A Binary Host Plant Volatile Lure Combined With Acetic Acid to Monitor Codling Moth (Lepidoptera: Tortricidae)

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ABSTRACT Field studies were conducted in the United States, Hungary, and New Zealand to evaluate the effectiveness of septa lures loaded with ethyl (*E,Z*)-2,4-decadienoate (pear ester) and (*E*)-4,8-dimethyl-1,3,7-nonatriene (nonatriene) alone and in combination with an acetic acid co-lure for both sexes of codling moth, *Cydia pomonella* (L.). Additional studies were conducted to evaluate these host plant volatiles and acetic acid in combination with the sex pheromone, (*E,E*)-8,10-dodecadien-1-ol (codlemone). Traps baited with pear ester/nonatriene + acetic acid placed within orchards treated either with codlemone dispensers or left untreated caught significantly more males, females, and total moths than similar traps baited with pear ester + acetic acid in some assays. Similarly, traps baited with codlemone/pear ester/nonatriene + acetic acid caught significantly greater numbers of moths than traps with codlemone/pear ester + acetic acid lures in some assays in orchards treated with combinational dispensers (dispensers loaded with codlemone/pear ester). These data suggest that monitoring of codling moth can be marginally improved in orchards under variable management plans using a binary host plant volatile lure in combination with codlemone and acetic acid. These results are likely to be most significant in orchards treated with combinational dispensers. Significant increases in the catch of female codling moths in traps with the binary host plant volatile blend plus acetic acid should be useful in developing more effective mass trapping strategies.

KEY WORDS Monitoring, apple, pear ester, nonatriene

Applied research detailing the chemical ecology of codling moth, *Cydia pomonella* (L.), has continued to search for host plant and microbial volatiles that can be used to monitor pest densities and develop effective control strategies, i.e., mass trapping and mating disruption (Light et al. 2001, Landolt et al. 2007, Knight et al. 2011a, Witzgall et al. 2012, El-Sayed et al. 2013, Landolt et al. 2014). Much of this work is focused on improving the current widely adopted use of the sex pheromone of codling moth, (*E,E*)-8,10-dodecadien-1-ol (codlemone), for monitoring and disrupting male moths (Witzgall et al. 2008). The frequent failure of traps baited with codlemone to predict fruit injury in sex pheromone-treated orchards likely leads to overuse of prescription insecticide sprays (Knight and Light 2005a). Targeting the population densities of female moths and disrupting their behaviors is thought to be a profitable route to improve pest management (Knight et al. 2002).

Development of combinational lures loaded with codlemone and kairomones, such as ethyl (*E,Z*)-2,4-decadienoate (pear ester), or (*E*)-4,8-dimethyl-1,3,7-nonatriene (nonatriene) combined with a second lure loaded with acetic acid has been effective in monitoring both sexes of codling moth in orchards under sex pheromone-based mating disruption (Landolt et al. 2007, Knight 2010, Knight et al. 2011a, Knight and Light 2012). Combining a microbial volatile, butyl sulfide, with pear ester and acetic acid has further increased catches (twofold) of both male and female codling moth, but this lure has not been tested in codlemone-treated orchards (Landolt et al. 2014). These authors suggest that their blend might be a suitable lure for monitoring codling moth in orchards treated with dispensers loaded with codlemone and pear ester, and butyl sulfide and acetic acid together should be tested with other attractive kairomones. Several combinational lures including (*E,E*)-farnesol, (*E*)-β-farnesene, or nonatriene with acetic acid co-lures worked as well as pear ester and acetic acid in orchards treated with dispensers loaded with codlemone plus pear ester (Knight et al. 2013); however, only nonatriene caught as many female moths as pear ester when both were tested as combinational lures plus acetic acid.

Nonatriene is a common homoterpene released by many plants, including the primary hosts of codling moth, apple, pear, and walnut (Bengtsson et al. 2001; Witzgall et al. 2005; Casado et al. 2006, 2008). Interestingly, while nonatriene is considered to be a herbivore-induced volatile, its release from codling moth-infested fruit has not been reported (Hern and Dorn 2001, 2002; Landolt and Guédot 2008). Nonatriene exhibited

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some attraction for male codling moth in a flight tunnel, but when used alone was unattractive in field trials (Knight et al. 2011a, El-Sayed et al. 2013). Traps baited with nonatriene plus acetic acid caught 40% as many moths of both sexes as the use of pear ester plus acetic acid (Knight et al. 2011a). However, nonatriene when used with acetic acid in codlemone- or codlemone plus pear ester-treated orchards was as attractive as pear ester and acetic acid (Knight and Light 2012, Knight et al. 2013). The combination of nonatriene plus pear ester performed similar to the use of pear ester plus acetic acid (El-Sayed et al. 2013). Unfortunately, this binary kairomone lure was not tested in this study combination with acetic acid.

Herein, are studies conducted in apple, *Malus domestica* Borkhausen, to test whether the ternary lure combining codlemone, pear ester, nonatriene, and acetic acid can further increase the catch of one or both sexes of codling moth. Studies were conducted in untreated orchards and in orchards treated with either codlemone or codlemone plus pear ester dispensers for mating disruption.

Materials and Methods

Chemicals and Lures. Ethyl (*E*,*Z*)-2,4-decadienoate (pear ester; 92% purity) and (*E*,*E*)-8,10-dodecadien-1-ol (codlemone; 99% purity) used in trials in the United States and Hungary were provided by Trécé Inc. (Adair, OK). (*E*)-4,8-dimethyl-1,3,7-nonatriene (nonatriene; 99% purity) in these trials was obtained from Plant Research Institute (Wageningin, The Netherlands). Glacial acetic acid (99.7% purity) was obtained from Sigma-Aldrich (St. Louis, MO). Pear ester used in New Zealand was purchased from Pherobank (Wageningen, The Netherland). Nonatriene (>98% purity) was synthesized according to method described by Leopold (1990).

Gray halobutyl septa (West Co., Lionville, PA) were extracted three times with dichloromethane (99.9% purity) and air-dried overnight prior to storage at −15°C. Septa lures were prepared by diluting chemicals in dichloromethane (99.9%) and adding 100 µl into the cup area of the septum. Active ingredients were added together in binary and tertiary combinational septa lures with pear ester, codlemone, and nonatriene. Similar volumes of dichloromethane were added three times after the initial loading to enhance penetration into the septum, and lures were air-dried for 24 h and stored at −15°C. Prepared septum lures were shipped to Hungary. Septa lures in New Zealand were prepared similarly with n-hexane as the solvent, except that additional aliquots of solvent were not added after the initial loading. Septa were stored in heat-sealed foil bags at −20°C until use.

The acetic acid lures used in the United States during 2013 were made by drilling 1.0-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 acetic acid. The acetic acid lures used in New Zealand were made by placing a 2-cm piece of cotton ball in a 5-ml polythene vial (JUST Plastics Ltd, UK) with a 1-mm hole drilled in the cap and 3 ml of acetic acid was added to the vial. A proprietary plastic membrane cup acetic acid lure (Pherocon AA, Trécé Inc.) was used in 2014 in the U.S. trials. The acetic acid lures in Hungary were made by placing a 1-cm piece of dental roll (Celluron®; Paul Hartmann, Heidenheim, Germany) treated with 400 µl of acetic acid into a heat-sealed small polyethylene sachet (ca. 1.5 by 1.5 cm) made of 0.02-mm linear polyethylene foil. The acetic acid lure was attached to a plastic strip (8 by 1 cm) for easy handling when assembling the traps. The acetic acid lures were replaced at 3-wk intervals. Septum dispensers in Hungary were also attached to the plastic strip and replaced at 4-wk intervals.

Comparison of Single, Binary, and Ternary Lures. Two sets of studies were conducted in the United States during 2013. In the first trial, seven lure treatments were compared, including acetic acid (AA), pear ester (PE), and nonatriene (DMNT) lures used alone; the three binary lures – PE/DMNT, PE+AA, and DMNT+AA; and the ternary lure – PE/DMNT+AA. Studies were conducted during two periods coinciding with the first and second moth flights in four orchards. Orchards were situated near Ashland, Oregon (42° 14′ N, 122° 44′ W); east of Moxee, WA, (46° 30′ N, 120° 10′ W), near Parker, WA (46° 29′ N, 120° 26′ W); and west of Yakima, WA (46° 36′ N, 120° 30′ W). None of the orchards were treated with codlemone dispensers. Orange delta traps were used in all studies (Pherocon VI, Trécé Inc.). Traps were attached to a white PVC pole and placed in the upper third of the canopy, approximately 3 m. Studies were initiated in early to mid-May. Traps in all of the sites except Ashland were rotated after 7–8 d. Each of the four studies lasted 17–21 d. Similar studies were repeated during the second moth flight in late July in the Moxee and Parker orchards, plus a third orchard situated southwest of Wapato, WA (46° 26′ N, 120° 25′ W). Traps were rotated after 1 wk and collected approximately 1 wk later. Lure treatments within each study were randomized, and traps were spaced 20–30 m apart within an array. Trap rotations consisted of moving traps to the next position within the array.

The second trial compared traps baited with either PE, DMNT, or PE/DMNT lures plus an AA co-lure. Ten 0.1-ha orchard blocks were established in the Moxee (untreated), Parker (treated with codlemone plus pear ester dispensers), and Wapato (codlemone dispensers) orchards. Cidetrak CMDA Combo PP PVC dispensers loaded with 90 mg codlemone and 60 mg pear ester and Isomate CM Flex polyethylene dispensers loaded with 88 mg codlemone were both applied at 800 ha^{-1}. Traps were spaced 30 m apart in each of the blocks, $N = 10$, and rotated weekly. Each study was conducted for 4 wk from 7 June to 5 July and 18 July to 15 August 2013.

Studies were conducted in a mixed cultivar apple orchard situated near Tordas in Fejér county (47° 21′ N, 18° 47′ E) in Hungary during 2013. The orchard was treated with 1,000 Isomate C LR (C) sex pheromone dispensers ha^{-1} (BioControl, Budapest, Hungary). Two lure treatments were compared, PE+AA and PE/DMNT+AA. Five blocks were established in the orchard and a pair of traps within blocks were separated by 5 to 8 m, and blocks were separated by 30 to 40 m. Delta-shaped traps (CSALOMON® RAG; Plant Protection Institute, Centre for Agricultural Research, Hungarian Academy of Sciences, Budapest, Hungary) were suspended at the top of the apple crown with a metal hook attached to the trap. The trial was conducted from 7 May to 3 September. Trap liners were replaced twice weekly and the numbers and sex of captured moths were recorded.

One field trial was conducted in New Zealand from 6 November 2013 to 1 January 2014, the period coinciding with the single moth flight. Two lure treatments were compared in this study, the binary lure PE+AA and the ternary lure PE/DMNT+AA. Traps were placed in a 'Red Delicious' apple orchard in Canterbury, the South Island, New Zealand, (43° 39′ S, 172° 27′ E). The orchard was not treated with codlemone dispensers for mating disruption. Traps baited with a blank lure (filled with 200 µl of n-hexane) were used as a negative control. Red delta traps made of plastic corflute with an adhesive-coated base (Suckling and Shaw 1992) were placed in five rows, with five replicates of each treatment in a randomized block design. Traps were positioned 2 m above the ground, and were spaced 20 m apart in each row. Each treatment was assigned randomly to a trap location within each row. Sticky bases were removed and replaced weekly.

Comparison of Combinational Lures. Studies were conducted in the United States in both 2013 and 2014 to compare moth catches in traps baited with an AA co-lure plus either a septa lure loaded with codlemone (PH) plus PE or PE/DMNT. Traps were paired as before and placed in blocks in the Wapato orchard treated with either Isomate CM Flex or Cidetrak CMDA Combo PP. Paired traps were spaced 30 m apart in each of the blocks, $N = 10$. Traps were rotated weekly and each study was conducted for 4 wk from 7 June to 5 July and 18 July to 15 August. The study was repeated in 2014 but replaced the use of Cidetrak CMDA Combo PP dispensers with Cidetrak CMDA Meso Combo dispensers. Meso Combo dispensers are applied at one-tenth the dispenser rate (80 ha^{-1}) and contained 10-fold more active material (850 mg codlemone and 500 mg pear ester) than the Combo PP dispensers. This study was conducted in several orchards situated south of Naches, WA (46° 43′ N, 120° 42′ W). The lure study was repeated in the Wapato orchard with Isomate CM Flex dispensers. Paired traps were spaced 30 m apart in each of the blocks, $N = 10$. Traps were rotated weekly and each study was conducted for 4 wk from 20 May to 17 June and from 25 July to 22 August.

Statistical Analysis. A square-root transformation was used to normalize count data prior to analysis (Statistix 9, Analytical Software, Tallahassee, FL). Data from studies conducted with all treatment replicates placed in one orchard (Hungary and New Zealand) were analyzed as a completely randomized ANOVA. Data collected from multiple orchards (United States) were analyzed with orchard treated as the block in a randomized complete block design. Tukey's HSD test was used to detect significant pair-wise mean comparisons within significant ANOVAs. A P value of 0.05 was used to establish significance in all tests.

Results

Comparison of Single, Binary, and Tertiary Lures. Significant differences were found for male, female, and total moth catch in traps baited with individual, binary, and ternary lures (Table 1).The PE/DMNT+AA lure caught significantly more males and total moths than any other lure in the first generation. The second highest catch of males and total moths was in traps baited with the PE+AA lure. The remaining five lures caught similar numbers of males and total moths. The PE/DMNT+AA lure caught significantly more female moths than every lure except PE+AA, and the PE+AA lure caught significantly more females than the AA, DMNT, and DMNT+AA lures.

Similar results occurred during the second generation among the seven lures tested (Table 1). The PE/DMNT+AA lure caught significantly more females than any other lure, significantly more total moths than all lures except the PE+AA lure, and significantly more males than every lure except PE+AA and DMNT+AA. The remaining four lures caught similar numbers of moths.

Significant differences were found among DMNT+AA, PE+AA, and DMNT/PE+AA lures during both generations in orchard blocks either untreated or treated with codlemone dispensers or dispensers loaded with codlemone and pear ester (Table 2). In general, traps baited with the DMNT+AA lure caught significantly fewer moths than traps with the PE/DMNT+AA lure. Traps baited with the PE+AA lure either caught an intermediate number of moths or significantly more than traps with the DMNT+AA lure. Results were comparable in the codlemone-treated blocks, except that the PE/DMNT+AA lure caught significantly more total moths than the PE+AA lure during the first generation. In the orchard blocks treated with the codlemone plus pear ester dispensers, traps baited with the PE/DMNT+AA lure often caught significantly more moths than traps with the DMNT+AA lure, with catch in traps baited with the PE+AA lure being intermediate. Significantly more female and total moths were caught in traps baited with PE/DMNT+AA lures than with the PE+AA lure in both Hungary and New Zealand during 2013 (Fig. 1).

Comparison of Combinational Lures. During 2013, the only difference found between the two combinational lures within traps placed in a codlemone-treated orchard was that the lure PH/PE/DMNT+AA caught significantly more female moths than the lure PH/PE+AA in the second generation (Table 3). Three significant differences were found for moth catches in traps when the two lures were compared in the blocks treated with codlemone and pear ester dispensers, including higher counts of females moths in the first

Table 1. Comparison of moth catches of *C. pomonella* in delta traps baited with individual, binary, or tertiary blends of acetic acid (AA), pear ester ethyl *(E,Z)*-2,4-decadienoate (PE), and (*E*)-4,8-dimethyl-1,3,7-nonatriene (DMNT) in apple orchards not treated with sex pheromone dispensers during each moth generation, *N* = 20 in first generation and *N* = 15 in second generation, USA, 2013

Lures[a]	Mean (SE) moth catch per trap[b]					
	First generation			Second generation		
	Male	Female	Total	Male	Female	Total
AA	1.4 (0.6)c	0.7 (0.2)c	2.1 (0.8)c	0.2 (0.1)b	0.3 (0.3)c	0.5 (0.4)c
PE	1.3 (0.4)c	0.8 (0.3)bc	2.1 (0.6)c	0.1 (0.1)b	0.2 (0.1)c	0.3 (0.1)c
DMNT	0.4 (0.4)c	0.1 (0.1)c	0.5 (0.4)c	0.1 (0.1)b	0.1 (0.1)c	0.1 (0.1)c
PE/DMNT	1.9 (0.7)c	0.9 (0.2)bc	2.8 (0.8)c	0.4 (0.2)b	0.6 (0.2)c	1.0 (0.4)c
PE + AA	4.1 (1.0)b	2.4 (0.7)ab	6.4 (1.4)b	3.0 (1.0)a	3.5 (0.6)b	6.5 (1.2)ab
DMNT + AA	1.9 (0.8)c	0.6 (0.2)c	2.4 (0.9)c	1.3 (0.4)ab	1.9 (0.6)bc	3.2 (0.8)bc
PE/DMNT + AA	9.1 (1.9)a	4.6 (1.2)a	13.7 (3.0)a	5.4 (2.6)a	8.5 (2.5)a	13.9 (4.2)a
ANOVA[c]	$F = 23.34$	$F = 12.93$	$F = 26.57$	$F = 7.45$	$F = 20.99$	$F = 19.59$
	$P < 0.0001$	$P < 0.0001$	$P < 0.0001$	$P < 0.0001$	$P < 0.0001$	$P < 0.0001$

Means within a column followed by a different letter were significantly different, $P < 0.05$, Tukey HSD test.
[a] Pear ester and DMNT (3 mg) were loaded in gray septa, AA lures were proprietary plastic membrane cup lures (Trécé Inc.).
[b] Studies were conducted during each summer generation for 17–21 d during May-June in four orchards and July-August in three orchards.
[c] Transformed data were analyzed with a complete randomized block design with degrees of freedom = 6, 130 and 6, 96 in the first and second generation, respectively.

Table 2. Comparison of moth catches of *C. pomonella* in delta traps baited with an acetic acid co-lure (AA) plus either a septum lure loaded with codlemone and pear ester ethyl *(E,Z)*-2,4-decadienoate or codlemone (*E,E*)-8,10-dodecadien-1-ol, pear ester, and (*E*)-4,8-dimethyl-1,3,7-nonatriene (DMNT) in orchards treated either with sex pheromone dispensers (PH) or dispensers loaded with both sex pheromone and pear ester (Combo Meso) for mating disruption during each moth generation, *N* = 10, USA, 2013

MD treatment[a]	Lures[b]	Mean (SE) moth catch per trap[c]					
		First generation			Second generation		
		Male	Female	Total	Male	Female	Total
Untreated	DMNT + AA	0.2 (0.1)b	0.6 (0.2)b	0.8 (0.2)b	12.8 (3.5)	6.0 (1.1)b	18.8 (4.2)b
	PE + AA	2.0 (0.7)a	2.2 (0.8)ab	4.2 (1.4)a	11.2 (2.6)	8.0 (1.0)ab	19.2 (3.0)ab
	PE/DMNT + AA	2.2 (0.4)a	2.8 (0.6)a	5.0 (0.6)a	15.8 (2.1)	10.6 (0.7)a	26.4 (2.6)a
ANOVA[d]		$F = 13.16$	$F = 4.59$	$F = 12.78$	$F = 0.65$	$F = 6.05$	$F = 4.42$
		$P < 0.001$	$P < 0.05$	$P < 0.001$	$P = 0.53$	$P < 0.01$	$P < 0.05$
PH	DMNT + AA	1.8 (0.6)b	2.0 (0.7)	3.8 (1.2)b	3.0 (0.8)	2.2 (0.7)b	5.2 (1.2)b
	PE + AA	3.0 (1.1)ab	2.0 (0.3)	5.0 (1.3)b	7.2 (2.9)	7.8 (1.8)a	15.0 (3.0)a
	PE/DMNT + AA	6.4 (1.5)a	4.0 (1.2)	10.4 (2.6)a	2.2 (0.6)	9.8 (1.4)a	12.0 (1.3)a
ANOVA[d]		$F = 4.16$	$F = 0.77$	$F = 10.18$	$F = 0.91$	$F = 16.26$	$F = 9.19$
		$P < 0.05$	$P = 0.47$	$P < 0.01$	$P = 0.42$	$P < 0.0001$	$P < 0.01$
Combo	DMNT + AA	1.8 (0.4)b	0.8 (0.4)	2.6 (0.6)b	0.4 (0.2)b	1.6 (0.3)	2.0 (0.3)b
	PE + AA	2.4 (0.8)ab	0.8 (0.4)	3.2 (0.7)ab	6.2 (2.2)ab	3.2 (0.5)	9.4 (2.5)a
	PE/DMNT + AA	3.8 (0.4)a	1.6 (0.5)	5.4 (0.6)a	9.0 (3.0)a	4.4 (1.4)	13.4 (4.4)a
ANOVA[d]		$F = 4.38$	$F = 1.87$	$F = 5.20$	$F = 7.88$	$F = 1.97$	$F = 8.13$
		$P < 0.05$	$P = 0.17$	$P < 0.05$	$P < 0.01$	$P = 0.16$	$P < 0.01$

Means within a column followed by a different letter were significantly different, $P < 0.05$.
[a] Orchard blocks were either untreated or treated with Isomate Cm Flex dispensers with codlemone, or Cidetrak CMDA Combo PP dispensers with codlemone and pear ester at 800 ha^{-1}.
[b] Pear ester and DMNT (3 mg) were loaded in gray septa, AA lures were proprietary plastic membrane cup lures (Trécé Inc.).
[c] Studies were conducted during each summer generation from 7 June to 5 July and 18 July to 15 August.
[d] Transformed data were analyzed with a complete randomized block design with degrees of freedom = 2, 18.

generation, and males and total moths in the second generation in traps with the PH/PE/DMNT+AA lure.

Results were similar in the codlemone-treated blocks in 2014, with significantly higher catch of females in traps during the second generation with PH/PE/DMNT+AA lures (Table 4). In the blocks treated with the codlemone and pear ester Meso dispensers, a significantly greater catch of females and total moths in the first generation, and males and total moths in the second generation occurred in traps baited with PH/PE/DMNT+AA lures.

Discussion

Both sexes of *C. pomonella* respond to sex and host cues in their environment, and signals initially detected by antennal receptors are coded as complex packages of data integrated within and across the brain's antennal lobe (Ansebo et al. 2005; Trona et al. 2010, 2013). The results from studies comparing moth catches in traps (Knight et al. 2005, Landolt et al. 2007) were found to be consistent with the synergized neuronal responses detected in antennal lobes to binary blends of both codlemone with pear ester and pear ester with acetic

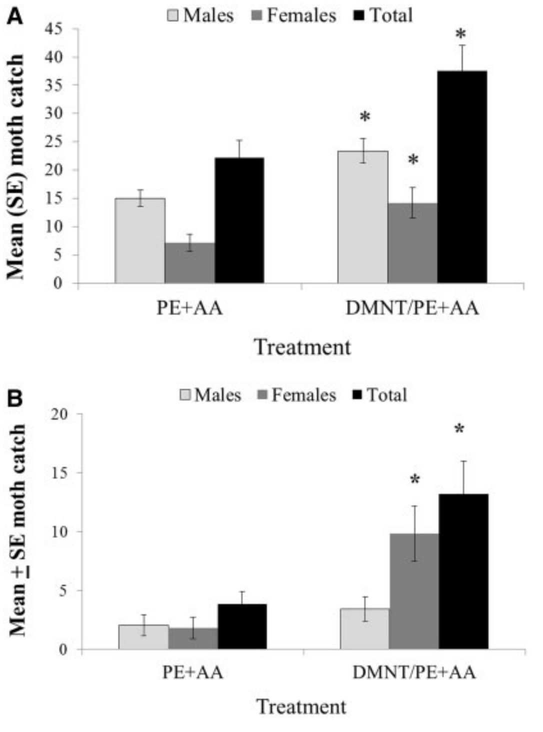

Fig. 1. Comparison of male, female, and total moth catch of *C. pomonella* in traps baited with either pear ester ethyl *(E,Z)*-2,4-decadienoate plus acetic acid or the combination of (*E*)-4,8-dimethyl-1,3,7-nonatriene (DMNT) and pear ester plus acetic acid in trials conducted in a sex pheromone-treated orchard in Hungary (A) and an untreated orchard in New Zealand (B) during 2013. "*" denotes a significant difference between mean catches, $P < 0.05$.

acid (Trona et al. 2010). These are exceptional results and contrast with unsuccessful efforts to develop effective lures in the field based on neural responses, or even from flight tunnel bioassays with individual lures placed in a background of laminar, clean air (Ansebo et al. 2004, Cha et al. 2008). A primary issue in developing an effective lure is the influence of the host's volatile background profile on moth's response to baited traps, and this has certainly been an important factor affecting the variable response of *C. pomonella* to pear ester across crops, among cultivars, and during the season (Light et al. 2001; Knight et al. 2005; Knight and Light 2004, 2005b). A geographical difference in the responses among populations of *C. pomonella* to pear ester has also been suggested (Trimble and El-Sayed 2005, Mitchell et al. 2008). However, the more recent development of new multicomponent attractants including pear ester as one of several components is encouraging: adding acetic acid, Landolt et al. (2007); adding apple volatiles, El-Sayed et al. (2013); adding butyl sulfide, Landolt et al. (2014).

The addition of pear ester to codlemone for improved mating disruption of *C. pomonella* is well-established and several dispensers have now been registered (Knight et al. 2011b, Knight et al. 2012, Knight and Light 2014, Knight 2015). Several host plant volatiles were tested with codlemone and acetic acid because of a general concern that the attractiveness of pear ester in the lure would be diminished by pear ester also being released from the dispensers (Knight et al. 2013). In this study, nonatriene was found to be an effective replacement for pear ester when used with codlemone and acetic acid in orchards treated with the combinational dispensers. Now, we show that the PH/PE/DMNT+AA lure is even more effective, and especially in orchards treated with PH/PE dispensers. Moth

Table 3. Comparison of moth catches of *C. pomonella* in delta traps baited with an acetic acid co-lure (AA) plus either a septum lure loaded with codlemone (*E,E*)-8,10-dodecadien-1-ol (PH) and pear ester ethyl *(E,Z)*-2,4-decadienoate or codlemone, pear ester, and (*E*)-4,8-dimethyl-1,3,7-nonatriene (DMNT) in orchards treated for mating disruption (MD) with either sex pheromone dispensers (PH) or dispensers loaded with both sex pheromone and pear ester (Combo) for mating disruption (MD) during each moth generation, $N = 10$ in both generations, USA, 2013

MD treatment[a]	Lures[b]	Mean (SE) moth catch per trap[c]					
		First generation			Second generation		
		Male	Female	Total	Male	Female	Total
PH	PH/PE + AA	2.1 (0.8)	0.9 (0.2)	3.0 (0.8)	9.0 (2.9)	1.5 (0.4)b	10.5 (3.3)
	PH/PE/DMNT + AA	6.1 (2.2)	1.2 (0.5)	7.3 (2.7)	9.9 (2.9)	3.4 (1.0)a	13.3 (3.9)
ANOVA[d]		$F = 3.94$	$F = 0.14$	$F = 2.95$	$F = 0.01$	$F = 5.19$	$F = 0.38$
		$P = 0.08$	$P = 0.72$	$P = 0.12$	$P = 0.94$	$P < 0.05$	$P = 0.55$
PH/PE	PH/PE+ AA	8.4 (4.0)	0.1 (0.1)b	8.5 (4.0)	3.4 (0.9)b	1.9 (0.3)	5.3 (0.9)b
	PH/PE/DMNT + AA	7.1 (2.6)	0.6 (0.2)a	7.7 (2.7)	8.1 (1.7)a	2.2 (0.6)	10.3 (2.1)a
ANOVA		$F = 0.07$	$F = 5.42$	$F = 0.27$	$F = 6.32$	$F = 0.04$	$F = 4.87$
		$P = 0.80$	$P < 0.05$	$P = 0.61$	$P < 0.05$	$P = 0.85$	$P < 0.05$

Means within a column followed by a different letter were significantly different, $P < 0.05$, Tukey's HSD test.

[a] MD dispensers included either Isomate CM Flex loaded with codlemone or Cidetrak CMDA Combo PP loaded with codlemone and pear ester.

[b] Septa lures were loaded with 3 mg of each host plant volatile either alone or together. AA lures were the proprietary Pherocon AA plastic cup membrane lures (Trécé Inc.).

[c] Studies were conducted during each summer generation from 7 June to 5 July and 18 July to 15 August.

[d] Transformed data were analyzed with a complete randomized block design with degrees of freedom = 1, 9.

Table 4. Comparison of moth catches of *C. pomonella* in delta traps baited with an acetic acid co-lure (AA) plus gray halobutyl elastomer septa loaded with codlemone (*E*,*E*)-8,10-dodecadien-1-ol (PH) and either the host plant volatile (*E*)-4,8-dimethyl-1,3,7-nonatriene (DMNT), pear ester ethyl (*E*,*Z*)-2,4-decadienoate, or both in orchards treated with sex pheromone dispensers (PH) or Meso dispensers loaded with both sex pheromone and pear ester (PH/PE) for mating disruption (MD) during each moth generation, $N = 10$, USA, 2014

MD treatment[a]	Lures[b]	Mean (SE) moth catch per trap[c]					
		First generation			Second generation		
		Male	Female	Total	Male	Female	Total
PH	PH/DMNT + AA	7.8 (1.6)	2.0 (0.9)	9.8 (1.9)	5.4 (1.1)	1.2 (0.6)b	6.6 (0.8)
	PH/PE + AA	6.6 (2.0)	1.4 (0.5)	8.0 (2.1)	3.4 (0.7)	3.8 (0.5)a	7.2 (1.1)
	PH/PE/DMNT + AA	8.0 (1.5)	2.6 (1.0)	10.6 (2.5)	7.0 (1.6)	8.6 (2.0)a	15.6 (3.3)
ANOVA[d]		$F = 0.52$	$F = 0.61$	$F = 0.59$	$F = 4.32$	$F = 12.09$	$F = 2.27$
		$P = 0.60$	$P = 0.55$	$P = 0.56$	$P = 0.06$	$P < 0.01$	$P = 0.12$
PH/PE	PH/DMNT + AA	8.8 (2.9)	0.0 (0.0)b	8.8 (2.9)ab	13.0 (2.0)a	1.2 (0.2)	14.2 (1.9)a
	PH/PE + AA	2.6 (0.6)	0.8 (0.4)ab	3.4 (1.0)b	2.8 (0.4)b	3.8 (1.3)	6.6 (1.6)b
	PH/PE/DMNT + AA	6.8 (1.5)	2.2 (0.8)a	9.0 (1.2)a	7.2 (1.2)a	2.8 (0.6)	10.0 (1.4)ab
ANOVA[d]		$F = 2.62$	$F = 5.62$	$F = 4.04$	$F = 16.66$	$F = 1.99$	$F = 6.46$
		$P = 0.10$	$P < 0.05$	$P < 0.05$	$P < 0.001$	$P = 0.16$	$P < 0.05$

Means within a column followed by a different letter were significantly different, $P < 0.05$, Tukey's HSD test.
[a] Orchard blocks were either treated with Isomate CM Flex dispensers with codlemone at 800 ha^{-1}, or Cidetrak CMDA Combo Meso dispensers with codlemone and pear ester at 80 ha^{-1}.
[b] Pear ester and DMNT (3 mg) were loaded in gray septa, AA lures were 8-ml plastic vials with 1.0-mm holes.
[c] Studies were conducted during each summer generation 20 May to 17 June and 25 July to 22 August.
[d] Transformed data were analyzed with a complete randomized block design with degrees of freedom = 2, 18.

catch was increased with PH/PE/DMNT+AA lures up to twofold compared with the widely used PH/PE+AA lure in our trials. The next step will be to evaluate whether adding butyl sulfide to PH/PE/DMNT+AA can further increase moth catches (Landolt et al. 2014). This step-wise improvement in lures that has developed to monitor female *C. pomonella* likely increases the potential to develop effective mass trapping or attract and kill strategies for this important pest (Knight et al. 2002, Cook et al. 2007). Yet, practical concerns about the cost, chemical stability, and safe handling of these more complex lures will likely impact industry adoption of these enhanced tools. Fortunately, the adoption of pear ester did not trigger any of these concerns, as it was already widely used in the food and cosmetic industry (Light et al. 2001). The marginal increase (twofold) in attractiveness provided by these newer lures will need to be evaluated and their value in pest management offset by their various concrete limitations.

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