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Use of Glacial Acetic Acid to Enhance Bisexual Monitoring of Tortricid Pests With Kairomone Lures in Pome Fruits

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ABSTRACT Studies were conducted to assess glacial acetic acid (GAA) with various host plant volatiles (HPVs) and the sex pheromone, (*E,E*)-8, 10-dodecadien-1-ol, of codling moth, *Cydia pomonella* (L), as lures in traps for tortricid pests that often co-occur in tree fruits in the western United States. In addition to codling moth, field trapping studies were conducted with oriental fruit moth, *Grapholita molesta* (Busck), obliquebanded leafroller *Choristoneura rosaceana* (Harris), the leafroller *Pandemis pyrusana* Kearfott, and the eyespotted budmoth, *Spilonota ocellana* (Denis and Schiffermüller). HPVs included ethyl (*E,Z*)-2,4-decadienoate (pear ester), (*E*)-4,8-dimethyl-1,3,7-nonatriene, butyl hexanoate, (*E*)-β-ocimene, (*E*)-β-farnesene, and farnesol. Three types of GAA co-lures differing in a 10-fold range in weekly evaporation rates were tested. The evaporation rate of GAA co-lures was an important factor affecting moth catches. The highest rate tested captured fewer codling moth but more leafrollers and eyespotted budmoth. GAA co-lures caught both sexes of each species. The field life of butyl hexanoate and (*E*)-β-ocimene lures were much shorter than pear ester or sex pheromone lures. Adding GAA to pear ester or to (*E*)-β-ocimene significantly increased the catches of only codling moth or oriental fruit moth, respectively. Combining pear ester or (*E*)-β-ocimene with GAA did not affect the catch of either species compared with the single more attractive HPV. Adding HPVs to GAA did not increase the catches of either leafroller species or eyespotted budmoth. Traps baited with pear ester, sex pheromone, and GAA for monitoring codling moth were also effective in classifying pest pressure of both leafroller species within orchards.

KEY WORDS codling moth, oriental fruit moth, eyespotted budmoth, obliquebanded leafroller, Pandemis leafroller

Western tree fruit orchards in the United States are attacked by a number of tortricid pests that are either key or important secondary pests directly damaging the fruit (Barnett et al. 1991, Beers et al. 1993). The key species include the codling moth, *Cydia pomonella* (L), which infests apple, *Malus domestica* Borkhausen, pear, *Pyrus communis* L., and walnut, *Juglans regia* L.; and oriental fruit moth, *Grapholita molesta* (Busck), which infests both stone fruits, *Prunus* spp., and pome fruits. Both of these species are internal fruit feeders. A number of other tortricid pests may also occur at population levels requiring direct management in these western crops, including the obliquebanded leafroller, *Choristoneura rosaceana* (Harris), *Pandemis pyrusana* Kearfott, and the eyespotted budmoth, *Spilonota ocellana* (Denis and Schiffermüller). Many orchards are attacked by more than one of these tortricid pests; for example, both codling moth and oriental fruit moth are managed in orchards in California, Michigan, and eastern fruit-growing regions in the United States and Canada (Rice et al. 1972, Hull et al. 2002, Kovanci et al. 2004, Bellerose et al. 2007, Stelinski et al. 2009). Leafrollers are widely dispersed among fruit-growing regions in the United States (Chapman 1973, Weires and Riedl 1991), and the univoltine eyespotted budmoth is a more occasional pest in commercial orchards in western North America (Madsen and Downing 1968, Beers et al. 1993). Leafrollers and budmoth are primarily leaf feeders, but also feed on the surface of adjacent fruits. Sex pheromone lures are available for all of these tortricids, and traps are commonly deployed for monitoring at various densities, ranging from 0.25 to 1.0 per hectare (Weires and Riedl 1991). Male flight patterns and the use of predictive phenology models based on male moth catches are useful tools to improve the management of tortricids in both conventional and organic orchards (Knight and Croft 1991). Further improvement in monitoring and management of these pests might be

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achieved with traps and lures that are effective in tracking female seasonal population dynamics (Light et al. 2001). For example, monitoring female codling moth populations within orchards with pear ester lures has allowed growers to: 1) predict the population density and seasonal timing of moth activity more effectively (Knight and Light 2005a,b); 2) predict the mating status of females in orchards treated with sex pheromones for mating disruption (Knight 2006, 2007); and 3) reduce insecticide use through site-specific management (Knight et al. 2009).

Research into the development of host plant volatiles (HPVs) for tortricids has followed a prescribed path from identifying the principal leaf and fruit volatiles released by host plants both early in the season with unripe fruits and later in the season with maturing fruits to the characterization of which volatiles are detected by the insect's periphery and integrated in the central nervous system. The third step has been to conduct a variety of behavioral studies in the laboratory using flight tunnels or olfactometers to evaluate the responses of both sexes to key HPVs (codling moth: Hern and Dorn 2001, 2004; Ansebo et al. 2004; Coracini et al. 2004; Yang et al. 2004; Trona et al. 2013; oriental fruit moth: Natale et al. 2003, 2004a,b; Piñero and Dorn 2007; Najar-Rodriguez et al. 2010; Varela et al. 2011a; Faraone et al. 2013). Following the identification of active HPVs in laboratory assays, a number of field trials have then identified a shorter list of HPVs that can be used to monitor either codling moth or oriental fruit moth within their host crops (codling moth: Coracini et al. 2004; Knight et al. 2011a, 2012; El-Sayed et al. 2013; oriental fruit moth: Il'ichev et al. 2009; Lu et al. 2012; Knight et al. 2011b, 2013). Interestingly, no previous laboratory or field studies have evaluated whether specific HPVs or blends could be used for both codling moth and oriental fruit moth. Also, similar studies testing HPVs with tortricid leafrollers and for the eyespotted budmoth have not been reported for populations in the western United States.

Acetic acid used with certain HPVs (pear ester and (*E*)-4,8-dimethyl-1,3,7-nonatriene) has been demonstrated to be a synergist for the attraction of both sexes of codling moth (Landolt et al. 2007, Knight et al. 2011a). The addition of a variety of co-lures releasing a 10-fold range of acetic acid have been tested with pear ester and codlemone, and all have significantly increased male and female moth catches (Knight 2010, Knight and Light 2012, Knight et al. 2012). Acetic acid has not been tested with HPVs for oriental fruit moth, but has been used in combination with sugar and ethanol in China (He et al. 2009). Several species of tortricids have been caught in trapping studies in apple with the use of acetic acid with pear ester (A.L.K., unpublished data), but acetic acid as a liquid bait in dome traps was found not to be very effective in monitoring leafrollers in apple orchards in Washington State (Knight 2001, Alway 2003).

Herein, studies from 2009 to 2012 are reported that examined the use of acetic acid with four HPVs to monitor five tortricid pests of tree fruits. HPVs included pear ester, butyl hexanoate, (*E*)-β-ocimene, and (*E*)-4,8-dimethyl-1,3,7-nonatriene. Species included codling moth, oriental fruit moth, Pandemis leafroller, obliquebanded leafroller, and eyespotted budmoth. The content of new and field-aged gray septa loaded with combinations of codlemone and these four HPVs was analyzed over 35 d. Field trials compared HPVs alone, in combination with acetic acid co-lures, and in three-way combinations with codlemone and acetic acid. In addition, two additional HPVs, (*E*)-β-farnesene and farnesol, with acetic acid were included in field tests with leafrollers. Three types of acetic acid lures that differed by >10-fold in release rate were evaluated in combination with HPVs plus codlemone for each tortricid. The classification of orchards' risk to leafroller infestation, based on the cumulative adult leafroller counts in traps baited with codlemone, pear ester, and acetic acid was conducted with both leafroller species.

Materials and Methods

Chemicals and Lures. Chemicals were obtained from several sources. Ethyl (*E,Z*)-2,4-decadienoate (pear ester; 92%) was provided by Trécé Inc. (Adair, OK). (*E*)-4,8-dimethyl-1,3,7-nonatriene (nonatriene; 99%) and (*E*)-β-ocimene (beta ocimene, 98%) were obtained from Plant Research Institute (Wageningin, The Netherlands). (*E*)-β-farnesene (beta farnesene, 98.5%), mixed-isomeric farnesol (farnesol, 96% with 48–62% *E,E*), and (*Z*)-3-hexenyl acetate (Z3–6Ac, >98%) were purchased from Bedoukian Research Inc. (Danbury, CT). Glacial acetic acid (GAA, 99.7%) and butyl hexanoate (>98%) were obtained from Sigma-Aldrich (St. Louis, MO).

All HPVs and codlemone were loaded into gray halobutyl septa (West Co., Lionville, PA). Septa were first extracted three times with dichloromethane (99.9% purity, Sigma-Aldrich) and air-dried overnight before storage at −15°C. Septum lures were prepared by diluting chemicals in dichloromethane and adding 100 μl into the cup area of the septum. Codlemone and all HPVs were loaded at 3 mg per septum. Similar volumes of dichloromethane were added three times and lures were air-dried for 24 h and stored at −15°C. Codlemone and HPVs in combination lures were prepared as blends in the solvent before lure loading. GAA co-lures were made by drilling 1.0- or 3.1-mm holes in the cap of 8-ml polyethylene vials (Nalg-Nunc International, Rochester, NY) and loading each vial with two small cotton balls and 5 ml of GAA. A third GAA co-lure, a proprietary round (3.4 cm in diameter) plastic membrane cup (TRE3321) was provided by Trécé Inc. Five commercial lures were provided by Trécé Inc., including the pear ester lure, Pherocon CM-DA; the codlemone lure, Pherocon CM L2; the pear ester plus codlemone lure, Pherocon CM-DA Com-

Table 1. Summary of field trials conducted with HPV and glacial acetic acid co-lures

Orchard	Trial location	Year	Species monitored[a]	Results summarized in
Toppenish	46° 24′ N, 120° 21′ W	2009–2011	CM	Tables 2, 3, and 4
Moxee1	46° 30′ N, 120° 10′ W	2009, 2011	PLR/OBLR	Table 8; Fig. 1
Moxee2	46° 33′ N, 120° 20′ W	2009	PLR/OBLR	Fig. 1
Parker	46° 29′ N, 120° 26′ W	2011–2012	CM, PLR, OFM	Tables 8 and 10; Fig. 2
Naches	46° 40′ N, 120° 39′ W	2011	CM, PLR	Tables 5 and 9
Medford	42° 16′ N, 122° 55′ W	2010	OFM	Table 2
Ashland	42° 14′ N, 122° 44′ W	2011–2012	CM, OBLR, ESBM	Tables 6 and 9

[a] Tortricids monitored included codling moth (CM), oriental fruit moth (OFM), Pandemis leafroller (PLR), obliquebanded leafroller (OBLR), and eyespotted budmoth (ESBM).

bo; and the sex pheromone lures for both leafrollers, Pherocon OBLR and Pherocon PL.

Field Aging and Analysis of Lures. Studies were conducted to assess the residual content of new and field-aged HPV and codlemone combination septa lures during 2011. Prepared septa were pinned to the inside top of red delta traps and placed in the USDA experimental research farm (Moxee1) on 16 August 2011. Five lures of each type were collected on days 0, 7, 14, 21, 28, and 35 (20 September 2011). Individual lures were wrapped in aluminum foil and stored at −15°C. Frozen lures were shipped to Florida for analysis. Lures were extracted by placing each septum into a 20-ml glass scintillation vial (Fisher, Pittsburgh, PA) and then adding 10 ml of dichloromethane. Thereafter, the vials were kept at room temperature for 24 h. A 900-μl aliquot from each extract was pipetted into a 4-ml glass screw-top vial after which 100 μl of an internal standard was added. The internal standard used was hexadecyl acetate (Sigma Aldrich) at a concentration of 1.123 μg/μl. A 1-μl sample of each extract containing the added internal standard was analyzed by gas chromatography. The amount of each compound within septa was calculated by comparing peak areas of extracted compounds to that of the internal standard. The retention times of all compounds in the extract were verified with synthetic standards. The gas chromatograph (GC) was a Varian CP-3800 equipped with a 30-m, 0.25-mm ID, 0.5-μm df film Restek RTX5 column (Restek Corp., Bellefonte, PA) and a flame-ionization detector. The GC temperature program was initially 40°C and increased at 10°C/min to 250°C with a 2.5-min final hold using helium as the carrier gas.

The mean weekly weight loss (evaporation rate) of GAA from the three lures was recorded each year. Individual vials ($N = 4$–10) were placed in red delta traps that were hung in the canopy of five linden trees, *Tilia cordata* Miller, at the Yakima Agricultural Research Laboratory, Wapato, WA. Lures were weighed initially and then every 7 d during the season. GAA co-lure aging studies were initiated in May and again in July each season to avoid significant reductions in their emission rates independent of temperature.

Field Experiment Protocols. HPV and HPV plus codlemone combination lures alone and with GAA co-lures were evaluated in a series of field tests conducted from 2009 to 2012 in seven orchard locations in central Washington State and southern Oregon (Table 1). All but two sites were apple orchards with trees of variables ages, planting densities, and with mixed cultivars. Medford was an organic peach orchard with >30 cultivars. Parker was an unmanaged peach orchard, and traps were placed along the edges of both the peach and the adjacent apple and pear orchards. Orange delta traps were used in all studies with sticky inserts. Treatment replicates were randomized and spaced 20–30 m apart. Traps for codling moth alone or with other tortricid species were attached to a pole and placed in the upper third of the canopy. Traps for oriental fruit moth were placed at 2.0 m in the canopy. Traps for either leafroller were placed at 2.5 m height in the canopy. GAA co-lures were placed on the liner and septa lures were pinned to the inside top of the trap. Traps were checked a variable number of times during each study and typically every 7–10 d in Washington State and 2–3 wk in Oregon. Traps were rotated in the trapping grid on each check date. Moths were sexed in all lure comparison studies. Leafrollers were not sexed in the 2011 study evaluating the correlation of moth catch with pest pressure.

2009. Two studies were conducted to evaluate the use of beta ocimene and butyl hexanoate as attractants for codling moth and to evaluate several HPVs for leafrollers. The first study was conducted in the Toppenish apple orchard from 5 to 19 August. Nine replicates of five treatments including GAA alone and beta ocimene and butyl hexanoate alone and with GAA co-lures were tested. Traps were rotated after the first week. GAA vials with 1.0-mm holes were used. The second study was conducted in the two Moxee orchards from 8 to 17 September in Moxee1 and from 7 to 14 July in Moxee2. Five replicates of 12 treatments were placed in both sites. Lure treatments included unbaited traps; traps baited with the various HPVs alone, including pear ester, beta farnesene, nonatriene, Z3–6Ac, and farnesol; and the same HPVs with a GAA co-lure. GAA co-lures were vials with a 3.1-mm hole. Traps baited with the sex pheromone lure of each species (Trécé Inc.) were placed in each orchard and caught both Pandemis and obliquebanded leafrollers in nearly equal proportions. Thus, the two leafroller species were combined when counting and sexing moths.

2010. Three studies were conducted in the second year of the project to further evaluate the effectiveness of beta ocimene and butyl hexanoate with a GAA co-lure for codling moth and oriental fruit moth, and to compare the GAA vial co-lures with either 1.0- or 3.1-mm holes for codling moth. The first study consisted of 10 replicates of five treatments including GAA alone and beta ocimene and butyl hexanoate alone and with GAA co-lures tested for oriental fruit moth from 14 to 28 June in the Medford peach orchard. Traps were not rotated during the trial. GAA vials with 1.0-mm holes were used. The second study was conducted from 13 May to 1 June with codling moth in the Toppenish orchard to compare GAA alone against four HPVs plus the GAA co-lure. HPV lures included pear ester, nonatriene, beta ocimene, and butyl hexanoate. Traps were rotated once after 9 d. The third study was conducted in the Toppenish orchard from 4 May to 27 July to compare the catch of codling moth in traps baited with the Pherocon CM-DA lure plus GAA co-lure vials with either a 1.0- or a 3.1-mm hole. Traps were rotated each week.

2011. Studies were conducted in the third year of the study to examine the use of HPV combination lures with codlemone for each of the tortricids and to examine the relative attractiveness of the three GAA co-lures for each species. In the first study, the relative effectiveness of combination HPV plus codlemone lures with a GAA co-lure were compared in the Naches orchard for codling moth and Pandemis leafroller from 10 August to 6 October. Nine replicates of the codlemone lure (Pherocon CM L2) and prepared combination lures with pear ester, nonatriene, beta ocimene, or butyl hexanoate were included in the study. Traps were rotated twice after two weeks. GAA co-lures were vials with a 3.1-mm hole. A similar study was conducted from 13 July to 3 August in the Ashland orchard with codling moth, obliquebanded leafroller, and eyespotted budmoth. Lure treatments included codlemone, and the combination lures with pear ester, nonatriene, and beta ocimene. GAA co-lures were vials with a 3.1-mm hole. Traps were not rotated during the trial. Moth catches of codling moth, Pandemis leafroller, and oriental fruit moth were recorded in the Parker orchard from 29 August to 6 September from 10 replicates of codlemone and the combination lures with pear ester and beta ocimene plus the plastic cup GAA co-lure.

Three studies were conducted to evaluate the relative attractiveness of the three GAA co-lures for the different tortricids. The first study was conducted with only codling moth in the Toppenish orchard from 13 June to 3 August. Traps were rotated each week. The second study was conducted in the Parker orchard from 13 June to 11 July for codling moth and oriental fruit moth. The third study was split between 23 June to 7 July in the Moxee orchard and 2 to 9 September in the Naches orchard for codling moth and Pandemis leafroller. Five replicates were included in each site and the traps were rotated once in the Moxee orchard.

2012. Studies focused on the use of lures to catch both codling moth and oriental fruit moth and the use of different GAA co-lures for eyespotted budmoth. Three experiments were conducted in the Parker orchard. The first of these compared the attractiveness of pear ester and beta ocimene individually and together for both codling moth and oriental fruit moth. This study was run twice with new lures for 7–10 d on 7 and 17 May. The second compared the same lures, but in combination with the plastic cup GAA co-lure. This test was replicated on three dates with new lures for 7–9 d between 6 June and 13 July. The third study conducted from 29 August to 16 September was a repeat of the 2011 Parker study with 10 replicates of traps baited with either codlemone alone or pear ester or beta ocimene combination lures all combined with the plastic cup GAA co-lure. Moth catches of codling moth, Pandemis leafroller, and oriental fruit moth were recorded, and traps were rotated once after 10 d. The fourth study was conducted in the Ashland apple orchard with codling moth, obliquebanded leafroller, and eyespotted budmoth from18 July to 8 August. Traps were baited with Pherocon CM-DA Combo lures with one of three different GAA co-lures, including vials with either a 1.0- or 3.1-mm hole or the plastic cup lure. Ten replicates of each lure type were included, and traps were not rotated during the test.

Correlation of Leafroller Counts and Pest Pressure. Studies were conducted in 31 orchards with either predominately Pandemis ($N = 12$) or obliquebanded ($N = 19$) leafrollers during 2011. Studies were conducted in seven Oregon pear orchards situated near Medford (42° 20′ N, 122° 51′ W) with obliquebanded leafroller, and 12 Washington State apple orchards with predominately one of each of the species situated near Brewster (48° 5′ N, 119° 47′ W), Quincy (47° 14′ N, 119° 51′ W), Wenatchee (47° 25′ N, 120° 19′ W), and Yakima (46° 36′ N, 120° 30′ W). Orchards studied outside of the Yakima and Brewster areas were chosen by collaborating orchard managers based on their expectations that orchards would have some measurable level of leafroller fruit injury. Orchards were scouted in April–May for overwintering larvae feeding on new growth. Visual sampling was also conducted during July–August for the presence of summer larval populations. Levels of fruit injury by leafrollers before harvest were evaluated by each of the field managers and the intensity of sampling varied among orchards. Two types of lure-baited traps were placed in each orchard to monitor both codling moth and leafrollers. One trap was baited with the sex pheromone lure of the leafroller species considered to be dominant in the area. The second trap was baited with the Pherocon CM-DA Combo lure plus the GAA vial with a 3.1-mm hole. All lures were replaced once at mid-season. The presence of commercial cherry orchards adjacent to each of the apple and pear blocks was noted, as these can serve as important reservoirs of both species of leafrollers.

Statistical Analysis. Mean moth catches are reported for each treatment over the length of each experiment. A square root and angular transformation were used to normalize count and proportional data before analysis, respectively (Statistix 9, Analytical Software, Tallahassee, FL). A Shapiro–Wilks test was used to test for the normality of the raw and transformed data. Analysis of variance (ANOVA)

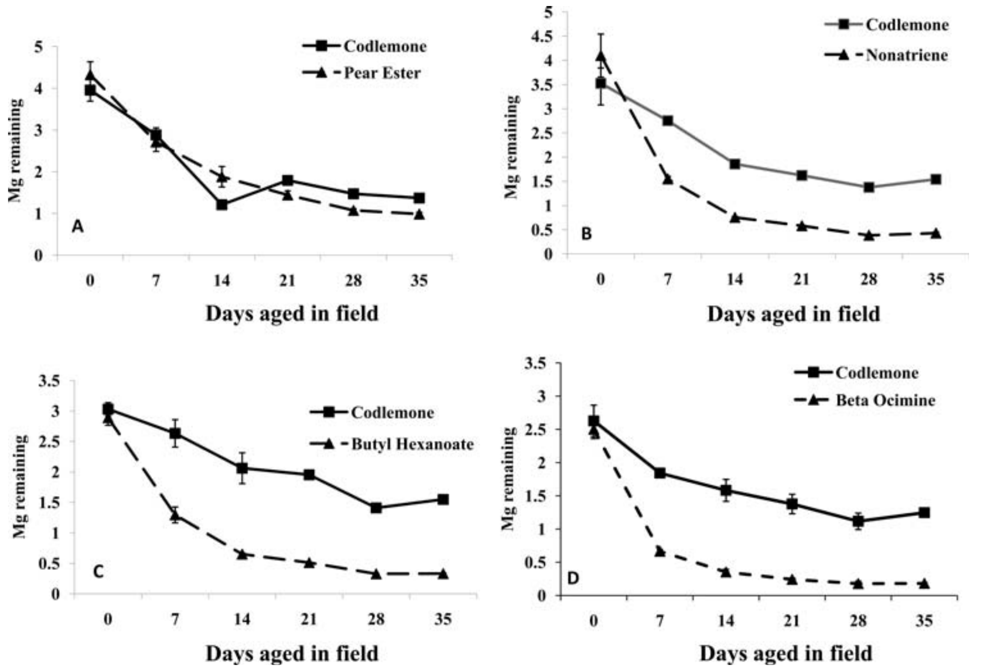

Fig. 1. Residual analyses of new and field-aged HPV combination lures loaded with codlemone and (A) pear ester, (B) nonatriene, (C) butyl hexanoate, and (D) beta ocimene, $N = 5$ lures analyzed on each date.

was used with normalized data and the nonparametric Kruskal–Wallis ANOVA of ranks was used for transformed data that were not normalized. Traps in some experiments were dislodged from trees, and these data were not included in the summary or analyses. A P value of 0.05 was used to establish significance in all statistical tests.

Results

Analysis of Lures. The expected loading of all HPV combination lures was 3 mg for both codlemone and the HPV, but some variability was noted in the analysis of day 0 lures (Fig. 1). In all four analyses of the combination lures, ≈50% of codlemone was lost after 35 d. The loss of HPVs from septa varied widely (Fig. 1). Pear ester was lost from septa at a rate similar to codlemone (Fig. 1A). Nonatriene and butyl hexanoate lost 50% of their initial loading by day 7 (Fig. 1B and C). Beta ocimene lures lost 75% of their initial loading by day 7 (Fig. 1D). The residual content of nonatriene, butyl hexanoate, and beta ocimene reached a low level by 21 d and remained flat over the next 2 wk (Fig. 1B–D).

2009 Field Trials. The combination of beta ocimene or butyl hexanoate with GAA caught significantly more total, but not female only, codling moths than GAA alone (Table 2). Beta ocimene plus GAA caught significantly more total moths and females than beta ocimene alone, and butyl hexanoate plus acetic

Table 2. Comparison of moth catches in traps baited with either the HPV butyl hexanoate or beta ocimene lures with and without a GAA co-lure; codling moth, $N = 18$, Toppenish, WA, 2009; and oriental fruit moth, $N = 10$, Medford, OR, 2010

HPV lure	GAA co-lure[b]	Mean (SE) moth catch[a]			
		Codling moth		Oriental fruit moth	
		Total	Females	Total	Females
−	+	1.6 (0.7)b	0.5 (0.2)ab	0.0 (0.0)	0.0 (0.0)
Beta ocimene	−	3.8 (1.3)b	0.1 (0.1)b	0.6 (0.2)	0.2 (0.1)
Beta ocimene	+	10.0 (1.3)a	4.4 (1.3)a	0.8 (0.4)	0.3 (0.2)
Butyl hexanoate	−	7.6 (2.2)ab	0.1 (0.1)b	0.2 (0.2)	0.0 (0.0)
Butyl hexanoate	+	10.4 (2.2)a	3.8 (1.2)a	0.2 (0.1)	0.1 (0.1)
ANOVA		$F_{4, 83} = 8.99$ $P < 0.0001$	$F_{4, 83} = 9.43$ $P < 0.0001$	$F_{4, 44} = 2.34$ $P = 0.07$	$F_{4,44} = 1.59$ $P = 0.19$

Column means followed by a different letter were significantly different, $P < 0.05$.

[a] The field trial with codling moth was conducted from 5 to 19 August 2009 in the Toppenish orchard, and the field trial with oriental fruit moth was conducted in the Medford orchard from 14 to 28 June 2010.

[b] "+" denotes the use of the GAA co-lure and "−" denotes no co-lure was used in the trap. The 8-ml vial with a 1.0-mm-hole was used as the GAA co-lure in both studies.

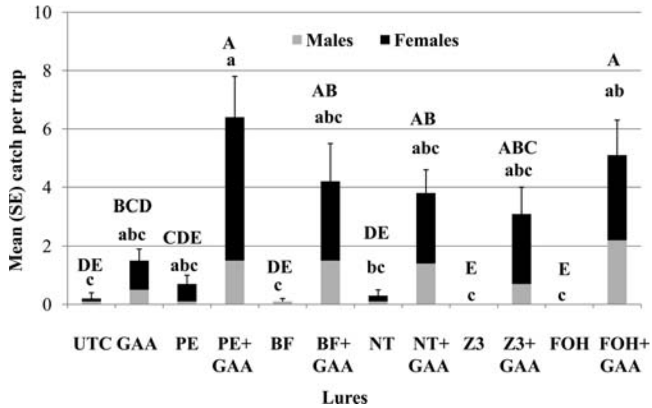

Fig. 2. Comparison of mean total (uppercase letters) and female (lowercase letters) leafrollers (combination of both obliquebanded and Pandemis leafroller adults) caught in traps unbaited (UTC) or baited with HPVs alone and in combination with GAA, 2009.

acid caught significantly more females, but not total moths, than butyl hexanoate alone. Beta ocimene or butyl hexanoate with the GAA co-lure caught similar numbers of total and female codling moths.

Traps with 3.1-mm GAA co-lures consistently caught greater numbers of female than male leafrollers across the HPVs tested (Fig. 2). Significant differences were found among lure treatments for total ($F_{11, 108} = 18.14, P < 0.0001$) and female codling moths ($F_{11, 108} = 15.90, P < 0.0001$). Traps baited with only HPV lures did not catch significantly more total or female leafrollers than the unbaited traps (Fig. 2). Both Z3–6Ac and farnesol alone failed to catch any leafroller adults (Fig. 2). The addition of the GAA co-lure significantly increased the moth catch of each HPV, but only for the female catch with farnesol (Fig. 2). No significant differences were found for either total or female catches among HPVs with GAA added. When used with the GAA co-lure, only pear ester and farnesol caught significantly more total moths than the GAA co-lure alone (Fig. 2).

2010 Field Trials. Low numbers of oriental fruit moths were caught in the Medford peach orchard in traps baited with GAA alone and beta ocimene and butyl hexanoate alone or with a GAA co-lure added (Table 2). No significant differences were found for either total moth or female catches among lure treatments. Significant differences were found in the Toppenish study with codling moth comparing GAA alone with four HPVs with a GAA co-lure. Pear ester and nonatriene caught significantly more total moths than GAA alone (Table 3). Pear ester combined with the GAA co-lure caught more total moths than both beta ocimene and butyl hexanoate with the GAA co-lure (Table 3). Similarly, pear ester with a GAA co-lure caught significantly more female codling moths than all treatments, except nonatriene with a GAA co-lure. Nonatriene with a GAA co-lure caught more females than GAA alone and butyl hexanoate with a GAA co-lure (Table 3). The combination of the GAA co-lure with a 1.0-mm hole with pear ester caught significantly more total and female codling moths than the combination of GAA co-lure with a 3.1-mm hole and pear ester (Table 4).

2011 Field Trials. Significant differences were found in the catch of codling moth but not Pandemis leafroller among traps baited with HPV combination lures and GAA co-lures (Table 5). HPV combination lures with either pear ester or beta ocimene caught more total moths than the combination lure with butyl hexanoate. The combination lure with pear ester caught significantly more female moths than the codlemone alone with the GAA co-lure (Table 5). The addition of the HPV to the codlemone with the GAA co-lure did not have any impact on Pandemis leafroller catches (Table 5). Similarly, the addition of HPVs to codlemone in combination lures had no effect on catches of obliquebanded leafroller in the Ashland orchard (Table 6). However, significant differences were found for moth catches of both codling moth and eyespotted budmoth. The pear ester combination lure caught significantly more total and female moths than the codlemone alone with the GAA co-lure (Table 6). In addition, the pear ester combination lure caught significantly more female codling moths than either the codlemone or

Table 3. Comparison of catches of codling moth in traps baited with HPV lures, including beta ocimene, butyl hexanoate, nonatriene, or pear ester with GAA co-lures or the GAA lure alone, *N* = 20, Toppenish, WA, 2010

Lure[a]	Mean (SE) moth catch[b]	
	Total	Females
GAA	0.6 (0.2)c	0.2 (0.1)c
Beta ocimene + GAA	3.9 (1.2)bc	1.8 (0.7)bc
Butyl hexanoate + GAA	4.5 (1.5)bc	0.3 (0.1)c
Nonatriene + GAA	7.3 (1.5)ab	2.8 (0.5)ab
Pear ester + GAA	20.5 (2.9)a	6.6 (1.3)a
ANOVA	$F_{4, 95} = 26.48$ $P < 0.0001$	$F_{4, 95} = 19.55$ $P < 0.0001$

Column means followed by a different letter were significantly different, $P < 0.05$.
[a] The 8-ml vial with a 1.0-mm-hole was used as the GAA co-lure.
[b] The field trial was conducted from 13 May to 1 June 2010 in the Toppenish orchard.

Table 4. Comparison of codling moth catches in delta traps baited with different GAA co-lures which varied in their range of weekly emission rates and used with either a pear ester (Experiment 1) or a combination pear ester and codlemone septa lure (Experiment 2)

Exp. no.[a]	Type of GAA co-lure	Range of mean weekly wt loss (mg) from GAA co-lure during trial	Mean (SE) weekly moth catch	
			Total	Females
1	1.0-mm vial	47–130	3.8 (0.5)a	1.3 (0.2)a
	3.1-mm vial	191–530	2.7 (0.3)b	0.8 (0.1)b
ANOVA			$F_{1, 238} = 14.55$ $P < 0.01$	$F_{1, 238} = 14.63$ $P < 0.01$
2	TRE3321	17–37	5.8 (0.7)	1.8 (0.2)a
	1.0-mm vial	75–185	4.4 (0.4)	1.1 (0.2)b
ANOVA			$F_{1, 138} = 1.61$ $P = 0.21$	$F_{1, 138} = 5.87$ $P < 0.05$

Column means within each experiment followed by a different letter were significantly different, $P < 0.05$.
[a] Experiment 1 was conducted from 4 May to 27 July 2010 and Experiment 2 from 13 June to 3 August 2011 in the Toppenish orchard.

the beta ocimene combination lures with the GAA co-lures (Table 6). Similarly, the pear ester combination lure outperformed the beta ocimene combination lure for eyespotted budmoth for both total and female moths (Table 6).

Mean weekly catches of codling moth varied in traps baited with Pherocon CM-DA Combo lures with either the cup membrane GAA co-lure or with vials with 1.0-mm holes significantly increased captures of females, but not total catches, during a 7-wk trial in the Toppenish orchard (Table 4). Also, significant differences were found in the catch of codling moth and oriental fruit moth in traps baited with Pherocon CM-DA Combo lures with one of three GAA co-lures (Table 7). Significantly more total moths of both species were caught in traps with the plastic cup GAA co-lure compared with the vial with the 3.1-mm hole. The weight loss of these dispensers varied by >10-fold during the experiment. Similarly, significantly more female oriental fruit moths, but not codling moths, were caught in traps with the plastic cup GAA co-lure than the vials with the 3.1-mm hole. Conversely, in a second test with codling moth and Pandemis leafroller in the Naches and Moxee1 orchards, significantly more total and female leafrollers were caught in traps baited with vials with the 3.1-mm hole than the plastic cup lure (Table 8). No differences in moth catches were found among GAA co-lures for codling moth in this test.

2012 Field Trials. The influence of the emission rate of the GAA co-lure was significant for eyespotted budmoth, but not for codling moth or obliquebanded leafroller in the Ashland orchard (Table 9). Traps baited with Pherocon CM-DA Combo lures plus GAA vials with the 3.1-mm hole caught significantly more total and female eyespotted budmoth than traps baited with plastic cup lures. Low numbers of obliquebanded leafrollers were caught in this study and none were caught in traps with the plastic cup lures.

Significant differences were found in comparisons of pear ester versus beta ocimene combination lures in the Parker orchard in 2011 and 2012 (Table 10). Significantly more female codling moths were caught with the pear ester combination lure plus GAA than the beta ocimene combination lure or codlemone alone (Table 10). In contrast, the beta ocimene combination lure caught significantly more total oriental fruit moths and females than either the pear ester combination lure or codlemone alone. No differences were found for catches of leafrollers (Table 10).

No oriental fruit moths were caught in delta traps baited with pear ester, beta ocimene, or both HPVs in test 1 in the Parker orchard (Fig. 3A and B). The pear ester plus beta ocimene lure caught significantly more codling moths than beta ocimene alone, and the effectiveness of the pear ester alone was intermediate, $F_{2, 27} = 3.63, P < 0.05$ (Fig. 3A). Female codling moths were only caught in traps with the HPV combo lure,

Table 5. Comparison of catches of codling moth and Pandemis leafroller in traps baited with septa lures loaded with codlemone (CM-PH) alone or in combination with different HPVs, including pear ester, nonatriene, butyl hexanoate, and beta ocimene plus the use of a GAA co-lure, N = 27, Naches, WA, 2011

Lures[a]	Mean (SE) catch[b]			
	Codling moth		Pandemis leafroller	
	Total	Females	Total	Females
CM-PH + GAA	1.0 (0.3)ab	0.0 (0.0)b	3.2 (0.8)	1.2 (0.3)
CM-PH–pear ester + GAA	2.9 (0.5)a	0.8 (0.2)a	4.5 (1.1)	1.8 (0.4)
CM-PH–nonatriene + GAA	1.4 (0.4)ab	0.4 (0.2)ab	4.2 (0.9)	1.9 (0.4)
CM-PH–butyl hexanoate + GAA	0.3 (0.1)b	0.2 (0.1)ab	3.8 (0.9)	1.3 (0.3)
CM-PH–beta ocimene + GAA	1.4 (0.3)a	0.1 (0.1)ab	4.8 (1.2)	2.0 (0.5)
ANOVA	$F_{4, 130} = 6.83$ $P < 0.001$	$F_{4, 130} = 5.90$ $P < 0.001$	$F_{4, 129} = 0.19$ $P = 0.94$	$F_{4, 129} = 0.67$ $P = 0.62$

Column means followed by a different letter were significantly different, $P < 0.05$.
[a] The 8-ml vial with a 3.1-mm hole was used as the GAA co-lure.
[b] The field trial was conducted from 10 August to 6 October 2011 in the Naches orchard.

Table 6. Comparison of catches of codling moth, obliquebanded leafroller, and eyespotted budmoth in traps baited with septa lures loaded with codlemone (CM-PH) alone or in combination with different host plant volatiles, including pear ester, nonatriene, or beta ocimene plus the use of a GAA co-lure, $N = 10$, Ashland, OR, 2011

Lures	Mean (SE) catch per trap					
	Codling moth		Obliquebanded leafroller		Eyespotted budmoth	
	Total	Females	Total	Females	Total	Females
CM-PH + GAA	0.7 (0.3)b	0.1 (0.1)b	1.5 (0.6)	1.2 (0.5)	3.4 (0.7)ab	1.6 (0.5)ab
CM-PH–pear ester + GAA	7.3 (1.6)a	1.1 (0.3)a	0.6 (0.2)	0.6 (0.2)	8.1 (1.9)a	6.0 (1.4)a
CM-PH–nonatriene + GAA	2.1 (0.7)ab	0.7 (0.3)ab	0.8 (0.2)	0.6 (0.2)	4.1 (1.3)ab	2.0 (0.5)ab
CM-PH–beta ocimene + GAA	2.8 (1.2)ab	0.1 (0.1)b	0.7 (0.4)	0.6 (0.4)	1.4 (0.5)b	0.8 (0.4)b
ANOVA	$F_{3, 36} = 6.19$ $P < 0.01$	$F_{3, 36} = 5.79$ $P < 0.01$	$F_{3, 36} = 0.73$ $P = 0.54$	$F_{3, 36} = 0.91$ $P = 0.45$	$F_{3, 36} = 5.70$ $P < 0.01$	$F_{3, 36} = 6.71$ $P < 0.01$

Column means followed by a different letter were significantly different, $P < 0.05$.
[a] The field trial was conducted from 13 July to 3 August 2011 in the Ashland orchard.
[b] The plastic cup GAA co-lure TRE3321 was used in all traps.

but treatment means did not differ significantly, $F_{2, 27} = 1.08$, $P = 0.36$ (Fig. 3B).

The addition of the GAA co-lure was effective in catching both sexes of both species (Fig. 3, test 2). The greatest number of oriental fruit moths in test 2 with the GAA co-lures was with beta ocimene, and this was significantly greater than with pear ester or GAA alone, $F_{3, 56} = 5.49$, $P < 0.01$ (Fig. 3A). Significantly more female oriental fruit moths were caught in traps with beta ocimene than in traps with pear ester, $F_{3, 56} = 5.20$, $P < 0.01$ (Fig. 3B, test 2). Significantly more codling moths were caught in traps including pear ester than GAA alone, $F_{3, 56} = 2.84$, $P < 0.05$ (Fig. 3A). Traps baited with the pear ester plus beta ocimene lure caught significantly more females than GAA alone, $F_{3, 56} = 5.51$, $P < 0.01$ (Fig. 3B).

Correlation of Leafroller Counts and Pest Pressure. Significant differences in male leafroller catches in traps were found for both species among the three orchard categories based on pest pressure (Table 11). Mean catches of leafrollers were 3–4-fold higher in sex pheromone-baited traps in orchards with sampled larvae or fruit injury than in uninfested orchards (Table 11). The increase in leafroller adult catches in traps baited with the pear ester combo lure plus GAA in infested as compared with uninfested orchards was much larger (40–90-fold increase) than when using pheromone-baited traps (Table 11). Leafroller catches were significantly higher in orchards with sampled larvae or injury than in uninfested orchards (Table 11). Moth catches in orchards categorized as being adjacent to cherry orchards were intermediate with respect to the other treatments (Table 11).

Examination of these data in more detail revealed a number of inconsistencies. No leafroller adults were caught in CM-DA plus GAA-baited traps in 11 orchards, and only in one of these orchards were larvae sampled. This orchard was adjacent to an infested orchard. Low levels of leafroller adults (≤1 moth per trap) were found in two uninfested orchards. Both orchards were sprayed throughout the season with a conventional insecticide program that may have masked the presence of a population. Leafrollers were caught in traps, and no larvae or injury was found in five orchards that were adjacent to cherry orchards, unsprayed backyard fruit trees, or both. Traps in all blocks in which leafroller fruit injury was detected also caught leafroller adults.

Discussion

Our studies found that acetic acid is attractive, either alone or in combination with HPVs, for a number of tortricid species in tree fruit orchards. Acetic acid is produced by microbial action during the fermentation of sugars as fruit ripens and decays (Atlas and Bartha 1981). Seasonal patterns of acetic acid in orchards have not been reported, but there likely could be a large variation during the season and among orchards. For example, apple orchards experience a natural, as well as, hand or chemical thinning of small

Table 7. Comparison of catches of codling moth and oriental fruit moth in traps baited with septa lures loaded with codlemone and pear ester plus one of three different GAA co-lures, with different ranges of emission rates during the study, $N = 40$, Parker, WA, 2011

GAA co-lure	Range of mean weekly wt loss (mg) from GAA co-lure	Mean (SE) moth catch[a]			
		Codling moth		Oriental fruit moth	
		Total	Females	Total	Females
TRE3321	25–39	6.1 (1.1)a	1.3 (0.3)	1.6 (0.3)a	0.9 (0.2)a
1.0-mm	135–179	4.7 (0.6)ab	0.7 (0.1)	1.0 (0.3)ab	0.7 (0.2)ab
3.1-mm	335–459	3.4 (0.5)b	0.8 (0.1)	0.4 (0.1)b	0.1 (0.1)b
ANOVA		$F_{2, 117} = 3.20$ $P < 0.05$	$F_{2, 117} = 0.76$ $P = 0.47$	$F_{2, 117} = 8.13$ $P < 0.001$	$F_{2, 117} = 8.88$ $P < 0.001$

Column means within each exp followed by a different letter were significantly different, $P < 0.05$.
[a] Experiment was conducted from 13 June to 11 July 2011 in the Parker orchard.

Table 8. Comparison of catches of codling moth and Pandemis leafroller in traps baited with septa lures loaded with codlemone and pear ester plus one of three different GAA co-lures, with different ranges of emission rates during the study, $N = 15$, Naches and Moxee, WA, 2011 TRE3321

GAA co-lure	Range of mean weekly wt loss (mg) from GAA co-lure	Mean (SE) moth catch: Codling moth Total	Codling moth Females	Pandemis leafroller Total	Pandemis leafroller Females
TRE3321	25–29	3.1 (0.6)	0.4 (0.2)	1.4 (0.4)b	0.9 (0.3)b
1.0-mm	137–215	3.1 (0.9)	0.2 (0.1)	7.8 (1.4)a	4.0 (1.0)ab
3.1-mm	294–557	1.6 (0.3)	0.3 (0.2)	9.7 (1.5)a	5.4 (1.2)a
ANOVA		$F_{2, 42} = 1.80$ $P = 0.18$	$F_{2, 42} = 0.46$ $P = 0.46$	$F_{2, 42} = 23.42$ $P < 0.0001$	$F_{2, 42} = 6.04$ $P < 0.01$

Column means within each experiment followed by a different letter were significantly different, $P < 0.05$.

[a] This experiment was conducted at two sites from 23 June to 7 July in the Moxee orchard and from 2 to 9 September in the Naches orchard during 2011. Traps were baited with combination codlemone plus pear ester lures plus the GAA co-lure.

fruits in June. These fruits are dropped to the floor of the orchard to decay. Later in the season, further hand-thinning and precocious ripening of damaged fruits from mechanical injury, birds, disease, and insects occurs, and additional fruit decay either on the tree or on the ground in the orchard. Thus, the concentration of acetic acid within orchards' air space is variable and this could impact the variability of the effectiveness of using acetic acid lures for monitoring tortricids.

Neural mapping of the male and female antennal lobes to investigate the complexity of message integration from specific subsets of olfactory receptor neurons activated by sex pheromones and environmental cues has been reported for both *C. pomonella* (Trona et al. 2011, 2013) and *G. molesta* (Varela et al. 2009, 2011a). These studies have revealed the complexity and the variability in the response specificity of antennal lobe neurons to both sex pheromones and plant cues (Trona et al. 2011, Varela et al. 2011a). Both studies found subsets of neurons that only responded to sex pheromone, only to HPVs, or to both. These data have shown that these moths perceive sex pheromones and HPVs as a blend (Trona et al. 2013). Applied behavioral studies have clearly shown that HPVs can increase the response of male moths to their sex pheromone (Yang et al. 2004, Knight et al. 2005, Varela et al. 2011b, Schmera and Guerin 2012). Unfortunately, the functional studies of the olfactory system of only *C. pomonella* have included its response to acetic acid (Trona et al. 2011).

Acetic acid released from fermenting baits is likely a long-range cue used by moths to locate fruit-laden hosts for oviposition and as sugary adult food sources (Landolt and Guedot 2008). Combining a ripening fruit odorant, such as pear ester, with a food cue (acetic acid) increases moth capture within traps (short-range behavior). Knight et al. (2011a) hypothesized that HPVs that have higher release rates due to natural or precocious fruit ripening or induction by herbivore damage or stress could be promising candidates as coattractants with acetic acid; e.g., beta ocimene and various butanoate and hexanoate esters (Takabayashi et al. 1994, Boevé et al. 1996, Scutareanu et al. 1997). Further development of improved HPV blends with GAA for primarily leaf feeding tortricids would benefit from investigation of leaf-related compounds induced by herbivory.

There are a number of practical issues associated with the development of HPV plus GAA lure combinations. In general, these lures catch <10% as many total moths as the standard sex pheromone lures. However, they do catch both sexes, which can provide additional information useful for monitoring and assessing these pests' population densities within orchards. Second, GAA lures are attractive to a number of often abundant nontargets insects, including dipterans and hymenopterans, and larger lepidopteran

Table 9. Comparison of catches of codling moth, obliquebanded leafroller, and eyespotted budmoth in traps baited with septa lures loaded with codlemone and pear ester plus one of three different GAA co-lures, with different ranges of emission rates during the study, $N = 10$, Ashland, OR, 2012

GAA co-lure	Range of mean weekly wt loss (mg) from GAA co-lure	Mean (SE) moth catch: Codling moth Total	Codling moth Females	Obliquebanded leafroller Total	Obliquebanded leafroller Females	Eye-spotted bud moth Total	Eye-spotted bud moth Females
TRE3321	30–33	10.2 (2.1)	1.7 (0.6)	0.0 (0.0)	0.0 (0.0)	6.8 (2.4)b	3.8 (1.4)b
1.0-mm	119–167	6.1 (1.6)	2.1 (0.5)	0.5 (0.3)	0.4 (0.3)	14.2 (3.4)ab	9.7 (2.1)ab
3.1-mm	245–401	6.4 (1.2)	1.1 (0.3)	0.5 (0.2)	0.3 (0.2)	17.3 (2.5)a	11.8 (1.9)a
ANOVA		$F_{2, 24} = 1.27$ $P = 0.30$	$F_{2, 27} = 1.15$ $P = 0.33$	$F_{2, 27} = 2.51$ $P = 0.22$	$F_{2, 27} = 1.62$ $P = 0.10$	$F_{2, 27} = 4.73$ $P < 0.05$	$F_{2, 27} = 6.46$ $P < 0.01$

Column means within each experiment followed by a different letter were significantly different, $P < 0.05$.

[a] Experiment was conducted from 18 July to 8 August 2012 in the Ashland orchard. Traps were baited with the combination pear ester plus codlemone lures.

Table 10. Comparison of catches of codling moth, Pandemis leafroller, and oriental fruit moth in traps baited with septa lures loaded with codlemone and pear ester plus a GAA co-lure, Parker, WA, 2011 and 2012

Lures[a]	Mean (SE) moth catch[b]					
	Codling moth		Pandemis leafroller		Oriental fruit moth	
	Total	Females	Total	Females	Total	Females
CM-PH + GAA	1.9 (0.8)	0.0 (0.0)b	2.1 (0.3)	0.9 (0.2)	0.3 (0.1)b	0.2 (0.1)b
CM-PH–pear ester + GAA	1.9 (0.4)	0.6 (0.1)a	1.4 (0.3)	0.6 (0.2)	0.4 (0.1)b	0.1 (0.1)b
CM-PH–beta ocimene + GAA	1.8 (0.5)	0.1 (0.1)b	1.8 (0.3)	0.5 (0.1)	1.6 (0.4)a	1.3 (0.3)a
ANOVA	$F_{2,\ 87} = 0.27$ $P = 0.77$	$F_{2,\ 87} = 16.19$ $P < 0.0001$	$F_{2,\ 87} = 1.74$ $P = 0.18$	$F_{2,\ 87} = 0.64$ $P = 0.53$	$F_{2,\ 87} = 10.10$ $P < 0.0001$	$F_{2,\ 87} = 16.41$ $P < 0.0001$

Column means followed by a different letter were significantly different, $P < 0.05$.
[a] The plastic cup GAA co-lure TRE3321 was used in all traps.
[b] The field trial was conducted from 29 August to 6 September 2011 and repeated from 29 August to 16 September 2012 in the Parker orchard.

species. Traps can fill with these nontargets in some environments; i.e., orchards near dairies (dipterans) or near grass fields (noctuids), or late in the season when pestiferous wasps (vespids) are present in large numbers in orchards with ripe fruits. Development of GAA lures with a minimal effective loading or the use of exclusion screens are possible solutions (Knight et al. 2013). Third, the relative longevity of HPV lures versus either the sex pheromone or GAA lures varies, depending on both the relative volatility of each compound and likely the chemical stability of compounds with multiple double bonds. Increasing the loading of beta ocimene or butyl hexanoate would likely increase the longevity of these attractants, but improved formulations and alternative lure substrates may also be needed to extend the effectiveness of these chemicals as lures.

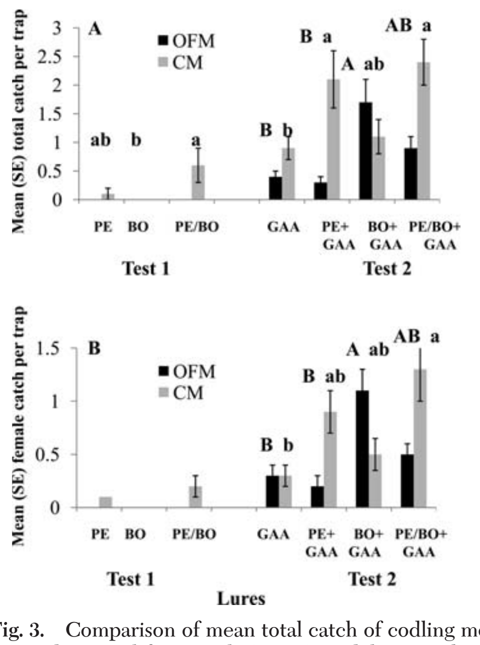

Fig. 3. Comparison of mean total catch of codling moth (CM) and oriental fruit moth (OFM) in delta traps baited with either pear ester, beta ocimene or both alone, or in combination with glacial acetic acid (GAA) co-lures; total moths (A) and female moths (B), 2012.

Development of monitoring systems to use for more than one of the tortricids present in an orchard has been attempted previously with sex pheromone lures to minimize the cost of monitoring (Knight and Christianson 1999). In general, related tortricid moths have narrowly tuned sexual signals that cause interference with other species. For example, the sex pheromone lures of codling moth and leafrollers had no effect on the cumulative catch of codling moth or obliquebanded leafroller, but did significantly reduce the catch of Pandemis leafroller (Knight and Christianson 1999) The combined use of sex pheromone lures for codling moth and oriental fruit moth has been shown to significantly increase and decrease the catches of oriental fruit moth and codling moth, respectively (Evenden and McLaughlin 2005). Nevertheless, combining sex pheromone lures for more than one species would not solve some of the current problems with the use of sex pheromone-baited traps, which catch only males, are impacted by the use of sex pheromone-based mating disruption, and whose active range may be too large to provide a useful correlation with local pest populations.

The successful use of traps baited with the Pherocon CM-DA Combo lure plus a GAA co-lure reported here for both codling moth and leafrollers is a new approach. A single monitoring trap for codling moth and leafrollers was found to provide useful management information. Traps failed to catch leafrollers in orchards where leafrollers were not present, except in some orchards adjacent to cherry blocks. Cherry orchards can serve as important reservoirs of both species of leafrollers, particularly following harvest (Long et al. 1997, Knight 2001). Thus, these catches likely provide some indication of the orchard's risk from immigrating moths and are useful data. Future studies should consider the sex of moths caught in these traps to establish a threshold based on female moth catches as well as total catch of leafrollers. In a few cases, overwintering larvae were sampled in orchards in which local traps did not later catch moths. This is likely due to suppression of leafroller adults with the use of insecticides. More importantly, no cases were found during this 2-yr study where traps failed to catch adult leafrollers and later detection of leafroller larvae was reported. Our results suggest that further studies

Table 11. Comparison of catches of either Pandemis or obliquebanded leafroller in orchards classified based on the presence of leafrollers within or nearby the orchard with traps baited either with the species sex pheromone or with a combination codlemone plus pear ester lure (PH/PE) with a GAA co-lure (vial with 3-mm hole), 2011

Orchard's leafroller classification[a]	Mean (SE) moth catch per trap					
	Pandemis leafroller		Obliquebanded leafroller		Combined	
	Pheromone	PH/PE + GAA	Pheromone	PH/PE + GAA	Pheromone	PH/PE + GAA
Larvae or injury	150.5 (97.5)	18.5 (11.5)a	226.0 (18.6)a	3.7 (0.9)a	2121.3 (35.1)a	6.4 (2.5)a
Nearby host	145.5 (50.4)	7.0 (5.7)ab	73.0 (26.2)ab	3.0 (1.0)ab	114.4 (32.2)ab	5.3 (3.2)a
Uninfested	51.8 (11.7)	0.2 (0.2)b	53.0 (21.9)b	0.1 (0.1)b	63.2 (22.6)b	0.2 (0.1)b
ANOVA	$F_{2, 9} = 2.85$ $P = 0.11$	$F_{2, 9} = 17.89$ $P < 0.001$	$F_{2, 16} = 5.93$ $P < 0.05$	$F_{2, 16} = 10.78$ $P < 0.001$	$F_{2, 28} = 8.79$ $P < 0.01$	$F_{2, 28} = 24.55$ $P < 0.0001$

Column means followed by a different letter were significantly different, $P < 0.05$.

[a] Orchards were classified into three groups based on the detection of larvae or fruit injury from sampling conducted during the season: seasonal presence of leafroller (larvae or injury), no larvae or injury detected during the season but the orchard was adjacent to a potential host; i.e., cherry (nearby host), and isolated orchard without any larvae or fruit injury (clean).

are needed to evaluate the use of lure combinations including GAA that can monitor both the key and secondary tortricid pests co-occurring in many tree fruit orchards.

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