Field Response of Alfalfa Looper and Cabbage Looper Moths (Lepidoptera: Noctuidae, Plusiinae) to Single and Binary Blends of Floral Odorants

PETER J. LANDOLT,[1] TODD ADAMS,[2] AND RICHARD S. ZACK[2]

Environ. Entomol. 35(2): 276–281 (2006)

ABSTRACT In field tests of floral chemicals dispensed singly, alfalfa looper moths, *Autographa californica* (Speyer), were captured in traps baited with phenylacetaldehyde, β-myrcene, or benzyl acetate. Cabbage looper moths, *Trichoplusia ni* (Hübner) were also captured in traps baited with phenylacetaldehyde, methyl salicylate, or methyl-2-methoxy benzoate. In evaluations of binary blends of those same compounds, generally more alfalfa looper moths were trapped when β-myrcene was presented with phenylacetaldehyde or with benzyl acetate compared with phenylacetaldehyde alone or benzyl acetate alone. Similarly, more cabbage looper moths were trapped with β-myrcene with phenylacetaldehyde compared with phenylacetaldehyde alone. These findings provide new chemical blends for luring and trapping both sexes of alfalfa looper and cabbage looper moths and suggest differences in preferences of these two moth species for floral odorants.

KEY WORDS lure, attractant, trap, feeding, floral

SEVERAL PEST SPECIES OF Noctuidae in the subfamily Plusiinae are common visitors at flowers at which they likely feed for nectar (Grant 1971, Landolt and Smithhisler 2003), and are attracted by the odors of those flowers (Cantelo and Jacobson 1979, Haynes et al. 1991, Heath et al. 1992, Beerwinkle et al. 1996, Plepys 2001). Such attractive floral odors have been characterized for the plants *Gaura drummondii* (Spach.) (Teranishi et al. 1991, Shaver et al. 1997), *Abelia grandiflora* (Andre) (Haynes et al. 1991), *Cestrum nocturnum* L. (Heath et al. 1992), *Araujia sericofera* Brot. (Cantelo and Jacobson 1979), *Lonicera japonica* (Schlotzhauer et al. 1996), *Platanthera bifolia* L. (Plepys 2001), and *Berberis aquifolium* (Landolt and Smithhisler 2003). The cabbage looper *Trichoplusia ni* (Hübner), the soybean looper *Pseudoplusia includens* (Walker), the alfalfa looper *Autographa californica* (Speyer), and other Lepidoptera can be trapped with several chemicals and chemical blends emitted by these flowers (Cantelo and Jacobson 1979, Haynes et al. 1991, Landolt et al. 1991, 2001, Heath et al. 1992, Pair and Horvat 1997). These floral chemicals probably function for the moths as feeding attractants.

The alfalfa looper is a pest of numerous crops in western North America (Essig 1926). Like other pest Plusiinae, it visits flowers at which it probably feeds (Essig 1926) and is attracted to some flowers by the floral odor (Landolt and Smithhisler 2003). Seven compounds emitted from moth-visited flowers were evaluated previously for their attractiveness to alfalfa looper moths (Landolt et al. 2001). Alfalfa looper moths were attracted to phenylacetaldehyde and to benzyl acetate, as was indicated by their capture in traps baited with these chemicals, but were not attracted to 2-phenylethanol, benzyl alcohol, benzaldehyde, *cis*-jasmone, or linalool. Additional volatile chemicals are odorants of flowers that are visited by Plusiinae, including the alfalfa looper. Testing of these compounds may reveal new chemical attractants or attractant blends and provide a more complete assessment of the roles of these floral compounds in mediating flower-visiting by moths, as well as potentially useful attractants for trapping or baiting the alfalfa looper moth.

We report here the evaluation of eight compounds as attractants or co-attractants for alfalfa looper moths. Both phenylacetaldehyde and benzyl acetate, which are attractive to alfalfa looper moths (Landolt et al. 2001), were tested singly and in combination with additional chemicals. Four of the compounds tested, β-myrcene, α-pinene, β-pinene, and limonene, are emitted along with phenylacetaldehyde, benzyl acetate, and other compounds by flowers of Oregon grape, which are visited by alfalfa looper moths when it blooms in early spring (Landolt and Smithhisler 2003). Methyl salicylate has been isolated from flowers of *Gaura drummondii* (Spach.) and *L. japonica*, whereas methyl-2-methoxy benzoate occurs in flowers *of G. drummondii* (Teranishi et al. 1991, Pair and Horvat 1997, Shaver et al. 1997). These two compounds are known to be attractants and co-attractants

[1] Corresponding author: USDA–ARS, Yakima Agricultural Research Laboratory, 5230 Konnowac Pass Rd., Wapato, WA 98951 (e-mail: landolt@yarl.ars.usda.gov).

[2] Department of Entomology, Washington State University, Pullman, WA 99164.

for other moths, including the cabbage looper and soybean looper (Pair and Horvat 1997, Lopez et al. 2000). However, they have not been tested before as attractants for alfalfa looper moths.

The objective of this study was to determine which, if any, of these compounds and certain binary combinations of these compounds are attractive to alfalfa looper moths. Subsequent testing was conducted to further evaluate alfalfa looper attraction to phenylacetaldehyde plus β-myrcene, both chemicals from Oregon grape shrubs. Data were also obtained on cabbage looper moth responses to these chemicals from experiments conducted during the 2001 field season and *Heliothis phloxiphaga* (Grote and Robinson) responses to phenylacetaldehyde and β-myrcene in the spring of 2005.

Materials and Methods

A multicolored version of the Universal Moth Trap, or UniTrap (AgriSense-BCS, Norwich, United Kingdom), was used in all experiments. The trap is an opaque white bucket beneath a yellow cone and a green lid. A 2.5 by 2.5-cm piece of Vaportape (Hercon Environmental, Emigsville, PA) was placed in each trap bucket as a killing agent. Traps were hung from stakes at a height of 1 m in uncultivated areas adjacent to fields of alfalfa or directly within alfalfa fields. Traps were placed 12 m apart in a north to south line, because of prevailing westerly winds.

For all experiments, a randomized complete block design was used, and treatments were randomized each time that traps were checked. Traps were checked once or twice per week, at which time all insects in traps were placed in prelabeled plastic bags for transport to the laboratory. Moths were identified and sorted by sex under a dissecting microscope. Lures in traps were replaced after 2 wk. Voucher specimens are deposited in the James Entomological Collection, Washington State University, Pullman, WA.

β-Pinene (99% purity), *R*-(+)-α-pinene (99%), (*S*)-(−)-limonene (99%), β-myrcene (90%), phenylacetaldehyde (90%), methyl salicylate (99%), benzyl acetate (99%), and methyl-2-methoxy benzoate (99%) were purchased from Aldrich (Milwaukee, WI). (*R*)-(+)-limonene (97%) was purchased from Acros Chemical (Milwaukee, WI).

Polypropylene vials (8 ml; Nalgene 2006-9025; Fisher, Pittsburgh, PA) were used as dispensers for the testing of chemicals, following the methods used by Landolt et al. (2001). Chemicals (5 ml) were pipetted onto cotton in the bottom of the vial. Holes made in vial lids (3 mm diameter, unless otherwise indicated) permitted the escape of volatilized chemicals. Vials were suspended with wire above the bottom of the inside of the trap bucket. When more than one chemical was used to bait a trap, a separate vial was used for each chemical. Dispensers were replaced after 2 wk when experiments lasted longer than 2 wk.

Experiment 1. Single Component Lures. A comparison was made of moth captures in traps baited with seven different floral chemicals. These were phenylacetaldehyde (included as a positive control and standard for comparison), methyl salicylate, racemic limonene, methyl-2-methoxy benzoate, (*R*)-(+)-α-pinene, (*S*)-β-pinene, and β-myrcene. Racemic limonene was a 1–1 mixture of the *S*-(−)- and *R*-(+)-enantiomers. Five replicate blocks, each including these seven chemical treatments and an unbaited trap, were maintained from 18 May to 1 June 2001, 20 km east of Moxee, Yakima County, WA. This test was repeated 3–27 July 2001, near Mattawa, in response to cabbage looper populations that developed in midsummer 2001.

Experiment 2. Double Component Lures: Phenylacetaldehyde Plus. The compounds methyl salicylate, racemic limonene, methyl-2-methoxy benzoate, *R*-(+)-α-pinene, *S*-β-pinene, and β-myrcene were tested in combination with phenylacetaldehyde for evidence of improvement over moth attraction to phenylacetaldehyde alone. Phenylacetaldehyde was the strongest attractant for alfalfa loopers among chemicals tested previously (Landolt et al. 2001). For each of these two-chemical combinations, two vials were placed in the bucket of the trap; one vial containing phenylacetaldehyde and the other vial containing the second chemical. Phenylacetaldehyde alone was included in the experiment as a treatment for comparison (positive control). Five replicate blocks, each block including the six different two-chemical combinations as well as phenylacetaldehyde alone, were maintained 8–22 June 2001, near Mabton, Yakima County, WA. This experiment was conducted again 2 July to 3 August 2001 near Mattawa, Grant County, WA.

Experiment 3. Double Component Lures, Benzyl Acetate Plus. The same compounds were tested as co-attractants with benzyl acetate, which is weakly attractive to alfalfa looper moths when presented alone (Landolt et al. 2001). Lures were made and presented as in the preceding experiment and treatments were (1) an unbaited trap as a negative control, (2) phenylacetaldehyde as a positive control, (3) benzyl acetate alone, (4) benzyl acetate plus α-pinene, (5) benzyl acetate plus β-pinene, (6) benzyl acetate plus β- myrcene, (7) benzyl acetate plus methyl salicylate, (8) benzyl acetate plus methyl-2-methoxy benzoate, and (9) benzyl acetate plus limonene. Five replicate blocks were maintained from 11 July to 5 August 2002. Trap sites were near Granger and Mabton, Yakima County, WA.

Experiment 4. Phenylacetaldehyde/β-Myrcene Ratios. The purpose of this experiment was to evaluate effects of attractant component ratios on alfalfa looper response to phenylacetaldehyde with β-myrcene. A series of ratios of the two compounds were tested by maintaining the same amount of phenylacetaldehyde and varying the amount of β-myrcene emitted. To vary the amount of β-myrcene emitted, five different hole diameters for the vial dispensers were made using a set of drill bits. Each treatment then included a vial of phenylacetaldehyde with a 3-mm-diameter hole in the lid and a vial of a β-myrcene with a hole diameter of either 0, 0.5, 1.0, 1.5, 3.0, or 6.0 mm. For each of these experiments, five replicate blocks were established, each block possessing one of each of the six treatments. The test was maintained 31 July to 31 August 2001.

Experiment 5. Phenylacetaldehyde/β-Myrcene Interaction. The combination of phenylacetaldehyde and β-myrcene was compared with each chemical separately to determine if the combination is more attractive than each chemical by itself. The two chemicals were dispensed from 15-ml vials in traps, each with a 12-mm-diameter hole in the lid. Experimental treatments were (1) no lure, (2) phenylacetaldehyde in a vial, (3) β-myrcene in a vial, and (4) phenylacetaldehyde in a vial and β-myrcene in a vial. Each vial was loaded with 5 ml of a chemical onto cotton balls in the bottom of the vial. Five replicate blocks of traps were maintained from 19 to 27 April 2005, 20 km east of Moxee. This experiment was repeated 27 April to 26 May using vial dispensers with 3-mm-diameter holes.

Experiment 6. Phenylacetaldehyde/β-Myrcene Doses. This test evaluated the effect of varying the amounts of a mixture of phenylacetaldehyde and β-myrcene on captures of moths in traps. The two chemicals were mixed at a one to one ratio and were loaded at 10 ml of the mixture per 15-ml vial dispenser. Differences in amounts of the blend emitted were accomplished by varying the size of the hole in the vial lid. Treatments were 1.5-, 3-, 6-, 12-, and 25-mm-diameter holes in vial lids. A randomized complete block experimental design was used, with five replicate blocks set up on 3 July 2003. These traps were checked and treatments were randomized weekly until 31 July 2003. A preliminary field test was conducted to compare the attractiveness of the two chemicals dispensed in separate vials (each with a 3-mm-diameter hole) versus the two chemicals mixed together in one vial (with a 6-mm-diameter hole), with no difference in mean catches of alfalfa looper moths in traps ($t = 0.67$, df = 29, $P = 0.13$).

Data Analysis. For experiments 1–3, per trap totals of males and females combined over the duration of the experiment were square root transformed before statistical analyses (Sokal and Rohlf 1981). Responses of males and females to lures were similar. Transformed data were analyzed by one way analysis of variance (ANOVA), and treatment means were separated using Newman-Keuls' test, following a significant ANOVA *F*. For experiments 4 and 6, regression analyses were used to determine if their was a relationship between vial hole size (as an indicator of chemical release) and numbers of moths captured in traps. For experiment 4, all treatments that combined phenylacetaldehyde and β-myrcene were also compared with traps with phenylacetaldehyde alone, using a *t*-test, to determine if moth captures were enhanced by the presence of β-myrcene. For experiment 5, square root transformed data (per trap totals for the duration of the experiment) were analyzed by a 2 by 2 factorial ANOVA. The two factors are phenylacetaldehyde at two levels (present or absent) and β-myrcene at two levels (present or absent). A significant interaction in the ANOVA would be evidence for nonadditive effects between the two components (i.e., either antagonism or synergism). Evidence that the individual components improved trap catch would be indicated by significance of their respective main effects in the ANOVA.

Table 1. Mean ± SE numbers of alfalfa looper moths and cabbage looper moths captured in Universal moth traps baited with individual floral chemicals dispensed from polypropylene vials

Chemical	Alfalfa looper moths	Cabbage looper moths
Test 1		
Control	0.2 ± 0.20a	—
Phenylacetaldehyde	9.4 ± 2.46b	—
α-Pinene	0.0 ± 0.00a	—
β-Pinene	0.0 ± 0.00a	—
Methyl salicylate	0.0 ± 0.00a	—
Methyl-2-methoxy benzoate	0.2 ± 0.20a	—
β-Myrcene	0.6 ± 0.40a	—
Limonene	0.0 ± 0.00a	—
Test 2		
Control	0.0 ± 0.00a	0.0 ± 0.0a
Phenylacetaldehyde	44.0 ± 10.61c	56.8 ± 13.9c
α-Pinene	0.0 ± 0.00a	0.4 ± 0.2a
β-Pinene	0.0 ± 0.00a	0.0 ± 0.0a
Methyl salicylate	1.0 ± 0.63a	1.2 ± 0.6b
Methyl-2-methoxy benzoate	0.4 ± 0.24a	4.6 ± 1.6b
β-Myrcene	4.6 ± 1.33b	1.0 ± 0.7ab
Limonene	0.0 ± 0.00a	0.2 ± 0.2a

Means within a column followed by the same letter were not significantly different by Newman-Keuls' test at $P \leq 0.05$, $n = 5$.

Test 1 was conducted in May 2001 and test 2 in July 2001.

Results

Experiment 1. Single Component Lures. Numbers of alfalfa looper moths in traps baited with phenylacetaldehyde were statistically greater than in unbaited traps in both the May and July single component tests (Table 1), whereas numbers in traps baited with β-myrcene were statistically greater than in unbaited traps in the July test. While no cabbage looper moths were captured in the first test, in the second test, numbers in treated traps were significantly greater than in control traps for phenylacetaldehyde, methyl salicylate, and methyl-2-methoxy benzoate treatments. For all other treatments in both tests, numbers of moths captured were not significantly greater than in unbaited traps (test 1 alfalfa: $F = 13.66$, df = 39, $P < 0.001$; test 2 alfalfa: $F = 16.34$, df = 39, $P < 0.001$; test 2 cabbage: $F = 16.90$, df = 39, $P < 0.001$). Totals of 125 male and 306 female alfalfa looper moths and 130 male and 192 female cabbage looper moths were captured.

Experiment 2. Double Component Lures: Phenylacetaldehyde Plus. In both tests, numbers of alfalfa looper moths captured with the combination of phenylacetaldehyde and β-myrcene were significantly greater than for phenylacetaldehyde alone (Table 2). In the second test, numbers of cabbage looper moths trapped with the combination of phenylacetaldehyde and β-myrcene were significantly greater than numbers trapped with phenylacetaldehyde alone (Table

Table 2. Mean ± SE numbers of alfalfa looper moths and cabbage looper moths captured in Universal moth traps baited with floral chemicals dispensed from vials along with phenylacetaldehyde (PAA) dispensed from vials

Chemical	Alfalfa looper moths	Cabbage looper moths
Test 1		
Unbaited	0.0 ± 0.00a	—
PAA	3.4 ± 1.75b	—
PAA plus α-pinene	2.6 ± 0.87b	—
PAA plus β-pinene	4.4 ± 1.17b	—
PAA plus methyl salicylate	2.6 ± 0.40b	—
PAA plus methyl-2-methoxy benzoate	2.4 ± 0.93b	—
PAA plus β-myrcene	11.4 ± 2.29c	—
PAA plus limonene	4.0 ± 0.84b	—
Test 2		
Unbaited	0.0 ± 0.00a	0.0 ± 0.00a
PAA	33.8 ± 5.56b	42.8 ± 10.63b
PAA plus α-pinene	35.8 ± 4.14b	53.2 ± 8.90bc
PAA plus β-pinene	32.2 ± 6.56b	52.2 ± 12.40bc
PAA plus methyl salicylate	33.2 ± 6.60b	58.8 ± 14.24bc
PAA plus methyl-2-methoxy benzoate	25.8 ± 3.97b	52.2 ± 8.65bc
PAA plus β-myrcene	100.0 ± 11.69c	63.4 ± 15.37c
PAA plus limonene	36.4 ± 5.28b	39.8 ± 10.12b

Means within a column followed by the same letter were not significantly different by Newman-Keuls' test at $P \leq 0.05$, $n = 5$.

Test 1 was in May 2001 and test 2 in July 2001.

2). Other chemicals tested did not significantly impact numbers of moths captured (test 1 alfalfa: $F = 7.29$, df = 39, $P < 0.001$; test 2 alfalfa: $F = 20.01$, df = 39, $P < 0.001$; test 2 cabbage: $F = 3.27$, df = 39, $P = 0.008$). Totals of 606 male and 1000 female alfalfa looper moths and 986 male and 1132 female cabbage looper moths were captured.

Experiment 3. Double Component Lures: Benzyl Acetate Plus. Numbers of alfalfa looper moths captured with benzyl acetate alone and with phenylacetaldehyde alone were significantly greater than numbers in unbaited traps (Table 3). Greater numbers of alfalfa looper moths were captured in traps with the combinations of benzyl acetate and β-myrcene compared with benzyl acetate alone (Table 3; $F = 2.75$, df = 44, $P = 0.01$). Totals of 68 male and 63 female

Table 3. Mean ± SE numbers of alfalfa looper moths captured in Universal moth traps baited with floral chemicals dispensed from vials

Chemical	Alfalfa looper moths
Benzyl acetate	3.2 ± 0.49c
Phenylacetaldehyde	6.0 ± 1.76d
Benzyl acetate/α-pinene	2.4 ± 0.68c
Benzyl acetate/β-pinene	2.4 ± 0.60c
Benzyl acetate/β-myrcene	6.8 ± 1.24d
Benzyl acetate/methyl Salicylate	4.0 ± 2.41c
Benzyl acetate/methyl-2-methoxy benzoate	2.0 ± 0.84bc
Benzyl acetate/limonene	2.8 ± 1.16c
No lure	0.0 ± 0.00ba

Means within a column followed by the same letter were not significantly different by Newman-Keuls' test at $P \leq 0.05$, $n = 5$.

July/Aug. 2002.

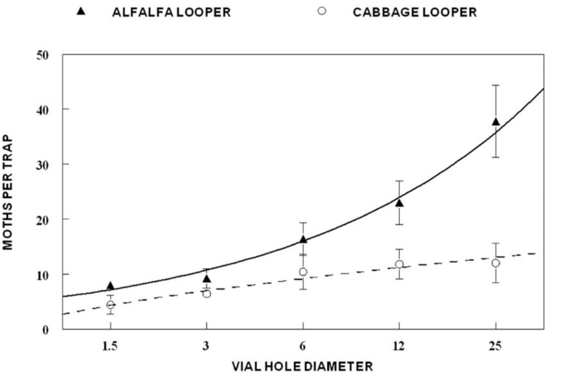

Fig. 1. Mean (±SE) numbers of alfalfa looper moths (▲) and cabbage looper moths (○) captured in traps baited with a range of ratios of phenylacetaldehyde in combination with β-myrcene. β-Myrcene emission was varied by vial hole diameter. For the alfalfa looper, bars with different letters are significantly different (t-test, $P < 0.05$).

alfalfa looper moths and no cabbage looper moths were captured in this experiment.

Experiment 4. Phenylacetaldehyde/β-Myrcene Ratios. Capture of either alfalfa looper or cabbage looper moths was not altered by increasing the ratio of β-myrcene to phenylacetaldehyde, which was accomplished by varying the β-myrcene vial hole size (alfalfa looper data: $r^2 = 0.11$, $P = 0.59$, df = 4; cabbage looper data: $r^2 = 0.08$, $P = 0.92$, df = 4; Fig. 1). More alfalfa looper moths were trapped with β-myrcene and phenylacetaldehyde together compared with phenylacetaldehyde alone for all β-myrcene vial hole diameters (0.5-mm holes: $t = 5.76$, $P < 0.001$, df = 19; 1.0-mm holes: $t = 4.57$, $P < 0.001$, df = 19; 1.5-mm holes: $t = 6.13$, $P < 0.001$, df = 19; 3.0-mm holes: $t = 5.51$, $P < 0.001$, df = 19; 6.0-mm holes: $t = 5.16$, $P < 0.001$, df = 19). Totals of 363 male and 443 female alfalfa looper moths were captured.

Numbers of cabbage looper moths captured with phenylacetaldehyde and β-myrcene were significantly greater than with phenylacetaldehyde alone for the 0.5-, 1.5-, and 6-mm vial hole sizes (0.5-mm holes: $t = 2.12$, $P = 0.02$, df = 19; 1.5-mm holes: $t = 3.46$, $P = 0.001$, df = 19; 6.0 mm holes: $t = 2.38$, $P = 0.01$, df = 19) and were numerically but not statistically greater for the 1.0- and 3.0-mm holes (1.0-mm holes: $t = 0.90$, $P = 0.19$, df = 19; 3.0-mm holes: $t = 0.73$, $P = 0.23$, df = 19). Totals of 445 male and 918 female cabbage looper moths were captured.

Experiment 5. Phenylacetaldehyde/β-Myrcene Interaction. There was no evidence of interactive effects of phenylacetaldehyde and β-myrcene on capture of alfalfa looper moths (Table 4; 3-mm vial hole, interaction effect: $F_{1,16} = 0.8$, $P = 0.40$; 12-mm vial hole, interaction effect: $F_{1,16} = 0.4$, $P = 0.56$). For both hole sizes, moth numbers increased significantly in traps baited with phenylacetaldehyde compared with traps lacking this compound (Table 4; 3-mm vial hole, main effects of phenylacetaldehyde: $F_{1,16} = 172.1$, $P < 0.0001$; 12-mm vial hole, main effects of phenylacet-

Table 4. Mean ± SE numbers of alfalfa looper moths captured in Universal moth traps baited with floral chemicals dispensed from vials

Lure chemical	Alfalfa looper moths		*H. phloxiphaga*
	3-mm vial hole	12-mm vial hole	12-mm vial hole
No Lure	0.0 ± 0.00a	0.0 ± 0.00a	0.0 ± 0.00a
PAA	83.4 ± 7.05b	74.0 ± 10.43b	22.0 ± 5.72b
β-Myrcene	6.8 ± 2.35a	9.4 ± 3.37a	0.8 ± 0.37a
PAA/β-myrcene	114.8 ± 22.73c	111.4 ± 12.93c	31.6 ± 8.01b

Means within a column followed by different letters are significantly different (2 by 2 ANOVA, $P \leq 0.05$).
April 2005.
PAA, phenylacetaldehyde.

aldehyde: $F_{1,16} = 201.3$, $P < 0.0001$). Moth numbers also increased significantly in traps baited with β-myrcene (Table 4; 3-mm vial hole, main effects of β-myrcene: $F_{1,16} = 8.7$, $P = 0.01$; 12-mm vial hole, main effects of β-myrcene: $F_{1,16} = 16.2$, $P = 0.001$), although the means summarized in Table 4 suggest that effects of β-myrcene on trap catch were less pronounced than the effects caused by the presence of phenylacetaldehyde. Totals of 445 male and 527 female alfalfa looper moths were captured in the experiment using 12-mm-diameter vial holes, whereas 518 male and 511 female alfalfa looper moths were captured in the experiment using 3-mm-diameter vial holes. No cabbage looper moths were captured.

One hundred eighteen male and 168 female *H. phloxiphaga* moths were captured in the test with the 12-mm-diameter vial holes. As for the alfalfa looper, there was no evidence of an interactive effect of the two compounds on numbers of moths trapped (Table 4; interaction effect: $F_{1,16} = 0.05$, $P = 0.82$). Numbers of *H. phloxiphaga* captured were larger in traps baited with phenylacetaldehyde compared with traps lacking this compound (Table 4; main effects of phenylacetaldehyde: $F_{1,16} = 89.7$, $P < 0.0001$). β-myrcene alone did not affect numbers of *H. phloxiphaga* trapped (Table 4; main effects of β-myrcene: $F_{1,16} = 2.6$, $P = 0.12$).

Experiment 6. Phenylacetaldehye/β-Myrcene Doses. Numbers of alfalfa looper moths and cabbage looper moths captured increased with greater vial hole sizes (Fig. 2). For alfalfa looper data, $r^2 = 0.99$, df = 5, $P = 4.9 \times 10^{-6}$, $Y = -5.2 + 0.78X$, where Y is the number of moths captured and X is the vial hole diameter. For cabbage looper data, $r^2 = 0.90$, df = 5, $P = 0.004$, $Y = -0.97 + 0.31X$, after a log transformation of the data. Greatest numbers of moths captured were in traps baited with vials with the 25-mm-diameter holes. Two hundred sixteen female and 279 male alfalfa looper moths and 127 male and 101 female cabbage looper moths were captured in this test.

Discussion

In this study, alfalfa looper moths were trapped with phenylacetaldehyde, benzyl acetate, and β-myrcene, whereas cabbage looper moths were trapped with phenylacetaldehyde, methyl salicylate, and methyl-2-methoxy benzoate. Phenylacetaldehyde has long been known to be attractive to a number of species of Lepidoptera, including the cabbage looper (Cantelo and Jacobson 1979, Haynes et al. 1991, Heath et al. 1992, Landolt et al. 1991) and alfalfa looper moths (Landolt et al. 2001). Landolt et al. (2001) also captured alfalfa looper moths in traps baited with benzyl acetate. Cabbage looper moths are also attracted to 2-phenylethanol, benzaldehyde, benzyl alcohol, and benzyl acetate (Haynes et al. 1991, Heath et al. 1992). All of these compounds are known from volatiles or extracts of flowers that are visited by moths (Cantelo and Jacobson 1979, Haynes et al. 1991, Teranishi et al. 1991, Heath et al. 1992, Schlotzhauer et al. 1996, Landolt and Smithhisler 2003). Methyl salicylate is part of the odor of flowers of *G. drummondi* (Teranishi et al. 1991), *L. japonica* (Schlotzhauer et al. 1996), and *P. bifolia* (Plepys 2001), and is a component of a blend of floral compounds attractive to moths, including the cabbage looper (Lopez et al. 2000).

β-Myrcene generally increased catches of alfalfa looper moths when presented along with phenylacetaldehyde or with benzyl acetate. Phenylacetaldehyde, and β-myrcene occur together in the odor of flowers of Oregon grape shrubs and may mediate alfalfa looper moth location of those flowers, at which they seem to feed (Landolt and Smithhisler 2003). Flowers of Oregon grape emitted eight compounds that made up the preponderance of the odorants (Landolt and Smithhisler 2003). Any role of the re-

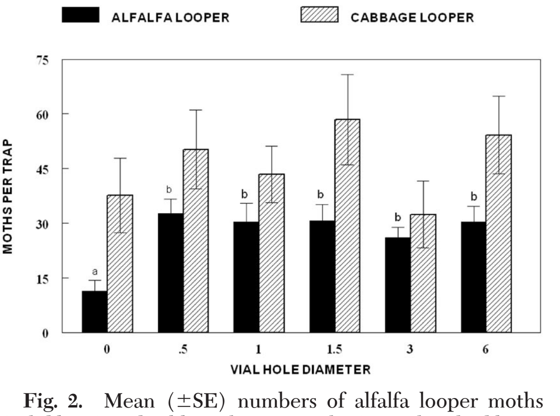

Fig. 2. Mean (±SE) numbers of alfalfa looper moths (solid bars) and cabbage looper moths (cross-hatched bars) captured in traps baited with lures containing both phenylacetaldehyde and β-myrcene. Amounts of lure emitted by dispensers was varied by vial hole diameter.

maining six chemicals of Oregon grape floral odor remains unknown, but three of those that were tested in this study (α-pinene, β-pinene, and limonene) had no effect on the trapping of alfalfa looper moths. Sabinene and *E*-β-ocimene, the additional odorants from Oregon grape flowers (Landolt and Smithhisler 2003), were not available in amounts suitable for these experiments and were not tested. No other chemicals tested increased alfalfa looper response to phenylacetaldehyde or to benzyl acetate.

Results of the two experiments evaluating ratios and release rates of the phenylacetaldehyde/β-myrcene blend suggest that the ratio is not important, but the release rate has a large effect on numbers of moths trapped over the ranges tested. The results of the two experiments together suggest that the increase in attractiveness of lures with increasing hole size was caused essentially by increased release of phenylacetaldehyde and not to greater release of β-myrcene. Increasing trap catches with increased phenylacetaldehyde release was noted by Landolt et al. 2001, using the same vial dispenser system.

The numbers of *H. phloxiphaga* captured in traps during April and May 2005 were surprising, given the absence of any significant response in previous tests. This moth also seems to respond to phenylacetaldehyde as an attractant and to β-myrcene as a co-attractant. Because the timing and selection of sites for these tests were based on the presence and abundance of alfalfa looper moths, it is assumed that other moths such as cabbage looper and *H. phloxiphaga* simply were not present in suitable numbers during some of the trapping experiments and were abundant at other times.

Results of several experiments showed increased attraction of alfalfa looper moths to β-myrcene with phenylacetaldehyde, or β-myrcene with benzyl acetate, over phenylacetaldehyde alone. They also show increased attraction of cabbage looper moths to β-myrcene and phenylacetaldehyde over phenylacetaldehyde alone. We do not yet know why the improved attraction with β-myrcene was very great in some tests, weak in others, and numerically greater but not statistically significant in yet another. Additional studies need to be conducted to evaluate additional parameters that might impact moth chemical attractiveness and moth capture, such as trap design, competition from other odor sources, chemical stability, and temperature.

Acknowledgments

This work was supported in part by funding from the Environmental Protection Agency and the Columbia Basin Vegetable Processors Council. Technical support was provided by J. Alfaro, J. Brumley, D. Green, and C. Smithhisler. We thank D. Horton for assistance with statistical analyses. S. Bangs, K. Foster, T. Harris, D. Martinez, P. Smith, and Del Monte Foods provided access to their fields for trapping experiments.

References Cited

Beerwinkle, K. R., T. N. Shaver, P. D. Lingren, and J. R. Raulston. 1996. Free-choice olfactometer bioassay system for evaluating the attractiveness of plant volatiles to adult *Helicoverpa zea.* Southwest. Entomologist. 21: 395–405.

Cantelo, W. W., and M. Jacobson. 1979. Phenylacetaldehyde attracts moths to bladder flower and to blacklight traps. Environ. Entomol. 8: 444–447.

Essig, E. O. 1926. Insects of western North America. MacMillan Co., New York.

Grant, G. G. 1971. Feeding activity of adult cabbage loopers on flowers with strong olfactory stimuli. J. Econ. Entomol. 64: 315–316.

Haynes, K. F., J. Z. Zhao, and A. Latif. 1991. Identification of floral compounds from *Abelia grandiflora* that stimulate upwind flight in cabbage looper moths. J. Chem. Ecol. 17: 637–646.

Heath, R. R., P. J. Landolt, B. Dueben, and B. Lenczewski. 1992. Identification of floral compounds of night-blooming jessamine attractive to cabbage looper moths. Environ. Entomol. 21: 854–859.

Landolt, P. J., and C. S. Smithhisler. 2003. Characterization of the floral odor of Oregongrape: possible feeding attractants for moths. Northwest Sci. 77: 81–86.

Landolt, P. J., B. Lenczewski, and R. R. Heath. 1991. Lure and toxicant system for the cabbage looper (Lepidoptera: Noctuidae). J. Econ. Entomol. 84: 1344–1347.

Landolt, P. J., T. Adams, H. C. Reed, and R. S. Zack. 2001. Trapping alfalfa looper moths (Lepidoptera: Noctuidae) with single and double component floral chemical lures. Environ. Entomol. 30: 667–672.

Lopez, J. D., Jr., T. N. Shaver, K. R. Beerwinkle, and P. D. Lindgren. 2000. Feeding attractant and stimulant for adult control of noctuid and/or other lepidopteran species. U.S. Patent 6,074,634. Issued June 13, 2000.

Pair, S. D., and R. J. Horvat. 1997. Volatiles of Japanese honeysuckle flowers as attractants for adult Lepidopteran insects. U.S. Patent 5,665,344. Issued 9 September 1997.

Plepys, D. 2001. Odour-mediated nectar foraging in the silver Y moth, *Autographa gamma.* PhD dissertation, Lund University, Lund, Sweden.

Schlotzhauer, W. S., S. D. Pair, and R. J. Horvat. 1996. Volatile constituents from the flowers of Japanese honeysuckle (*Lonicera japonica*). J. Agric. Food Chem. 44: 206–209.

Shaver, T. N., P. D. Lingren, and H. F. Marshall. 1997. Nighttime variation in volatile content of flowers of the night blooming plant *Gaura drummondii.* J. Chem. Ecol. 23: 2673–2682.

Sokal, R. R., and F. J. Rohlf. 1981. Biometry. The principles and practice of statistics in biological research. W. H. Freeman and Company, New York.

Teranishi, R., R. G. Buttery, S. Kent, G. Takeoka, P. D. Lingren, J. R. Raulston, and T. N. Shaver. 1991. Chemical composition of *Gaura drummondii* flower volatiles. J. Ess. Oil Res. 3: 287–288.

Received for publication 31 May 2005; accepted 25 January 2006.