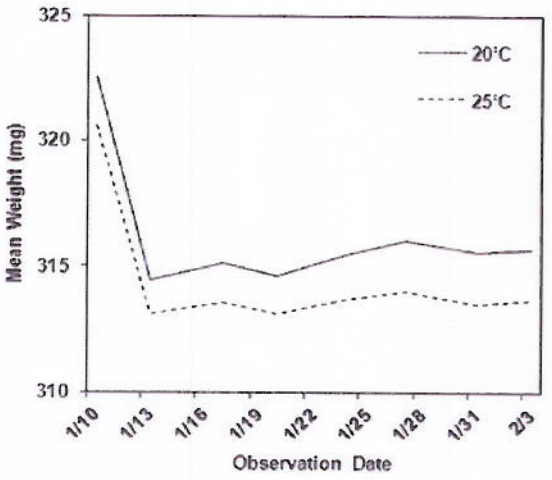

Fig. 5. Gravimetric analysis at weekly intervals of lures containing 66 mg of methyl (2*E*,4*E*,6*Z*)-decatrienoate and held at 20°C in a fume hood (5 lures) and at 25°C in a controlled environmental chamber (5 lures).

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References Cited

Aldrich, J. R., A. Khrimian and M. J. Camp. 2007. Methyl 2,4,6-decatrienoates attract stink bugs and tachinid parasitoids. J. Chem. Ecol. 33: 801-815.

Aldrich, J. R., M. P. Hoffmann, J. P. Kochansky, W. R. Lusby, J. E. Eger and J. A. Payne. 1991. Identification and attractiveness of a major pheromone component for Nearctic *Euschistus spp.* stink bugs (Heteroptera: Pentatomidae). Environ. Entomol. 20: 477-483.

American/Western Fruit Grower. 2011. Brown Marmorated Stink Bug Causes $37 Million in Losses to Mid-Atlantic Apple Growers. 2011 Apr 14. http://www.growingproduce.com/ news/afg/index.php?storyid=5372. Accessed 2011 Aug 2.

Hoebeke, E. R. and M. E. Carter. 2003. *Halyomorpha halys* (Stål) (Heteroptera: Pentatomidae): a polyphagous plant pest from Asia newly detected in North America. Proc. Entomol. Soc. Wash. 105: 225-237.

Hogmire, H. W. and T. C. Leskey. 2006. An improved trap for monitoring stink bugs in apple and peach orchards. J. Entomol. Sci. 41: 9-21.

Khrimian, A., P. W. Shearer, A. Zhang, G. C. Hamilton and J. R. Aldrich. 2008. Field trapping of the invasive brown marmorated stink bug, *Halyomorpha halys*, with geometric isomers of methyl 2,4,6-decatrienoate. J. Agric. Food Chem. 56: 197-203.

Leskey, T. C. and H. W. Hogmire. 2005. Monitoring stink bugs in mid-Atlantic apple and peach orchards. J. Econ. Entomol. 98: 143-153.

Leskey, T. C., S. E. Wright, B. D. Short and A. Khrimian. 2012. Development of behaviorally based monitoring tools for the brown marmorated stink bug, *Halyomorpha halys* (Stål) (Heteroptera: Pentatomidae) in commercial tree fruit orchards. J. Entomol. Sci. 47: 76-85.

Nielsen, A. L. and G. C. Hamilton. 2009. Seasonal occurrence and impact of *Halyomorpha halys* (Hemiptera: Pentatomidae) in tree fruit. J. Econ. Entomol. 102: 1133-1140.

Nielsen, A. L., G. C. Hamilton and P. W. Shearer. 2011. Seasonal phenology and monitoring of the non-native *Halyomorpha halys* (Hemiptera: Pentatomidae) in soybean. Environ. Entomol. 40: 231-238.

SAS Institute. 2008. Version 9.2, SAS Institute Inc., Cary, NC.

Sugie, H., M. Yoshida, K. Kawasaki, H. Noguchi, S. Moriya, K. Takagi, H. Fukuda, A. Fujiie, M. Yamanaka, Y. Ohira, T. Tsutsumi, K. Tsuda, K. Fukumoto, M. Yamashita and H. Suzuki. 1996. Identification of the aggregation pheromone of the brown-winged green bug *Plautia stali* Scott (Heteroptera: Pentatomidae). Appl. Entomol. Zool. (Jpn.) 31: 427-431.