Journal of Economic Entomology Advance Access published February 8, 2015

Temporal Effects on the Incidence and Severity of Brown Marmorated Stink Bug (Hemiptera: Pentatomidae) Feeding Injury to Peaches and Apples during the Fruiting Period in Virginia

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J. Econ. Entomol. 1–8 (2015); DOI: 10.1093/jee/tou059

ABSTRACT Exclusion cages were used to compare the incidence and severity of feeding injury from brown marmorated stink bug, *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae), on 'Redhaven' peaches, 'Golden Delicious' apples, and 'Smoothee Golden' apples at harvest, following sequential periods of exposure to natural *H. halys* populations during the 2011 and 2012 growing seasons in Virginia. The fruit used in these experiments were in orchards or on trees that were not managed for *H. halys*. Treatments were sets of 50 fruit that were always caged, never caged, or exposed during one interval during the fruiting period of peaches and apples in the Mid-Atlantic region of the United States. The cages effectively prevented feeding injury from *H. halys*. Peaches and apples that were never caged showed the highest percentages of injured fruit at harvest. Exposure treatment had a significant effect on the percentage of fruit showing external injury at harvest in both years for apples and in 2012 for peaches, and a significant effect on the percentage of apples and peaches showing internal injury at harvest in both years. There was no consistent effect of each exposure period on peach injury, but apples exposed during the mid- to latter portion of the season tended to show most injury. Across all exposure periods, more internal than external injuries were recorded at harvest from peaches, while apples tended to have equal or very similar numbers of both kinds of injury. The implications of these results to *H. halys* management in eastern apple orchards are discussed.

KEY WORDS *Halyomorpha halys*, *Malus domestica*, *Prunus persica*, injury

Introduction

Brown marmorated stink bug, *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae), emerged as a serious threat to numerous crops in the Mid-Atlantic region of the United States during the 2010 growing season (Nielsen and Hamilton 2009, Leskey et al. 2012a) and its range has subsequently has expanded to 41 states (Northeastern IPM Center [2012] [www.stopbmsb.org]). Significant economic losses from *H. halys* have been reported from peaches, apples, some small fruits, vegetables, and row crops (Leskey et al. 2012a); its economic impact on the apple crop in 2010 was estimated at US$37 million (American/Western Fruit Grower 2011). Being highly polyphagous, *H. halys* feeds and reproduces on a broad range of cultivated plants and wild hosts that often border cropland (Hoebeke and Carter 2003, Lee et al. 2013). In response to this threat, some Mid-Atlantic tree fruit growers increased their insecticide spray applications by as much as fourfold in 2011 (Leskey et al. 2012b), using mostly broad-spectrum chemistries with demonstrated activity against the pest (Leskey et al. 2012b,c).

Although native stink bugs such as brown, *Euschistus servus* (Say), dusky, *Euschistus tristigmus* (Say), and green, *Acrosternum hilare* (Say), and the tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois), have long been considered perennial pests of tree fruit in the Mid-Atlantic region, researchers and growers in this area have ascribed the tremendous increase in feeding injury from this pest complex since 2010 to *H. halys*. Typically, only adults of native stink bugs feed on fruit, whereas both nymphs and adults of *H. halys* can cause feeding injury, particularly because *H. halys* can reproduce in commercial orchards (Leskey et al. 2012b) and their strong nymphal dispersal capacity (Lee et al. 2014) can lead to them moving into blocks from orchard edges. Beyond the many anecdotal reports and observations of high pest pressure and injury from *H. halys* in affected crops and of the often massive inundation of some buildings and homes by adults in the fall, previous and current studies support the fact that the population density of *H. halys* in the Mid-Atlantic region is orders of magnitude greater

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Fig. 1. *H. halys* feeding injury on peach fruit: (a) surface deformation/depression; (b) internal necrosis.

than that of the aforementioned species combined. For example, Leskey and Hogmire (2005) recorded season-long captures of native stink bugs in managed and abandoned peach and apple orchards in West Virginia using pyramid traps baited with commercial lures containing ∼200 mg of the *Euschistus* spp. aggregation pheromone, methyl (2*E*,4*Z*)-decadienoate (Aldrich et al. 1991). Between 2002 and 2003, the largest cumulative captures occurred in 2003, during which total captures of adult brown, dusky, and green stink bugs combined ranged from 79.7 ± 47.7 SE in the managed apple orchard to 22.0 ± 3.2 SE in the abandoned peach orchard. In contrast, pyramid traps baited with a pair of lures containing ∼ 10 mg of the *H. halys* aggregation pheromone, (3*S*,6*S*,7*R*,10*S*)- and (3*R*,6*S*,7*R*,10*S*)-10,11-epoxy-1-bisabolen-3-ol, (Khrimian et al. 2014) and 60–66 mg of the *H. halys* pheromone syngerist, methyl (2*E*,4*Z*)-decadienoate (Weber et al. 2014), captured 5,635 and 7,471 *H. halys* nymphs and adults in 2012 at sites in West Virginia and Maryland, respectively. Maximum fortnightly captures of nymphs plus adults in 2012 were 2,626 in West Virginia and 2,211 in Maryland. A homeowner in rural Maryland collected 26,205 overwintering adult *H. halys* from the attic and living spaces of his residence between January and June 2011 (Inkley 2012). Annual surveys of the stink bug species in southwestern Virginia raspberry plantings in 2008–2009 and 2011–2013 revealed that *H. halys* was first detected in 2011 and subsequently became the predominant species in that system (Basnet et al. 2014).

In Virginia and West Virginia, the emergence of *H. halys* adults from overwintering sites begins in April and peaks between late May and early June (Bergh and Leskey 2015), which, in a typical season, spans the early stages of development of stone and pome fruit. Leskey et al. (2012b) observed severe *H. halys* feeding injury to young peach fruit in May. *H. halys* has two overlapping generations in northern Virginia and West Virginia (Leskey et al. 2012d) and is present continuously from April through about mid-October. Although the seasonal patterns of movement of *H. halys* among its many wild and cultivated host plants remain poorly understood, adult and nymphal populations on various wild hosts adjacent to orchards during most of the growing season pose an ongoing threat to fruit crops. From late August through much of September, large populations of *H. halys* adults and nymphs have been observed and trapped in and around Mid-Atlantic orchards (Nielsen and Hamilton 2009, Leskey et al. 2012b, Joseph et al. 2013). In Virginia, West Virginia, and Maryland, mass movement of adults to overwintering sites occurs between late September and early October.

On very young peach fruit, external injury from *H. halys* feeding is expressed as discrete areas of gummosis and surface discoloration or deformations that may become more pronounced in mature fruit (Fig. 1a). Internal injury to young and mature peaches is expressed as discrete or coalesced areas of discolored necrotic tissue (Fig. 1b; Leskey et al. 2012b). *H. halys* feeding through the skin of apple fruit causes small holes (Fig. 2a), which can lead to discolored spots or depressions of varying size and intensity on the fruit surface (Fig. 1b) and discrete areas of brown, necrotic tissue internally (Fig. 1c; Leskey et al. 2009, Brown and Short 2010). The internal injury is similar in appearance to the effects of a physiological disorder caused by calcium deficiency in some apple cultivars, known as cork spot (Brown 2003a,b), although when associated with *H. halys* feeding, it can be confirmed by the presence of a feeding sheath that is usually perpendicular to the fruit surface and extends into the flesh beneath surface injury (Fig. 2d; Leskey et al. 2009).

The unfortunate need for aggressive and frequent intervention using broad-spectrum chemistries against *H. halys* in many eastern tree fruit orchards has resulted in significant disruption of orchard integrated pest management (IPM) practices and increased incidences of secondary pest outbreaks. A return to less ecologically disruptive orchard pest management programs will require research on numerous fronts, including ways by which growers may refine their programs to minimize *H. halys* injury at harvest, mitigate adverse effects on natural enemies of secondary pests, and reduce labor and material costs. Understanding the relative risk from *H. halys* to stone and pome fruit at points throughout their respective fruiting periods would help producers refine their management

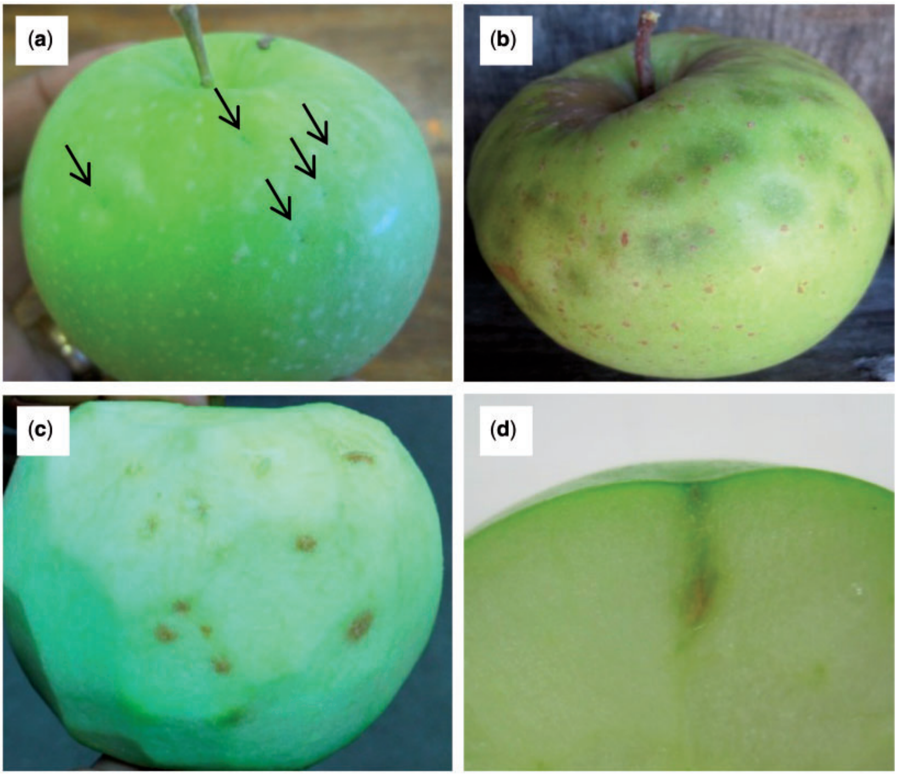

Fig. 2. *H. halys* feeding injury on apple fruit: (a) feeding puncture; (b) discolored depressions; (c) internal necrosis; and (d) stylet sheath.

programs. Accordingly, the objective of the study reported here was to determine the incidence and severity of injury to peaches and apples exposed to natural populations of *H. halys* during discrete intervals throughout the fruiting period.

Materials and Methods

Orchard Sites. Studies were conducted in 2011 and 2012 in experimental peach and apple orchards at Virginia Tech's Alson H. Smith, Jr., Agricultural Research and Extension Center, Winchester, VA. The same peach orchard was used in both years, while a different apple orchard was used each year. The 0.2-ha 'Redhaven' peach orchard was planted in 2002 and its center was ~72 and ~80 m from woodlots with wild hosts of *H. halys* to the east and west, respectively. In 2011, 35-yr-old 'Golden Delicious' apple trees on M.111 rootstock were used. The trees were interspersed within a 1.5-ha orchard of 'Redspur Delicious' apples, the center of which was ~113 and ~116 m from woodlots to the southeast and west, respectively. In 2012, a 1.1-ha orchard of 4-yr-old 'Smoothee Golden' apple trees on EMLA.26 rootstock was used, and had woodlots at ~198 and ~51 to the east and west of its center, respectively.

Disease management in the orchards followed standard recommendations for this region (Virginia Cooperative Extension 2012). In 2011, the peach trees sampled were not treated with insecticides. In 2012, maintenance insecticides applied to in the entire peach orchard between prebloom and petal fall included chlorpyrifos, indoxacarb, permethrin, and imidacloprid; thereafter, only spinetoram and chlorantraniliprole were used against the oriental fruit moth. In 2011, the Golden Delicious trees used were not sprayed with insecticides. In 2012, the Smoothee Golden orchard was treated with buprofezin and acetamiprid during prebloom and only chlorantraniliprole or spinetoram were used in the postbloom period. None of the insecticides applied to the trees used in these studies during the period of peach and apple fruit development have efficacy against this pest (Leskey et al. 2012c). To minimize the potential for confounding effects of a physiological disorder associated with calcium deficiency, known as "cork spot," on injury evaluations, foliar $CaCl_2$ was applied to apple trees during the 2011 season. In 2012, Ca levels in the soil were adequate and foliar $CaCl_2$ was not applied.

Exclusion Cage Experiments. A pest exclusion approach was used to assess the effects of selective exposure of peach and apple fruit to natural *H. halys* populations for discrete, sequential intervals throughout the fruiting period. Cylindrical, open-ended cages (17.8 cm in diameter and length) were constructed from semi-rigid, black plastic mesh (13 by 13 mm openings) covered by a flexible fabric mesh sleeve

Table 1. Exclusion cage protocols used to expose peaches and apples to natural populations of *H. halys* for discrete intervals during the fruiting period in experimental orchards in Virginia, 2011 and 2012

Crop/Year	Cultivar	Date fruit caged[a]	Date on which exposure interval began (exposure duration; days)					Harvest date
Peach/2011	Redhaven	9 May	9 May (31)	9 June (28)	7 July (14)	–	–	21 July
Peach/2012	Redhaven	1 May	1 May (31)	1 June (31)	2 July (3)	–	–	5 July
Apple/2011	Golden Delicious	9 May	9 May (31)	9 June (28)	7 July (32)	8 Aug. (24)	1 Sept. (22)	22 Sept.
Apple/2012	Smoothee Golden	1 May	1 May (31)	1 June (31)	2 July (30)	1Aug. (29)	–	30 Aug.

[a] Except for 50 control fruit that were never caged. In addition, 50 fruit were caged on date indicated for each year and were always caged.

(~30.5 cm in diameter and 53.3 cm in length). A wooden dowel (0.7 cm in diameter and 18 cm in length) placed vertically in the middle of the cage was attached to the cage at both ends using wire.

At the beginning of May, cages were deployed over peach and apple limbs with one young fruit that showed no evidence of injury from *H. halys* or other pests. Plastic cable ties were used to attach the dowel to the limb, so that the fruit was not touching the cage wall, and to close the ends of the mesh sleeve around the limb. Treatments ($n = 50$ fruits per treatment) included fruit that were always caged, never caged, or selectively exposed to natural *H. halys* populations by specific cage removal in May, June, or July (peaches), or in May, June, July, August, or September (apples). Table 1 provides dates on which fruit were initially caged, dates on which each exposure period began, the exposure duration for each treatment, and the harvest date. Initially, our targeted exposure duration for each exposed fruit treatment was ~28 d. In 2011, the mean exposure durations (d ± SE) for apples and peaches were 27.4 ± 1.9 and 24.3 ± 5.2 d, respectively, with the July exposure duration in peach affected by the date of commercial harvest (Table 1). In 2012, unusually warm temperatures in March and April resulted in a very early bloom and harvest dates that were 2 to 3 wk earlier than is typical for this area, although these conditions did not appear to advance the timing of emergence of overwintering *H. halys* adults (S.V.J., unpublished data). Consequently, the September exposure treatment in Smoothee Golden apples was not possible and the commercial harvest of Redhaven peaches in early July enabled only a 3-d exposure interval in that month (Table 1). Mean exposure durations (d ± SE) for apples and peaches in 2012 were 30.3 ± 5.2 and 21.7 ± 9.3, respectively.

In 2011, there were five fruit per treatment on each of the 10 peach and apple trees. A frost event during peach bloom in 2012 resulted in a variable crop load among trees. Consequently, five peaches per treatment were used on seven trees and the remaining replicates were randomly distributed among six other trees. The younger and smaller Smoothee Golden apple trees used in 2012 necessitated one replication of each treatment on each of 50 trees. To expose fruit, cages were removed entirely for the duration of each designated exposure period and then replaced at the end of the period. To prevent infestation by the oriental fruit moth and the codling moth, chlorantraniliprole (Altacor, DuPont, Wilmington, DE) was applied to the test fruit within 3-d after cage removal using a hand sprayer.

Fruit Evaluation. Although native stink bugs and other piercing or sucking pests can injure peaches and apples, the vastly increased incidence and magnitude of such injury since 2010 has been attributed to *H. halys*, as described previously. Therefore, for the purposes of this study, we assumed that most of this injury was caused by *H. halys*. To avoid potential handling injury and fruit abscission during the experiments, *H. halys* feeding injury to each fruit was evaluated once at harvest, which was timed to coincide with commercial harvest of the same peach and apple cultivars in the Winchester, VA, area. Because Virginia peaches are typically produced for the fresh market and sold soon after picking, fruit were evaluated within 48 h after harvest. Apples are typically held in cold storage for some period between harvest and distribution, so the fruit were held in a commercial cold storage facility for 4 wk before being evaluated. Each peach was first evaluated for external injury by recording the number of depressions (Fig. 1a) and was then peeled and sliced to core in all quadrants to determine the number of discrete areas of necrosis in the flesh (Fig. 1b). On apples, the number of feeding punctures (Fig. 2a) and discolored depressions on the surface (Fig. 2b) was recorded first, followed by peeling and slicing them to the core in all quadrants to record the number of discrete areas of internal necrosis (Fig. 2c). A wedge-shaped cut was made on at least one external discolored spot on all apples before peeling to confirm the presence of a feeding sheath (Fig. 2d).

Statistical Analyses. Treatment effects (i.e., exposure period) on the number of injured fruit were analyzed using a nominal logistic regression (SAS Institute 2012a, Cary, NC). When there was a significant overall treatment effect for each experiment based on the likelihood ratio chi-square test, the difference between two treatments was examined using the odds ratio. Differences in probabilities of finding an injured fruit were examined using the chi-square value of the odds ratios between two treatments. Treatment effects on the number of external and internal feeding injury sites were examined using a linear mixed model analysis of variance (ANOVA; PROC MIXED) in SAS (SAS Institute 2012b). For each analysis, treatment was considered as a fixed effect and fruit were considered as random effects. Fisher's least significant difference (LSD) with an error rate of 0.05 was used to separate means. In addition, the differences between the number of external and internal feeding injuries on each fruit were examined using a nonparametric Wilcoxon matched-pair signed-rank test for pair-wise

Table 2. Feeding injury from *H. halys* on Redhaven peaches at harvest following exposure to natural *H. halys* populations for discrete intervals during the fruiting period in 2011 and 2012

Year	Exposure treatment	No. fruit harvested ($N^a = 50$)	% fruit with external injury[b]	% fruit with internal injury	Mean ± SE no. external injuries per fruit[c]	Mean ± SE no. internal injuries per fruit
2011	Always caged	49	0.0 a	0b	0 ± 0a	0 ± 0b
	May	46	6.4a	17.0a	0.08 ± 0.05a	0.43 ± 0.18ab
	June	47	2.1a	21.3a	0.04 ± 0.04a	0.55 ± 0.22ab
	July	45	2.2a	22.2a	0.02 ± 0.02a	0.80 ± 0.35ab
	Never caged	43	6.9a	30.2a	0.21 ± 0.14a	1.26 ± 0.46a
Statistics[d]			$x_4^2 = 6.2$; $P = 0.186^d$	$x_4^2 = 24.1$; $P < 0.001$	$F_{4,\,225} = 1.7$; $P = 0.162$	$F_{4,\,225} = 2.8$; $P = 0.03$
2012	Always caged	48	0c	0d	0 ± 0b	0 ± 0c
	May	46	0c	19.5c	0 ± 0b	0.50 ± 0.19c
	June	33	15.1b	48.5b	0.24 ± 0.11b	2.91 ± 0.85b
	July	31	6.5bc	12.9[b]c	0.22 ± 0.16b	0.71 ± 0.49c
	Never caged	44	29.5a	79.5a	0.95 ± 0.31a	6.70 ± 0.98a
Statistics[d]			$x_4^2 = 33.3$; $P < 0.001$	$x_4^2 = 89.6$; $P < 0.001$	$F_{4,\,192} = 6.2$; $P < 0.001$	$F_{4,\,192} = 22.9$; $P < 0.001$

[a] Initial cohort for each treatment consisted of 50 fruit.
[b] Note that peaches in the July 2012 exposure treatment were exposed for only 3 d due to unusually early bloom and harvest dates.
[c] Means within columns for each year followed by the same letter are not significantly different. χ^2 value from the odds ratio comparison between two treatments ($P < 0.05$) was used for percentage of injured fruit and LSD ($P < 0.05$) for number of injuries per fruit.
[d] For percentage of injured fruit, χ^2 value from likelihood ratio test of nominal logistic regression is presented. For the number of injuries per fruit, F-statistics from ANOVA using a linear mixed model are presented.

comparisons (Sheskin 2011; SAS Institute 2012a). A nonparametric method was used because the distributions of number of injury deviated from the normal distribution when we examined the data using PROC UNIVARIATE in SAS. This is a nonparametric equivalent of a pair-wise t-test, and the significantly higher (or lower) injury level by treatment is described by a high sum of rank score (S), which results in a low (< 0.05) P-value.

Results

Peach. In 2011, the percentage of peaches that remained on the tree at harvest ranged from 86 to 98% among the treatments (Table 2). The cages were effective at preventing injury from *H. halys* feeding; fruit that were always caged showed no external or internal injury. There were not significant differences between the exposed treatments and the always caged controls in the percentage of peaches with external injury, although all exposed treatments showed significantly higher percentages of internal injury than always caged fruit, with no significant differences among them. The highest percentage of fruit with external and internal injury was recorded from the never caged treatment. In each exposed treatment, there were more fruit showing internal than external injury. The mean number of external injuries per fruit did not differ significantly among the treatments, but was numerically highest in never caged fruit. All exposed fruit treatments showed higher numbers of internal injuries per fruit than the always caged control, although only peaches that were never caged showed significantly more of these than fruit that were always caged.

In 2012, the percentage of peaches that remained on the tree at harvest ranged from 62 to 96% among the treatments (Table 2). As in 2011, the cages prevented fruit injury in the always caged controls. Among the other treatments, there were significant differences in the percentages of fruit with external and internal injury, with significantly highest values from fruit that were never caged, and as in 2011, there were more fruit with internal than external injury across all exposed fruit treatments. There was a significant effect of treatment on the mean number of external and internal injuries per fruit, with highest values recorded from the never caged fruit.

Apple. In 2011, the percentage of apples that remained on the tree at harvest ranged from 68 to 98% among the treatments (Table 3). Fruit in the always caged treatment showed no external or internal injury. There was a significant effect of treatment on the percentage of fruit showing external and internal injury, which were significantly or numerically highest in apples that were never caged. Most exposed fruit treatments showed similar or identical percentages of apples with external and internal injury. Of those with greater differences in these measurements, fruit with external injury were more prevalent than those with internal injury. There was a significant effect of exposure treatment on the mean number of external and internal injuries per fruit; apples exposed in August and those that were never caged had significantly or numerically higher numbers of these than the other treatments.

In 2012, the percentage of apples that remained on the tree at harvest ranged from 66 to 100% among the treatments (Table 3). One fruit in the always caged treatment showed feeding injury from *H. halys*. As in 2011, there was a significant effect of treatment on the percentage of fruit with external and internal injury, with significantly or numerically highest levels in apples that were never caged. Across all exposed treatments, there were identical or very similar percentages of fruit with external and internal injury. There were also significant effects of treatment on the mean number of external and internal injuries per fruit. Significantly or

Table 3. Feeding injury from *H. halys* on Golden Delicious (2011) and Smoothee Golden (2012) apples at harvest following exposure to natural *H. halys* populations for discrete intervals during the fruiting period

Year	Exposure treatment[a]	No. fruit harvested ($N^b = 50$)	% fruit with external injury[c]	% fruit with internal injury	Mean ± SE no. external injuries per fruit[d]	Mean ± SE no. internal injuries per fruit
2011	Always caged	37	0d	0c	0 ± 0b	0 ± 0b
	May	43	9.3bc	9.3b	0.14 ± 0.08b	0.14 ± 0.08b
	June	34	2.9cd	2.9bc	0.12 ± 0.12b	0.12 ± 0.12b
	July	35	20.0b	20.0ab	0.71 ± 0.31ab	0.60 ± 0.24ab
	August	40	25.0b	22.5ab	1.65 ± 0.66a	1.35 ± 0.56a
	September	36	16.7b	5.6bc	0.33 ± 0.13b	0.06 ± 0.04b
	Never caged	49	48.9a	24.5a	1.65 ± 0.42a	0.73 ± 0.27ab
Statistics			$x_6^2 = 50.3$; $P < 0.001$	$x_6^2 = 26.0$; $P < 0.001$	$F_{6,266} = 4.0$; $P < 0.001$	$F_{6,266} = 3.3$; $P = 0.004$
2012	Always caged	43	2.3e	0d	0.05 ± 0.05b	0 ± 0b
	May	46	13.0d	15.2c	0.23 ± 0.11b	0.30 ± 0.13b
	June	48	25.0cd	25.0bc	0.73 ± 0.31b	0.73 ± 0.31b
	July	36	58.7ab	56.5b	4.15 ± 1.00a	3.50 ± 0.87a
	August	33	42.4bc	42.4b	0.73 ± 0.17b	0.73 ± 0.17b
	Never caged	50	68.0a	68.0a	3.06 ± 0.54a	2.84 ± 0.49a
Statistics			$x_5^2 = 76.4$; $P < 0.001$	$x_5^2 = 80.4$; $P < 0.001$	$F_{5,259} = 10.1$; $P < 0.001$	$F_{6,266} = 10.1$; $P < 0.001$

[a] Note that the September exposure treatment was not possible in 2012 due to unusually early bloom and harvest dates.
[b] Initial cohort for each treatment consisted of 50 fruit.
[c] For percentage of injured fruit, χ^2 value from likelihood ratio test of nominal logistic regression is presented. For the number of injuries per fruit, *F*-statistics from ANOVA using a linear mixed model are presented.
[d] Means within columns for each year followed by the same letter are not significantly different. χ^2 value from the odds ratio comparison between two treatments ($P < 0.05$) was used.

Table 4. Comparisons of the mean number of external and internal injury sites from *H. halys* feeding on peach and apple fruit

Crop	Exposure treatment	2011		2012	
		S^z	P^y	S^z	P^y
Peach	May	10.5	0.09	22.5	0.004*
	June	25	0.01*	68	<0.001*
	July	30.5	0.005*	3	0.25
	Never caged	27.5	0.002*	315	<0.001*
Apple	May	0	1	0.5	1
	June	0	1	0	1
	July	−1.5	0.5	−1.5	0.5
	Aug.	10.5	0.03*	0	1
	Sept.	−7.5	0.06*		
	Never caged	−85.5	<0.001*	−14	0.06

S^z, sum of rank score by Wilcoxon signed rank test; P^y, probability of one measurement being higher or lower (i.e., two-tailed) than the other.

Asterisk indicates a significant difference at $P < 0.05$.

numerically highest numbers of external and internal injuries were recorded from apples that were exposed in July.

Comparisons of the number of internal and external injuries per fruit in 2011 and 2012 showed pronounced differences between peaches and apples across the exposure treatments (Table 4). In most instances, peaches showed significantly more internal than external injury sites per fruit. Conversely, apples most often showed no significant difference between these two measures of *H. halys* feeding injury.

Discussion

Among the exposure periods that spanned fruit development and maturation of Redhaven peaches and Golden Delicious and Smoothee Golden apples, fruit sustained varying amounts of *H. halys* injury. In the absence of a broad understanding of the relative susceptibility of different peach and apple cultivars to *H. halys*, the varieties evaluated here may serve as indicators of the potential risk from *H. halys* at points during the growing season.

Conforming to repeated observations of the onset of movement of adult *H. halys* into orchards in May and to systematic studies of the timing of adult emergence from overwintering sites (Bergh and Leskey 2015), the results indicated that apples and peaches can sustain feeding injury soon after fruit set. In peaches, there were no consistent indications of increasing numbers of fruit showing external injury or in the number of external injuries per fruit at harvest across the discrete exposure periods. To some extent, this may have been due to the shorter exposure durations in July, necessitated by the dates of commercial harvest. Ripening peaches are vulnerable to attack by *H. halys*. It is noteworthy that despite the very brief (3 d) peach exposure duration in July 2012 (due to the very early bloom and harvest), 6.5% of peaches in that treatment exhibited external injury. There were, however, indications of increasing numbers of peaches showing internal injury and increasing numbers of internal injury sites per fruit across the exposure periods. The large differences in the percentage of peaches showing internal versus external injury and in the number of injury sites per fruit are of great significance to peach producers and the marketing of their crop, as fruit that appear unblemished at harvest can contain necrotic areas in the flesh. This is highlighted by the finding that across the exposed fruit treatments, 19.4 ± 2.4 SE and 27.1 ± 9.5 SE percent of peaches showed only internal injury at harvest in 2011 and 2012, respectively.

In apples, there were indications of increasing numbers of fruit showing external injury across the exposure periods, with highest levels in July and August, and substantial injury in September 2011 as well. The large difference between the number of peaches showing internal versus external injury at harvest and between the numbers of internal versus external injury sites per fruit was not observed in apples. Rather, *H. halys* feeding through the skin of apples often caused equal or very similar frequency of both external and internal injury, conforming to the results of Joseph et al. (2014). Across the exposed fruit treatments, 0.0 and 1.1 ± 0.6 SE percent of apples showed only internal injury at harvest in 2011 and 2012, respectively. While the underlying reason(s) for this difference between peaches and apples remains speculative, it seems plausible that peach and apple skin may react differently to punctures by *H. halys* stylets or are differentially able to heal the wound. These differences in injury expression between the crops are directly relevant to scouting efforts, as documenting the percentage of fruit showing external injury symptoms should reflect general injury levels in apples but would underestimate peach injury. It is, therefore, recommended that scouting for *H. halys* injury to peaches includes cutting fruit to inspect the flesh for necrotic areas.

There were differences between years in the extent of *H. halys* injury to both peaches and apples. In 2011 and 2012, respectively, 30.2 and 79.5% of peaches that were never caged showed internal injury at harvest. For apples, 24.5% of fruit in the never caged treatment showed internal injury at harvest in 2011, whereas in 2012, 68% of the fruit in the same treatment showed internal injury at harvest. Again, the reasons for these differences in the amount of injury between years are speculative, but may be associated with annual variations in *H. halys* populations, weather during critical developmental periods of *H. halys*, and the phenology and quality of other hosts nearby and their effects on the extent and timing of *H. halys* movement into orchards.

The data revealed high injury levels in apples and peaches in both years and indicated the need for early and on-going intervention against this pest each season. This is particularly true for peaches, given their higher value and that most of the peach crop in the Mid-Atlantic region is grown for the fresh market. Similarly, apples produced for fresh consumption need protection throughout much of the fruiting period. Apple growers in this region have become more tolerant of *H. halys* injury to fruit grown for processing as sauce, as the damage does not affect the quality of the finished product. However, the value of processing apples for fruit slices is adversely affected by internal injury.

H. halys management could certainly be further improved and refined by understanding its seasonal patterns of presence and abundance in and near individual orchards and the relationship between captures and fruit injury at points during the season. Toward that end, the recent identification of its aggregation pheromone (Khrimian et al. 2014) and the discovery of synergized captures when the pheromone was combined with methyl-(2*E*,4*E*,6*Z*)-decatrienoate (Weber et al. 2014) has provided an important tool. In addition, the pheromone plus synergist lure combination may enable an attract-and-kill tactic involving targeted insecticide applications to baited host trees at or near orchard borders, thereby likely reducing the disruptive effects on natural enemies of secondary pests. However, until new and effective management strategies for *H. halys* are developed and validated, affected tree fruit producers will need to intervene against it using the most efficacious insecticides (Leskey et al. 2012c, Bergh 2013a,b), many of which are known to disrupt IPM and biological control.

In semifield studies, Leskey et al. (2013) showed that the susceptibility of adult *H. halys* to several insecticides changed during the growing season. Early in the season, adults that had emerged from overwintering sites were older and likely depleted of resources as compared with adults from subsequent generations, and showed higher mortality following exposure to the same rate of insecticide. In laboratory studies, Nielsen et al. (2008) found that the LC_{50} of fifth-instar *H. halys* nymphs was lower than that for adults for several of the insecticides evaluated. In combination with these findings, our results provide some guidance toward the development of seasonal insecticide programs for *H. halys*. In peaches, our results suggest that *H. halys* management should be initiated soon after crop set and continue through harvest. In adjacent peach and apple orchards, adult *H. halys* from the overwintering generation have been observed on young peaches more commonly than on young apples, further supporting the contention that peaches require protection throughout their developmental period.

In apples, the results suggest that the most effective insecticides against *H. halys*, which in many cases are potentially the most disruptive to biological control, should be applied during mid- to late season, when injury was highest, although this tactic may not necessarily prevent secondary pest populations from reaching economically damaging levels in apples late in the growing season. The use of less aggressive products earlier in the season when apples showed least injury, when *H. halys* adults appear to be more susceptible to insecticides, and when the progeny of the overwintering population are developing may to some extent mitigate the incidence or extent of secondary pest outbreaks in eastern apple orchards.

Acknowledgments

Thanks to J. Engelman for technical assistance, and to our summer interns, A. Eakins, A. Smith, L. Williamson, S. Hover, K. Witte, T. Eakins, and S. Poulose. This research was supported by U.S. Department of Agriculture–Agricultural Research Service (USDA-ARS) Specific Cooperative Agreement 58-1931-0-109, U.S. Department of Agriculture–National Institute of Food and Agriculture–Specialty Crop Research Initiative (USDA-NIFA-SCRI) Grant 2011-51181-30937, and the Virginia Apple Research Program.

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Received 4 July 2014; accepted 1 December 2014.