Open Access Articles

Monitoring Oriental Fruit Moth and Codling Moth (Lepidoptera: Tortricidae) With Combinations of Pheromones and Kairomones

The Faculty of Oregon State University has made this article openly available.
Please share how this access benefits you. Your story matters.

Citation	Knight, A., Cichon, L., Lago, J., Fuentes-Contreras, E., Barros-Parada, W., Hull, L., Krawczyk, G., Zoller, B., Hansen, R., Hilton, R. and Basoalto, E. (2014). Monitoring oriental fruit moth and codling moth (Lepidoptera: Tortricidae) with combinations of pheromones and kairomones. Journal of Applied Entomology, 138(10), 783–794. doi:10.1111/jen.12138
DOI	10.1111/jen.12138
Publisher	John Wiley & Sons Ltd.
Version	Accepted Manuscript
Terms of Use	http://cdss.library.oregonstate.edu/sa-termsofuse

Submitted to:

J. Appl. Entomol.

Please send galley proof to:

A. L. Knight

USDA, ARS

5230 Konnowac Pass Rd

Wapato, WA 98951

Phone (509) 454-6566

Fax (509) 454-5646

Email: alan.knight@ars.usda.gov

Running Head: Knight et al.: Monitoring oriental fruit moth and codling moth

Monitoring Oriental Fruit Moth and Codling Moth (Lepidoptera: Tortricidae) With Combinations of Pheromones and Kairomones

A. Knight [1], L. Cichon [2], J. Lago [2], E. Fuentes-Contreras [3,4], W. Barros-Parada [3,4], L. Hull [5], G. Krawczyk [5], B. Zoller [6], R. Hansen [7], R. Hilton [8], and E. Basoalto [8]

[1] Yakima Agricultural Research Laboratory

Agricultural Research Service, USDA

5230 Konnowac Pass Rd

Wapato, WA 98951

ABSTRACT

Experiments were conducted in North and South America during 2012-2013 to evaluate the use of lure combinations of sex pheromones (PH), host plant volatiles (HPV), and food baits in traps to capture the oriental fruit moth, *Grapholita molesta* (Busck) and codling moth, *Cydia pomonella* (L.) in pome and stone fruit orchards treated with sex pheromones. The combination of the sex pheromone of both species (PH combo lure) significantly increased *G. molesta* and marginally decreased *C. pomonella* captures as compared with captures of each species with either of their sex pheromones alone. The addition of a HPV combination lure ((*E,Z*)-2,4-ethyl decadienoate plus (*E*)-β-ocimene) or acetic acid used alone or together did not significantly increase the catch of either species in traps with the PH combo lure. The Ajar trap baited with terpinyl acetate and brown sugar (TAS bait) caught significantly more *G. molesta* than the delta trap baited with PH combo plus acetic acid in California during 2012. The addition of a PH combo lure to an Ajar trap significantly increased catches of *G. molesta* compared to the use of the TAS bait or PH combo lure alone in 2013. Female *G. molesta* were caught in TAS-baited Ajar traps at similar levels with or without the use of additional lures. Ajar traps baited with the TAS bait alone or with (*E*)-β-ocimene and/or PH combo lures caught significantly fewer *C. pomonella* than delta traps with sex pheromone alone. Ajar traps with 6.4-mm screened flaps caught similar numbers of total and female *G. molesta* as similarly baited open Ajar traps, and with a significant reduction in the catch of nontargets. Broader testing of HPV and PH combo lures for *G. molesta* in either delta or screened or open Ajar traps is warranted.

Key words: *Grapholita molesta*, *Cydia pomonella*, peach, apple

INTRODUCTION

Monitoring of tortricid pests attacking fruits in order to better time insecticide sprays and determine the need for control actions is well established in various crops, including tree fruits (Charmillot and Vickers 1991). Several recent studies have focused on developing new monitoring tools for oriental fruit moth, *Grapholita molesta* (Busck), especially in pome and stone fruit orchards treated with sex pheromones for mating disruption. These studies are relevant because traps baited with standard sex pheromone lures typically perform poorly in tracking the seasonal dynamics of *G. molesta* compared with codling moth, *Cydia pomonella* (L.), in orchards treated with dual species sex pheromone programs (Evenden and McLaughlin 2005, Il'ichev et al. 2007, Steliniski et al. 2007, 2009).

Studies have reported the development of new trap designs and lures for both sexes of *G. molesta*. Clear plastic delta-shaped traps baited with terpinyl acetate outperformed colored traps baited with sex pheromone (Knight et al. 2011a). Also, the addition of the green leaf volatile, (Z)-3-hexen-1-yl acetate further increased the number of moths caught in the clear trap. Studies in South America evaluated a new trap design (Ajar) using terpinyl acetate and brown sugar (TAS bait) in a jar as the attractant but not as the catching medium (Cichon et al. 2013). Instead, the liquid bait reservoir was attached to a delta trap and moths were caught on a regular sticky liner placed inside the trap. Studies in North America and Europe refined the Ajar trap and standardized its color and bait replenishment schedule (Knight et al. 2013). This work also evaluated the placement of screens over each end of the trap to reduce the catch of nontargets insects, i.e. diptera, hymenopteran, and other lepidopterans.

The use of various host plant volatiles as lures for adult *G. molesta* has been investigated by several laboratories over the last 10 years. These studies have identified a number of major apple and peach volatiles and these were tested for female moth attraction in a dual choice glass arenas. A three-component blend of a 4:1:1 ratio of (*Z*)-3-hexen-1-yl acetate, (*Z*)-3-hexen-1-ol, and benzaldehyde was reported to be attractive (Natale et al. 2003). A similar study also reported that butyl hexanoate was attractive (Natale et al. 2004). A third laboratory assay found that a 5-component blend including three green leaf volatiles, benzaldehye and benzonitrile was as attractive as volatiles emanating from peach shoots (Piñero and Dorn 2007). Furthermore, the addition of this 5-component blend to suboptimal doses of the sex pheromone increased the behavioral response of male *G. molesta* in a flight tunnel (Varela et al 2011).

The first field study reporting attractive host plant volatiles for *G. molesta* found a 1:2:2 ratio of (*Z*)-3-hexenyl acetate, (*E*)-β-ocimene and (*E*)-β-farnesene or either (*E*)-β-ocimene or (*E*)-β-farnesene alone were as attractive as the TAS bait to male but not female *G. molesta* in Australia (Il'ichev et al. 2009). The first field study demonstrating a host plant volatile blend attractive to both sexes of *G. molesta* used 6- and 8-component blends derived from Chinese pear varieties (Lu et al. 2012). A more recent investigation found that neither the Australian or Chinese blends were attractive in a Chilean peach orchard nor improved the performance of a sex pheromone lure (Barros et al. submitted.). In contrast, the addition of either (*E*)-β-farnesene, (*E*)-β-ocimene or butyl hexanoate lures in the Ajar trap with the TAS bait increased total moth catches and (*E*)-β-ocimene also increased female moth catches compared with the TAS bait alone (Knight et al. 2013).

The attractiveness of host plant volatiles for *C. pomonella* has also been broadly investigated in laboratory and field studies (reviewed in Knight et al. 2011b). Functional imaging of neural responses in the antennal lobes and laboratory assays of the behavioral response of host plant volatile and sex pheromone blends in *C. pomonella* has been used to clarify the integration of pheromonal and kariomonal information in the process of mate finding (Trona et al. 2010, 2013). Specifically, pear ester, (*E,Z*)-2,4-ethyl decadienoate, was found to be highly attractive to both sexes of *C. pomonella*, and this attraction was synergized by the addition of acetic acid (Light et al. 2001, Landolt et al. 2007). Other common pome fruit volatiles were found not to be attractive or synergized by acetic acid (Knight et al. 2011). (*E*)-β-ocimene with *C. pomonella* was found not to elicit an antennal response in females (Bengtsson et al. 2001), but was active with male antennae (Casado et al. 2006). (*E*)-β-ocimene as a lure has only been tested with *C. pomonella* in the field as a component of an unattractive monoterpene blend, and has not been tested with the addition of acetic acid (Light and Knight 2005). The addition of acetic acid with various HPV's has not been tested with *G. molesta*.

Ajar traps with the TAS bait plus a sex pheromone lure have been evaluated previously (Cichon et al. 2013, Knight et al. 2013). However, these studies showed that the contribution to moth catch efficacy provided by the sex pheromone lure in the sex pheromone-treated orchards was low. Allred et al. (1995) examined the use of the sex pheromone of *C. pomonella*, codlemone, (*E,E*)-8,10-dodecadien-1-ol, to possibly synergize the sex pheromone blend of *G. molesta*. Their studies suggested the addition of codlemone at 10 to 20-fold higher loadings than the *G. molesta* sex pheromone blend affected the short-range behaviors of male *G. molesta* leading to increased moth captures in traps. Interestingly, they did not get the same results by just increasing the amount of the natural sex pheromone alcohol, (*Z)*8-dodecenol to these levels. Field trials of this two-species' blends have not been tested in sex pheromone dispenser-treated orchards.

Herein, we report studies in North and South America conducted in stone and pome fruit orchards treated with sex pheromones for mating disruption of both *G. molesta* and *C. pomonella* to compare the relative attractiveness of standard sex pheromone lures alone with combinations of both sex pheromones either alone or with host plant volatiles and food baits added. Standard and combination sex pheromone lures with both 1% and 5% *Z*8-12:OH were tested. Our primary objective was to determine if combinations of these putative attractants could increase the catches of *G. molesta* without reducing the catch of *C. pomonella*. Our two secondary goals were to develop trap-lure combinations to monitor female *G. molesta* and to minimize the catch of nontargets insects in these traps.

MATERIALS AND METHODS

Traps, lures, and field study protocol.

Studies were conducted with three types of delta-shaped traps and several commercial and experimental lures during 2012-13. Traps included the standard orange Pherocon VI trap (28 x 20 x 20 cm, Trécé Inc., Adair, OK) and custom orange delta traps (Ajar) modified to include an attached 250 ml jar. The Ajar trap had a screened (1.2 mm holes) jar lid (7.3 cm o.d.) glued to the inside bottom of the trap. The third trap was a modified Ajar trap made from red polypropylene plastic with twenty-seven, 6.4-mm holes punched in a triangular-shape array on closed flaps at each end of the trap (Marginal Design, Oakland, CA). Paper liners coated with a polybutane adhesive (Trécé Inc.) were used in all studies in 2012 and in Pennsylvania and South America in 2013. Liners coated with a proprietary dry adhesive were used in all traps in the western U.S. in 2013 (AlphaScents, Portland, OR). Liners placed in Ajar traps had a central 8.0-cm circular area removed so that the liners would fit around the jar's cap. The proprietary sex pheromone lures (grey halobutyl septa) Pherocon CM L2 (codlemone, (*E,E*)-8,10-

dodecadien-1-ol) and Pherocon OFM L2 (93:6:1 blend of (*E*)-8-dodecenyl acetate, (*Z*)-8-dodecenyl acetate, and (*Z*)-8-dodecenol) were provide by Trécé Inc. Experimental septa lures were either loaded with sex pheromones or host plant volatiles alone or combined. Most of these experimental lures were prepared by Trécé Inc. chemists and shipped to the various researchers. The three components of *G. molesta* pheromone (*E*)-8-dodecenyl acetate (98.6% purity), (*Z*)-8-dodecenyl acetate (98.1% purity) and (*Z*)-8-dodecenol (98.3% purity); and the sex pheromone of *C. pomonella*, codlemone, (*E,E*)-8,10-dodecadien-1-ol, (97% purity) were purchased from Bedoukian Research, Danbury, CT. Experimental multi-component sex pheromone lures for *G. molesta* were prepared with either 1% (2012 OFM L2) or 5% (2013 OFM L2) of (*Z*)-8-dodecenol in the blend (0.41 mg total active loading). The proportion of (*Z*)-8-dodecenol in the blend was increased by the manufacturer to improve lure performance. Lures were prepared with either these blends alone or in combination with codlemone (PH combo) loaded at 3.0 mg (TRE0643 and TRE0864, respectively). TRE0643 was tested during 2012 in both hemispheres and in South America in 2013. TRE0864 was used in the western U.S. during 2013. (*E*)-β-ocimene (98% purity) was purchased from PRI Pherobank, Houten, The Netherlands; and pear ester, (*E,Z*)-2,4-ethyl decadienoate (>92% purity) was purchased from Bedoukian Research. These two host plant volatiles (3.0 mg each) were loaded individually (TRE0649 and TRE3460) or together (HPV combo, TRE0644) into grey septa in 2012 by Trécé Inc. β-ocimene (BOC) (mixture of (*E*) and (*Z*) isomers with > 90% (*E*)-isomer was purchased from Aldrich-Sigma (St. Louis, MO) for use in 2013. BOC lures (3.0 mg in red rubber septa) were prepared in the USA and Chile by diluting BOC in dichloromethane (99.9% purity, Sigma-Aldrich) and adding 100 µl into the cup area of the septum. Similar volumes of dichloromethane alone were added two times to increase the penetration and distribution of the active material into the septum. Acetic acid lures were tested only in 2012. These lures were 8 ml polyethylene vials (Nalg-Nunc International, Rochester, NY) loaded with two cotton balls and 8 ml of glacial acetic acid (99.9% purity, Aldrich-Sigma). The cap of the vial had a 3.0 mm hole drilled into the center. Ajar traps were loaded with 200 ml of an aqueous bait (TAS bait) comprised of 0.05% terpinyl acetate (99% purity, Sigma-Aldrich) plus 10% sugar (C&H Dark Brown Cane Sugar, Domino Foods, Yonkers, NY).

A general protocol for all lure studies was adopted across the various geographical regions. Septa lures were pinned to the inside roof of the trap. Treatments were randomized in each orchard with five replicates. Traps were placed in the upper third of the canopy, 20 – 30 m apart, and > 20 m from the borders of orchards. Moths were removed and counted weekly or biweekly. Traps were rotated among positions on each date they were checked. Studies lasted from one week to five months. Liners were replaced as needed and at least every four weeks in the longer studies. Lure replacement schedules varied for different lures. The TAS bait and septa loaded with HPVs were replaced every two weeks. Sex pheromone lures for both species were replaced every four weeks. Moths were sexed in the field or with the use of a microscope in the laboratory. Key nontargets catches in traps were recorded in a few studies, including muscid flies, hymenopterans, and moths with wingspans > 15 mm. A few exceptions to this general protocol occurred during this two-year study and will be noted.

Pennsylvania, 2012

Two apple sites situated near stone fruit orchards in Adams County, PA (39°56’N, 77°15’W) were used in 2012. One was a commercial orchard (N = 3) and the other was a research block (N = 2) on the Penn State Farm near Biglerville, PA. The study began on 23 May and was discontinued on 6 September 2012. Four trap-lure treatments were included: a delta trap with a codlemone lure, a delta trap with the *G. molesta* sex pheromone lure, a delta trap with both sex pheromones, and the Ajar trap with the TAS bait. Initially, the dual sex pheromone treatment included the use of two separate lures by mistake, but on 6 July this was changed to the single PH combo lure, TRE0643. The single species sex pheromone lures were also changed on this date. Additional TAS bait was added to replenish jars every week. Both orchards were treated with Isomate-CM/OFM TT dispensers at 500 ha^{-1} (Pacific Biocontrol, Vancouver, WA). Dispensers were loaded with 97 mg of a 93:6:1 blend of (*E*)-8-dodecenyl acetate, (*Z*)-8-dodecenyl acetate, and (*Z*)-8-dodecenol, and 268 mg of codlemone.

California, 2012-13

Studies were conducted in two regions characterized by mixed stone fruit and pome fruit production near Marysville in Yuba County (39^{o}8'N, 121^{o}35'W) and Lakeport in Lake County California (39^{o}2'N, 122^{o}55'E). The same five orchards were used in both years in Lake County, and in Yuba County five orchards were included in 2012 and four, including two new sites in 2013. All but one orchard in Lake County in both years were treated with CheckMate Puffer CM-O aerosol emitters (Suterra LLC, Bend, OR) loaded with 69.3 g codlemone and applied at 3.7 units ha^{-1} in an internal grid on 1 April. Puffers released 7.2 mg codlemone in a 40 µl puff every 15 min from 1500 to 0300 h. These four orchards received border applications of Isomate-C TT (Pacific Biocontrol) loaded with 228 mg of codlemone at a density of 500 dispensers ha^{-1} the following week. These orchards were also treated with three alternate-row spray applications of microencapsulated sex pheromone; CheckMate OFM-F (Suterra LLC) at 22.2 g AI ha^{-1} timed 30 d apart in mid- to late May, June, and July. CheckMate OFM-F (0.23 g AI ml^{-1}) was formulated with a 93:6:1 blend of (*Z*)- and (*E*)-8-dodecenyl acetate and (*Z*)-8-dodecenol. The 5th orchard in Lake County was treated in both years with Isomate-CM

TT at 500 ha^{-1} in early-April and 250 ha^{-1} Isomate-OFM TT dispensers (Pacific Biocontrol) in early May. This latter dispenser was loaded with 480 mg of a 93:6:1 blend of (*Z*)- and (*E*)-8-dodecenyl acetate and (*Z*)-8-dodecenol.

Orchards in Yuba County were treated with a variety of sex pheromone-based tactics in both years, including Isomate-OFM TT applied at 250 dispensers ha^{-1}, Isomate-OFM Ring (Pacific Biocontrol) loaded with 2.50 g of a 93:6:1 blend of (*Z*)- and (*E*)-8-dodecenyl acetate and (*Z*)-8-dodecenol and applied at 50 dispensers ha^{-1}, and the CheckMate Puffer CM-OFM O aerosol emitter (Suterra LLC) loaded with 94 g AI and releasing 7.2 mg codlemone and 5.0 mg of the three component *G. molesta* sex pheromone per 40 µl puff. Puffers were set in two orchards in early April 2012 and hand-applied dispensers (Isomate-CM TT and Isomate-M Rosso) were added to these orchards in late June. Isomate-M Rosso was applied at 250 dispensers ha^{-1} and was loaded with 250 mg of the thre- component blend for *G. molesta*. During 2013, two new orchards were treated with both Isomate-CM Ring and Isomate-OFM Ring at 50 dispensers ha^{-1} in late April. Isomate-CM Ring was loaded with 1.2 g of codlemone and applied at 100 ha^{-1}.

Trap-lure treatments evaluated in California differed between years. During 2012, Ajar traps with the TAS bait were compared with delta traps loaded with PH combo lure (TRE0643) plus acetic acid, and delta traps with the sex pheromone of each species in both counties. During 2013, the trap-lure treatments included a delta trap baited with sex pheromone of each species, an Ajar trap with the TAS bait, and an Ajar trap with the TAS bait plus PH combo (TRE0864) and BOC lures. In addition, in Lake County Ajar traps with the TAS bait plus a BOC lure were included; while, in Yuba County an Ajar trap with the TAS bait plus the TRE0864 lure was tested. Traps were checked every week from 7 April to 29 September in 2012 and from 7 April to 21 September in

2013 in Lake County. Traps in Lake Country orchards were positioned in the lower half of trees. Traps were checked from 17 April to 18 September in 2012 and from 10 April to 24 September in 2013 in Yuba County. Moth catch data were summarized beginning with the first application of the sex pheromone for *G. molesta* in both regions in both years. Catches of *C. pomonella* were zero in all traps in 2013 and these are not reported. *G. molesta* was sexed only in Lake County.

Oregon and Washington, 2012-13

Studies were conducted in both years in an organic peach orchard situated near Medford, OR in Jackson County (42°14'N, 122°47'W) and in an unsprayed peach orchard surrounded by apple and pear orchards situated near Parker, WA (46°30'N, 120°28'W). Both orchards in 2012 were treated with CheckMate OFM SL dispensers (Suterra LLC) loaded with 515 mg of a 93:6:1 blend of (*Z*)- and (*E*)-8-dodecenyl acetate and (*Z*)-8-dodecenol at a rate of 500 ha^{-1}, and only the Washington orchard was treated with dispensers in 2013.

Two studies were conducted during 2012. Five lure treatments were evaluated in delta traps in three, week-long experiments in the Oregon peach orchard from 9 July to 2 August 2012. Lure treatments included the sex pheromone of *G. molesta*, the PH combo lure (TRE0643), TRE0643 plus acetic acid, TRE0643 plus the HPV combo lure (TRE0644), and the same two combo lures plus acetic acid. A similar study was conducted including the sex pheromone lure for *C. pomonella* in a "Delicious' and 'Golden Delicious' apple orchard at the U.S.D.A. Research Farm situated 15 km east of Moxee, WA (46°33'N, 120°23'W). The study was run twice from 10 – 17 August and from 17 August to 4 September 2012.

Several studies were conducted during 2013. In the first trial, four or five trap-lure combinations were compared; including delta traps baited with the sex pheromone of either species. Only the sex pheromone of *G. molesta* was used in Oregon and the sex pheromone lures of both species were included as separate treatments in the Washington trial. In addition, delta traps with the PH combo lure (TRE0864), and the Ajar trap with TAS bait or the TAS bait plus the TRE0864 lure were included in both sites. Oregon studies were conducted from 17 – 24 May, 19 – 24 June, and 15-29 July 2013. Washington trials were run from 16-21 August, 21 -28 August, and 28 August to 2 September 2013. A similar study evaluated the attractiveness of these various trap-lure combinations plus the additional inclusion of delta traps with TRE0864 plus the BOC lure and the Ajar trap with the TAS bait plus TRE0864 and BOC lures for *C. pomonella*. The sex pheromone lure for *G. molesta* was not included. This study was conducted in the 'Fuji' orchard at the U.S.D.A. Research farm. The orchard was treated with experimental Cidetrak Meso dispensers (Trécé Inc.) for both species applied at a rate of 60 dispensers ha^{-1}. Meso dispensers are loaded with 10-fold more sex pheromone than the standard Cidetrak dispensers, 2.5 g for *G. molesta* and 1.2 g for *C. pomonella*. The study was repeated on three dates (3 May, 5 June, and 2 August and each ran for 14 days. A final study was conducted in 2013 in the Washington peach orchard evaluating the modified Ajar trap with screened flaps with an array of holes that closed each end of the trap. Weekly trials were run three times from 1 to 23 May. In this study, we compared the catch of both sexes of *G. molesta* and the catch of muscid flies as nontargets in a delta trap and in both a screened and unscreened Ajar traps all baited with the PH combo lure (TRE0864). In addition, both Ajar traps also included the TAS bait.

Chile and Argentina, 2012-13

Studies in Argentina were conducted in a mixed 'Red Delicious' and 'Gala' block under organic management situated near Antigua Chacra, General Roca, (39º32'S, 67º36'W).

The orchard in 2012 was treated with Rak 20 OFM dispensers (BASF, Buenos Aires, Argentina) loaded with 400 mg of an unspecified blend of (*Z*)- and (*E*)-8-dodecenyl acetate at 500 ha^{-1} and Isomate-CM Plus at 1,000 dispensers ha^{-1} loaded with 109 mg codlemone on 1 October 2011. Additional Isomate-CM Plus dispensers were added (1,000 ha^{-1}) 1 January 2012 and Isomate-OFM TT dispensers (215 ha^{-1}) were added on 25 February 2012. Five replicates of seven lure treatments in white delta traps were included in the 2012 study. These included blank traps and traps baited with either the sex pheromone lure of *C. pomonella* or *G. molesta* (Kumei Mapu, General Roca, Rio Negro, Argentina). The remaining four treatments were with Trécé Inc. supplied lures, including the sex pheromone lures OFM L2 and CM L2 together plus acetic acid, the same two septa lures plus the HPV combo lure (TRE0644), TRE0644 plus acetic acid, and the PH combo lure (TRE0643), The study was initiated on 22 February and traps were checked twice per week until 10 April 2012.

Studies in Chile were conducted in a peach orchard near Talca (35º33'S, 71º33'W). The orchard was treated with Isomate-OFM TT at 200 dispensers ha^{-1} on 1 February 2012. Six treatments included delta traps left blank or with either the sex pheromone lure of each species, the PH combo lure (TRE0643) plus acetic acid, the HPV combo lure (TRE0644) plus acetic acid, and both TRE0643 and TRE0644 plus acetic acid lures. Traps were placed on 8 February and checked weekly until 21 March 2012.

Two studies were conducted in Argentina during 2013. Isomate-C Plus at 1,000 dispensers ha^{-1} were applied on 14 October and Isomate-OFM TT was applied on 28 October at 400 dispensers ha^{-1}. Isomate-C Plus dispensers were loaded with 109 mg codlemone. An additional 1,000 dispensers ha^{-1} for *C. pomonella* and 400 ha^{-1} for *G. molesta* were added 10 January and 1 February 2013, respectively. Six trap-lure treatments were included in the first study, including a delta trap baited with the sex pheromone lure of *G. molesta*, a PH combo lure (TRE0643) and both TRE0643 and the BOC lure. Also, Ajar traps with the TAS bait alone, the TAS bait plus TRE0643, and the TAS bait plus TRE0643 and a BOC lure were included. Traps were put out on 22 February and checked twice per week until 4 April 2013. The second study evaluated the use of screens on Ajar traps for *G. molesta*. Two new treatments were added to the previous study, screened Ajar traps baited with either the TAS bait alone or the TAS bait plus TRE0643 and BOC lures. Traps were re-randomized on 22 February and checked twice per week until 9 April 2013. Total captures of nontargets insects including moths, hymenopterans, and muscid flies were combined. Data for *G. molesta* and nontargets in over this time interval were compared with unscreened Ajar and delta traps baited with the TRE0643 and BOC lures.

Two studies were conducted in Chile during 2013. The first was conducted from 24 January to 11 February 2013. Five replicates of delta traps baited with the sex pheromone of *G. molesta*, the PH combo lure (TRE0643), and TRE0643 plus the BOC lure were included in the study. The orchard was treated with Cidetrak OFM L dispensers at 400 ha^{-1} loaded with 250 mg of the three-component blend in the 93:6:1 ratio on 14 February 2013. The second study evaluated the use of screens on Ajar traps for *G. molesta*. Treatments included a delta trap baited with sex pheromone, and screened and unscreened Ajar traps baited with the TAS bait alone or the TAS bait plus TRE0643 and the BOC lure. Traps were placed 19 February and checked twice per week until 8 March 2013. Total captures of nontargets insects, including moths, bees, and flies were recorded.

Statistical analyses.

Catch data were summarized across each test's time period and analyzed with Statistix 9 (Analytical Software Inc., Tallahassee, FL). A square-root transformation was used to normalize count data prior to analysis of variance. The normality of data was inspected with a Shapiro-Wilks test. If the transformed data were not normalized they were analyzed with a non-parametric Kruskal-Wallis ANOVA of ranks. Normalized data were analyzed with a completely randomized ANOVA. A *P*-value of 0.05 was used to establish significance in all tests, Tukey's test.

RESULTS

2012 studies

Field trials in Argentina, Chile, and USA found significant differences in the mean catches of both species in traps baited with their sex pheromone alone versus the use of the PH combo lure (Table 1). The PH combo lure caught significantly more *G. molesta* than the sex pheromone lure in Argentina and Oregon; and in combination with acetic acid significantly more in Chile and Oregon. The addition of acetic acid to the PH combo lure did not significantly increase the catch of *G. molesta* in Argentina or Oregon. Catch was also not increased by the addition of the HPV combo lure in either country in South America or in Oregon. A relatively low number of female *G. molesta* were caught in traps baited with acetic lures in Argentina, and these did not differ among lure treatments, $F_{2, 12} = 0.67$, $P = 0.53$. Similarly, a low proportion of female moths were caught in trials in Chile and Oregon (3 – 5% of total catch). In Chile, the mean female catch was significantly lower in traps baited with the HPV combo plus acetic acid lures than in traps combining these lures with the PH combo lure, $F_{4, 44} = 18.78$, $P < 0.0001$. In Oregon, the mean female moth catch in the three multiple lure treatments did not differ, $F_{2, 42} = 0.51$, $P = 0.61$.

Significant differences were found among lures for *C. pomonella* in all three studies (Table 1). Total catch of *C. pomonella* was significantly reduced with the use of the PH combo lure plus acetic acid compared with the sex pheromone lure. The addition of the

HPV combo lure and/or acetic acid did not significantly differ from the moth catch with the PH combo lure alone. The HPV combo and acetic acid lure treatment performed as well as the sex pheromone lure and better than the PH combo plus acetic acid in Argentina but not in Chile. Female *C. pomonella* were only caught in traps including an acetic acid lure in Argentina, but there was no difference among these three lures, $F_{2, 12} = 3.10$, $P = 0.08$. Only one female *C. pomonella* was caught during the entire study in Chile in a trap baited with the PH and HPV combo lures plus acetic acid. Few female *C. pomonella* moths were caught in the Washington apple study, ≤ 0.5 per trap, and only in traps baited with the acetic acid or HPV combo lures, $F_{2, 27} = 2.34$, $P = 0.12$ (Table 1).

Seasonal trapping studies in California and Pennsylvania during 2012 found significant differences in moth catches among trap-lure treatments (Table 2). The Ajar trap with TAS bait caught significantly more total and female *G. molesta* than delta traps with the sex pheromone or the PH combo lure plus acetic acid in California. Mean catches of *G. molesta* were low in the apple orchards in Pennsylvania and no significant differences were found among trap-lure treatments (Table 2). Traps caught a low and highly variable number of *C. pomonella* in California and the mean catch was not significantly different among treatments. No female codling moths were caught in California orchards. A significant difference was found among trap-lure treatments in the total catch of *C. pomonella*, but not for female moths in Pennsylvania. Also, the sex pheromone lure-baited trap caught 20-fold more *C. pomonella* than the TAS-baited Ajar trap in Pennsylvania (Table 2).

2013 studies.

Significant differences were found among treatments comparing delta and Ajar traps baited with the PH combo lures in the total mean catch of *G. molesta* in both an Oregon peach orchard not treated with sex pheromones and a treated peach orchard in

Washington during 2013 (Table 3). Without a sex pheromone dispenser treatment, the PH combo lure caught significantly more moths than the sex pheromone alone or the TAS bait. Combining the TAS bait and the PH combo lure together in an Ajar trap increased moth catches compared to the TAS bait but not the PH combo lure. In contrast, the Ajar trap with the TAS bait plus the PH combo lure outperformed both trap types with each individual component lure in an orchard treated with sex pheromone dispensers. Female *G. molesta* were only caught in Ajar traps, and mean catches did not vary among the two lure treatments (Table 3).

Significant differences were found in studies including the addition of the BOC lure in both delta and Ajar traps in 2013 (Table 4). A significant increase in moth catch of *G. molesta* compared with the sex pheromone lure was achieved with a combination of the TAS bait, the PH combo lure and the BOC lure in an Argentina apple orchard (Table 4). Some of the trap-lure treatments caught an intermediate number of moths (5-fold range). A more limited study in Chile found that the PH combo lure plus BOC outperformed the sex pheromone lure. Despite catching 2.5-fold more moths this lure was not significantly better than the PH combo lure alone. Female *G. molesta* were caught in similar numbers in all three of the Ajar-TAS treatments (Table 4).

Significant differences were found among trap-lure treatments in the catch of *C. pomonella* (Table 4). Primarily, TAS-baited Ajar traps caught significantly fewer *C. pomonella* than delta traps with either its sex pheromone or the PH lure. The four trap-lure treatments including the PH combo lure in Argentina did not differ statistically in their total catch of *C. pomonella* (Table 4). Similar results were found for *C. pomonella* in the apple study in Washington; however, the sex pheromone lure caught significantly more *C. pomonella* than all treatments except for the PH combo lure alone. Female *C. pomonella* were only caught in two Ajar traps including the PH combo lure in

Argentina, and low numbers of female *C. pomonella* were caught in each of the three Ajar trap treatments in Washington, means ≤ 0.5 per trap (Table 4).

Significant differences in the catches of *G. molesta* were found in the season-long programs in orchards in California during 2013 (Table 5). Both Ajar traps with TAS bait and either the BOC lure alone or with the PH combo lure caught significantly more moths than the PH combo lure within a delta trap in Lake County. Similar results were also found in Yuba County with Ajar taps baited with either the TAS bait plus the PH combo lure or with the further addition of the BOC lure compared with the PH combo lure alone. A relatively high proportion of *G. molesta* caught in the Ajar traps were females in Lake County and the mean catch did not vary among traps (Table 5).

The use of screens did not significantly reduce the total or female moth catches of *G. molesta* in Ajar traps with either TAS bait alone or the TAS bait plus the BOC and PH combo lures (Table 6). Total moth catches did not differ between a delta and an unscreened or screened Ajar trap with TAS bait and BOC plus PH combo lures in Argentina and Washington, but not in Chile. Similarly, mean female catches were significantly higher only with the unscreened Ajar versus delta traps in Argentina and Washington, but not in Chile. Numerically, screens had the largest negative effect on trap performance in Argentina with 63 – 82% and 84 – 92% reductions in total moth and female moth catch, respectively (Table 6).

The level of incidental catch of nontarget insects varied widely among studies and among trap-lure treatments (Table 6). Screened Ajar traps caught significantly fewer nontargets than unscreened Ajar traps in four of the five comparisons. The mean catch of nontargets in the screened Ajar traps was similar to the catch in delta traps without the TAS bait (Table 6).

DISCUSSION

G. molesta is a key pest of stone fruits throughout the world and an important pest of apple and pear in many regions. Effective management programs utilizing sex pheromones for mating disruption through the application of hand-applied dispensers, microencapsulated sprays, or aerosol emitters have been implemented. Dual-species sex pheromone dispensers, sprays, and aerosol emitters have been developed for orchards with both *G. molesta* and *C. pomonella*. Monitoring the seasonal population dynamics of both species is a key prerequisite to supplement the mating disruption programs with well-timed and necessary insecticide sprays.

Our studies in both North and South America over two years found that the total catch of *G. molesta* could be increased in stone and pome fruit orchards treated with mating disruption from 4 to 21-fold by switching from simply a sex pheromone lure to various combinations of a PH combo, TAS bait, and HPV lures. Adding the PH combo lure to the Ajar trap increased mean moth catches in traps at least 2-fold (not always statistically different), and this increased catch was comparable to moth catch in delta traps baited with the PH combo lure. However, female moths were only caught in Ajar traps so that the combination of the TAS bait and the PH combo lure provides additional information to track seasonal pest population dynamics. The TAS bait was not attractive to *C. pomonella*; and the PH combo lure in general, caught 47-62% fewer *C. pomonella* than the sex pheromone lure alone.

Different results were found with catches of *C. pomonella* using the PH combo lure alone and with other attractants. Previous studies in orchards without mating disruption have shown that *C. pomonella* catches in traps baited with *C. pomonella* and *G. molesta* pheromone are lower than in traps baited with *C. pomonella* pheromone alone (Arn et al. 1974, Evenden and McLaughlin 2005). Inclusion of *G. molesta* pheromone components reduces upwind flight to *C. pomonella* pheromone sources in wind tunnel experiments (Preiss and Priessner 1988). On the other hand, previous studies in orchards without mating disruption have found that *G. molesta* catches are increased when *C. pomonella* pheromone is included compared with traps baited with *G. molesta* pheromone alone (Allred et al. 1995, Evenden and McClaughlin 2005). Our data from mating disruption orchards support the same results of a reduced *C. pomonella* and an increased *G. molesta* catch in traps baited with both species pheromones. This suggests that separate traps should be used to monitor the two species within orchards treated with dual mating disruption.

C. pomonella is most effectively monitored in sex pheromone-treated orchards with a sex pheromone plus HPV combo lure with acetic acid added as a co-lure (Knight and Light 2012). The addition of acetic acid can increase moth catches with attractive HPVs, pear ester for *C. pomonella* and (*E*)-β-ocimene for *G. molesta* (Knight et al. in press). Yet, in our studies when acetic acid was either added alone or with the HPV combo lure it did not improve the attractiveness of the PH combo lure for either species. Interestingly, the BOC lure used in 2013 nearly doubled the catches of *G. molesta* when used with the PH combo lure in delta traps. The delta trap also performed as well as the TAS-baited Ajar trap with PH combo and BOC lures added to each in studies in Argentina and Washington. The trade-offs in using either the delta or Ajar trap would be that the latter trap uses a potentially messy liquid bait, but catches female moths.

The placement of screens on each end of the Ajar trap was effective in reducing the catch of nontargets. The TAS bait is a potent non-specific attractant and standard bait buckets often fill with hundreds of nontargets (Rothschild et al. 1984). Yet, the need for screens to reduce this non-specific catch may be site specific. For example, Ajar traps used in California over the past three years typically caught 10 to 80-fold more flies than *G. molesta* per season (B. Zoller and R. Hansen, unpubl. data), and a similar pattern was seen in Washington in 2013. In contrast, the total catch of non-targets in orchards in South America have been relatively low, except for bees when white Ajar traps were used (Cichon et al. 2013). A previous study found that the use of similar screens reduced the catch of *G. molesta* and in particular female moths which are larger (Knight et al. 2013). Our data from Argentina suggests that the current prototype design has some negative effect on catches of *G. molesta*, and further refinements may be needed.

The ability to seasonally track both male and female flights for pests, such as *G. molesta* could have several advantages. For example, monitoring *C. pomonella* females with pear ester can improve the predictive timing of egg hatch and the establishments of action thresholds (Knight and Light 2005a, b), can allow their mating status to be determined (Knight 2006, 2007a), and can provide a more local assessment of pest density as females are less dispersive, while males disperse towards sex pheromone-treated orchards and to sex pheromone-baited traps (Knight 2007b). TAS-filled bait buckets, while cumbersome, have allowed pest managers to track female *G. molesta* populations for decades (Rothschild et al. 1984). Yet, management programs using seasonal counts of female *G. molesta* have not been developed. In comparison, a site-specific management program largely based on spatial moth catches of male and female *C. pomonella* has been developed which has significantly reduced insecticide usage for this pest and reduced management costs (Knight et al. 2009). Adoption of the Ajar trap design may more easily allow a similar approach to be developed for *G. molesta*.

ACKNOWLEDGEMENTS

We thank Duane Larson, USDA, ARS, Wapato, WA and Shannon Davis, Oregon State University, Medford, OR for their help in setting up the field trials and conducting laboratory analyses in Washington and Oregon, respectively. Field studies were conducted with the permission of Riley Wallace, Parker, WA and Dave Belzberg, Medford, OR. Bill Lingren (Trécé Inc., Adair, OK) generously provided traps and lures. We thank Alexis Muñoz, Manuel Maldonado and Carlos Cavieres, Laboratorio de Sanidad Vegetal, Universidad de Talca, Talca, Chile for their technical assistance. We also thank Alfonso Reyes for providing the peach orchard and Felipe Thurn and Verónica Soffia (Arysta Life Science, Santiago, Chile) for providing traps and dispensers. In Argentina funds for the test (trial) came from PNFRU INTA Project 52001. Our rough draft was improved by the helpful comments provided by Doug Light, Agricultural Research Service, Albany, CA, Dong Cha, Agricultural Research Srvice, Wapato, WA, and Lukasz Stelinski, University of Florida, Lake Alfred, FL.

REFERENCES

Allred D, Croft B, Riedl H, 1995. Response of oriental fruit moth to codlemone. Proceedings of the 69th Western Orchard Pest and Disease Management Conference, 11 - 13 January 1995, Portland, OR.

Arn H, Schwarz C, Limao H, Mani E, 1974. Sex attractant inhibitors of the codling moth *Laspeyresia pomonella* L. Experientia 30, 1142-1144.

Barros, W, Basoalto, E, Levi A, Fuentes-Contreras E, Gemeno C, 2014. Plant volatiles reduce male oriental fruit moth, *Grapholita molesta* (Lepidoptera: Tortricidae) response to sex pheromone. J. Appl. Entomol. Submitted.

Bengtsson A, Bäckman A-C, Liblikas I, Ramirez MI, Borg-Karlson A-K, Ansebo L, Anderson P, Löfqvist J, Witzgall P, 2001. Plant odor analysis of apple: antennal response of codling moth females to apple volatiles during phenological development. J. Agric. Food Chem. 49, 3736-3741.

Casado D, Gemeno C, Avila J, Riba M, 2006. Day-night and phenological variation of apple tree volatiles and electroantennogram responses of *Cydia pomonella* (Lepidoptera: Tortricidae). Environ. Entomol. 35, 258-267.

Charmillot PJ, Vickers RA, 1991. Use of sex pheromones for control of tortricid pests in pome and stone fruits, pp. 487-496. *In* Tortricid pests, L. P. S. Van der Geest and H. H. Evenhuis (Eds.). Elsevier, Amsterdam, The Netherlands.

Cichon L, Fuentes-Contreras E, Garrido S, Lago J, Barros-Parada W, Basoalto E, Hilton R, Knight A, 2013. Monitoring oriental fruit moth (Lepidoptera: Tortricidae) with sticky traps baited with terpinyl acetate and sex pheromone. J. Appl. Entomol. 137, 275-281.

Evenden ML, McLaughlin JR, 2005. Male oriental fruit moth response to a combined pheromone-based attracticide formulation targeting both oriental fruit moth and codling moth (Lepidoptera: Tortricidae). J. Econ. Entomol. 98, 317-325.

Il'ichev AL, Williams DG, Gut LJ, 2007. Dual pheromone dispenser for combined control of codling moth, *Cydia pomonella* L. and oriental fruit moth *Grapholita molesta* (Busck) (Lep., Tortricidae) in pears. J. Appl. Entomol. 131, 368-376.

Il'ichev AL, Kugimya S, Williams DG, Takabayashi J, 2009. Volatile compounds from young peach shoots attract males of oriental fruit moth in the field. J. Plant Interact. 4, 289-294.

Knight AL, 2006. Assessing the mating status of female codling moth (Lepidoptera: Tortricidae) in orchards treated with sex pheromone using traps baited with ethyl (*E, Z*)-2,4-Decadienoate. Environ. Entomol. 35, 894-900.

Knight AL, 2007a. Multiple mating of male and female codling moth (Lepidoptera: Tortricidae) in apple orchards treated with sex pheromone. Environ. Entomol. 36, 157-164.

Knight AL, 2007b. Influence of within-orchard trap placement on catch of codling moth (Lepidoptera: Tortricidae) in sex pheromone-treated orchards. Environ. Entomol. 36, 425-432.

Knight AL, Light DM, 2005a Timing of egg hatch by early-season codling moth (Lepidoptera: Tortricidae) predicted by moth catch in pear ester- and codlemone-baited traps. Can. Entomol. 137, 728-738.

Knight AL, Light DM, 2005b. Developing action thresholds for codling moth (Lepidoptera: Tortricidae) with pear ester- and codlemone-baited traps in apple orchards treated with sex pheromone mating disruption. Can. Entomol. 137, 739-747.

Knight AL, Light DM, 2012. Monitoring codling moth (Lepidoptera: Tortricidae) in sex pheromone-treated orchards with (*E*)-4,8-Dimethyl-1,3,7-Nonatriene or pear ester in combination with codlemone and acetic acid. Environ. Entomol. 41, 407-414.

Knight A, Hawkins L, McNamara K, Hilton R, 2009. Monitoring, managing codling moth clearly and precisely. Good Fruit Grower 60 (5), 26-27.

Knight A, Pickel C, Hawkins L, Abbott C, Hansen R, Hull L, 2011a. Monitoring oriental fruit moth (Lepidoptera: Tortricidae) and peach twig borer (Lepidoptera: Gelechiidae) with clear delta-shaped traps. J. Appl. Entomol., 135, 106-114.

Knight AL, Light DM, Trimble RM, 2011b. Identifying (*E*)-4,8-Dimethyl-1,3,7-Nonatriene plus acetic acid as a new lure for male and female codling moth (Lepidoptera: Tortricidae). Environ. Entomol. 40, 420-430.

Knight AL, Basoalto E, Hilton R, Molinari F, Zoller B, Hansen R, Krawczyk G, Hull L, 2013. Monitoring oriental fruit moth (Lepidoptera: Tortricidae) with the Ajar bait trap in orchards under mating disruption. J. Appl. Entomol. 137, 650-660.

Knight A, Hilton R, Basoalto E, and Steliniski L, in press. Use of glacial acetic acid to enhance bisexual monitoring of tortricid pests in pome fruits with kairomone lures. Environ. Entomol.

Landolt PJ, Suckling DM, Judd GJR, 2007. Positive interaction of a feeding attractant and a host kairomone for trapping the codling moth, *Cydia pomonella* (L.). J. Chem. Ecol. 33, 2236-2244.

Light DM, Knight AL, 2005. Specificity of codling moth (Lepidoptera: Tortricidae) for the host plant kairomone, ethyl (2*E*, 4*Z*)-2,4-Decadienoate: field bioassays with pome fruit volatiles, analogue and isomeric compounds. J. Agric. Food Chem. 53, 4046-4053.

Light DM, Knight AL, Henrick CA, Rajapaska D, Lingren B, Dickens JC, Reynolds KM, Buttery RG, Merrill G, Roitman J, Campbell BC, 2001. A pear-derived kairomone with pheromonal potency that attracts male and female codling moth, *Cydia pomonella* (L.). Naturwissenschaften 88, 333-338.

Lu PF, Huang L-Q, Wang C-Z, 2012. Identification and field evaluation of pear fruit volatiles attractive to the oriental fruit moth, *Cydia molesta*. J. Chem. Ecol. 38, 1003-1016.

Natale D, Mattiacci L, Hern A, Pasqualini E, Dorn S, 2003. Response of female *Cydia molesta* (Lepidoptera: Tortricidae) to plant derived volatiles. Bull. Entomol. Res. 93, 335-342.

Natale D, Mattiacci L, Pasqualini E, Dorn S, 2004. Apple and peach volatiles and the apple constituent butyl hexanoate attract female oriental fruit moth, *Cydia molesta*, in the laboratory. J. Appl. Entomol. 128, 22-27.

Pinero, JC, Dorn S, 2007. Synergism between aromatic compounds and green leaf volatiles derived from the host plant underlies female attraction in the oriental fruit moth. Entomol. Exper. Appl.125, 185-194.

Preiss R, Priesner E, 1988. Responses of male codling moths (*Laspeyresia pomonella*) to codlemone and other alcohols in a wind tunnel. J. Chem. Ecol. 14, 797- 813.

Rothschild GHL, Vickers RA, Morton R, 1984. Monitoring the oriental fruit moth, *Cydia molesta* (Busck) (Lepidoptera: Tortricidae) with sex pheromone traps and bait pails in peach orchards in south-eastern Australia. Protec. Ecol. 6, 115-136.

Steliniski LL, Gut LJ, Haas M, McGhee P, Epstein D, 2007. Evaluation of aerosol devices for simultaneous disruption of sex pheromone communication in *Cydia pomonella* and *Grapholita molesta* (Lepidoptera: Tortricidae). J. Pest Sci. 80, 225-233.

Steliniski LL, Il'ichev AL, Gut LJ, 2009. Efficacy and release rate of reservoir pheromone dispensers for simultaneous mating disruption of codling moth and oriental fruit moth (Lepidoptera: Tortricidae). J. Econ. Entomol. 102, 315-323.

Trona F, Anfora G, Bengtsson M, Witzgall P, Ignell R, 2010. Coding and interaction of sex pheromone and plant volatile signals in the antennal lobe of the codling moth *Cydia pomonella*. J. Exp. Biol. 213, 4291-4303.

Trona F, Anfora G, Balkenius A, Bengtson M, Tasin M, Knight A, Janz N, Witzgall P, Ignell R, 2013. Neural coding merges sex and habitat chemosensory signals in an insect herbivore. Proc. Royal Soc. B 280, doi.org/10.1098/rspb.2013.0267.

Varela N, Avilla J, Anton S, Gemeno C, 2011. Synergism of pheromone and host-plant volatile blends in the attraction of *Grapholita molesta* males. Entomol. Exper. Appl. 141, 114-122.

Footnotes

[1] USDA, Agricultural Research Service, Wapato, WA, USA

[2] Estación Experimental Agropecuaria, INTA – Alto Valle, General Roca, Rio Negro, Argentina

[3] Facultad de Ciencias Agrarias, Universidad de Talca, Talca, Chile

[4] Millennium Nucleus in Molecular Ecology and Evolutionary Applications of Agroecosystems, Universidad de Talca, Talca, Chile

[5] Penn State University, Biglerville, PA, USA

[6]The Pear Doctor, Kelseyville, CA, USA

[7]Hansen Associates, Placerville, CA, USA

[8]Oregon State University, Medford, OR, USA