Use of Ethyl and Propyl (*E,Z*)-2,4-decadienoates in Codling Moth Management: Improved Monitoring in Bartlett Pear with High Dose Lures

A.L. KNIGHT[1] and D.M. LIGHT[2]

ABSTRACT

The propyl and ethyl esters of (*E,Z*)-2,4-decadienoic acid were evaluated in gray halobutyl septa as kairomone lures for both sexes of codling moth, *Cydia pomonella* (L.). All studies were conducted in 'Bartlett' pear orchards with moderate to high codling moth adult population densities and treated with sex pheromone dispensers for mating disruption. Variable results were obtained with kairomone loading experiments. Increasing the lure loading to 40.0 mg of either the ethyl or propyl ester significantly increased male and total moth catch in separate experiments. However, in other tests with the ethyl ester no difference was found in total moth catch in traps baited with 0.1, 1.0, 3.0 or 10.0 mg versus 40.0 mg lures. The 40.0 mg ethyl and propyl ester lures were both more effective than a 3.0 mg ethyl ester lure and comparable to a sex pheromone lure in detecting the beginning of codling moth flight in the spring generation. No difference was found in moth catch between 40.0 mg propyl and ethyl ester lures. Significantly more females were caught in traps baited with 1.0 – 10.0 mg than with 1.0 – 100.0 µg lures loaded with the ethyl ester. In general, kairomone lures caught significantly fewer moths than sex pheromone lures.

Key Words: *Cydia pomonella*, monitoring, kairomone, trapping

INTRODUCTION

Codling moth, *Cydia pomonella* (L.) (Lepidoptera: Torticidae), is a worldwide, key internal pest of pear, *Pyrus communis* L., and adult populations in commercial orchards are typically monitored with traps baited with sex pheromone lures (Riedl *et al.* 1986). Reliable adult monitoring is especially critical in orchards where codling moth is managed with applications of its sex pheromone for mating disruption (Knight 2002a). The sex pheromone treatment disrupts the attractiveness of the sex pheromone-baited trap, and traps can fail to alert pest managers of potential problems. Efforts to improve the usefulness of traps in sex pheromone-treated orchards have included the use of high-dose lures (Charmillot 1990) and an increased density of traps (Gut and Brunner 1996).

Identification of ethyl (*E,Z*)-2,4-decadienoate as a potent kairomone attractant for codling moth adults and larvae has allowed the development of several new approaches to successfully monitor and manage this pest (Knight and Light 2001; Light *et al.* 2001). Ethyl (*E,Z*)-2,4-decadienoate is attractive to both sexes of codling moth, and traps can be used to assess the timing of female emergence and activity, as well as mating status. In addition, the attractiveness of the lure is not strongly affected by the application of sex pheromones (Light *et al.* 2001), and the lure can improve the prediction of local pest population densities (Knight 2002b).

Ethyl (*E,Z*)-2,4-decadienoate is a major volatile of ripe pear (Jennings *et al.* 1964), and is not found in immature fruit or pear-

[1] Yakima Agricultural Research Laboratory, Agricultural Research Service, USDA 5230 Konnowac Pass Rd., Wapato, WA 98951
[2] Western Regional Research Center, Agricultural Research Service, USDA, Albany, CA 94710

leaf volatiles (Miller *et al.* 1989, Scutareanu *et al.* 1997). An initial evaluation suggested that ethyl (*E*,*Z*)-2,4-decadienoate might not be an effective attractant for codling moth adults in pear orchards (Light *et al.* 2001). However, this conclusion was based on data collected with 1.0 mg lures placed in three conventional 'Bartlett' orchards with high levels of codling moth (> 3 moths trapped per day with a sex pheromone lure and detectable levels of fruit injury). The relatively low attractiveness of the synthetic ethyl (*E*,*Z*)-2,4-decadienoate lure in these pear orchards was hypothesized to be due to olfactory "masking" of the lure by natural sources of ethyl (*E*,*Z*)-2,4-decadienoate released either from injured or ripening fruits or by competing host volatiles (Light *et al.*, 2001). A second study found that lures loaded with 3.0 mg of ethyl (*E*,*Z*)-2,4-decadienoate were similar or more attractive than sex pheromone lures in four cultivars of pear when orchards were treated with sex pheromones (Knight *et al.* 2005). Ethyl (*E*,*Z*)-2,4-decadienoate lures performed similarly early and late in the season relative to a sex pheromone lure in these cultivars suggesting that maturation of fruit was not an important factor affecting lure attractiveness. Ethyl (*E*,*Z*)-2,4-decadienoate lures again performed poorly only in 'Bartlett' pear orchards with high population densities of codling moth that were defined by catches in sex pheromone-baited traps exceeding 20 moths per season and the presence of fruit injury (Knight *et al.* 2005).

Improvements in developing a more attractive kairomone lure for codling moth in pear may involve optimizing its emission rate and/or the use of alternative attractants. Light *et al.* (2001) reported that ethyl (*E*,*Z*)-2,4-decadienoate loaded into gray halobutyl lures was attractive at doses > 10.0 μg, and the highest moth catches in walnut orchards occurred with 10.0 mg lures. Studies testing doses of ethyl (*E*,*Z*)-2,4-decadienoate > 3.0 mg in pear have not been reported. Among the 23 volatile blends tested by Light *et al.* (2001), only the blend of methyl and ethyl esters of ten-carbon acids were attractive to adult codling moth. Within this group, methyl (*E*,*Z*)-2,4-decadienoate was found to be somewhat attractive in both apple and walnut orchards. This compound was also attractive to neonate codling moth (Knight and Light 2001). Unfortunately, the methyl ester is another component of ripe pears (Heinz *et al.* 1966, Shiota 1990), and its attractiveness to codling moth would also likely be influenced by competition with volatile fruit odors within the orchard.

An alternative approach in developing an improved kairomone may be to utilize a related volatile that is not present in pear orchards. Propyl (*E*,*Z*)-2,4-decadienoate has been identified from pear by GLC analysis following an isopentane extraction of ripe 'Bartlett' puree (Creveling and Jennings 1970), but not from volatile headspace collections of intact fruit (Light *et al.* 2001) or codling moth-injured fruit (D. M. L., unpublished data). GC-EAD antennal response to a synthetic homologous series of decadienoic esters found that codling moth's antennal receptivity is stimulated by the ethyl ester, with both the methyl- and propyl-esters eliciting a smaller depolarization response (D. M. L., unpublished data). The behavioral effects elicited in codling moth by propyl (*E*,*Z*)-2,4-decadienoate are unreported. Herein, we report studies optimizing the dose of ethyl and propyl (*E*,*Z*)-2,4-decadienoate in separate lures for monitoring adult codling moth in 'Bartlett' pear.

MATERIALS AND METHODS

Field test protocol. Field trials were conducted in 1999, 2001, and 2002 to evaluate the attractiveness of lures loaded with different doses of ethyl and propyl (*E*,*Z*)-2,4-decadienoate versus sex pheromone lures (L2™ and Megalure™, Trécé Inc., Salinas, California [CA]). The ethyl (93.7% A.I.) and propyl esters (94.7%

A.I.) were synthesized by Trécé Inc. and loaded in gray halobutyl elastomer septa. All studies were conducted in 'Bartlett' pear orchards located near Wapato, Washington (WA) and treated with 700 – 1,000 Isomate-C PLUS sex pheromone dispensers (Pacific Biocontrol, Vancouver, WA) per ha. All studies were conducted with diamond-shaped sticky traps (Pherocon IIB, Trécé Inc., Salinas, CA) attached to poles placed in the upper third of the trees' canopy. Traps were placed 30 – 50 m apart within each orchard. Traps were checked weekly and replaced when needed. Moths were sexed in all studies.

Optimizing the lure dose of ethyl (*E,Z*)-2,4-decadienoate. Two experiments were conducted in 1999 to examine various doses of ethyl ester. Experiment 1 compared the attractiveness of lures loaded with the ethyl ester at doses of 1.0, 10.0, and 100.0 µg and 1.0, 3.0, and 10.0 mg versus the L2™ sex pheromone lure. Eight replicates of each lure dose were used. Traps were randomized, placed in the orchard on 21 May, and checked weekly until 28 June. Traps were not rotated in this study. Experiment 2 evaluated a smaller subset of lure doses of the ethyl ester: 1.0, 10.0, and 40.0 mg, versus the Megalure™. Nine replicates of each lure type were randomized in the field on 30 June, and traps were checked and rotated weekly until 27 July.

Optimizing the lure dose of propyl (*E,Z*)-2,4-decadienoate. An experiment was conducted in 2001 to compare the attractiveness of the propyl ester at lure doses of 1.0, 3.0. 10.0 and 40.0 mg versus the standard 3.0 mg ethyl ester lure. Ten replicates of each lure dose and type were randomly placed within a single orchard on 9 May and checked weekly until 5 July. Traps were rotated within the orchard each week.

Comparison of kairomone and sex pheromone lures. Two experiments were conducted to compare the attractiveness of lures loaded with 3.0 or 40.0 mg ethyl ester, a lure loaded with 40.0 mg propyl ester, and the commercial high-dose sex pheromone lure, Megalure™. The first experiment was conducted during 2001 in ten orchards. Traps were placed in each orchard on 3 July and checked and rotated each week until 15 August. The second experiment was conducted in 2002 in the same ten orchards. Traps were placed in the orchards on 22 April and checked and rotated weekly until 1 July.

Data analysis. Significant differences in the cumulative moth catch in traps baited with each lure over the specified time interval were determined with one way analysis of variance (ANOVA), $P < 0.05$ (Analytical Software 2000). Count data were transformed prior to analysis with square root $(x + 0.01)$. Differences in the detection of first moth flight among lures were determined by ANOVA with data collected in 2002. Means were separated with Fisher's least significant difference test within all significant ANOVA's.

RESULTS

Optimizing the lure dose of ethyl (*E,Z*)-2,4-decadienoate. Significant differences were found among the various doses of the ethyl ester and the sex pheromone lure in the cumulative catch of male ($F = 20.38$; df = 6, 49; $P < 0.001$) and total moths ($F = 16.09$; df = 6, 49; $P < 0.001$) in experiment 1 (Table 1). The sex pheromone lure caught significantly more males and total moths than any of the ethyl ester lures. Traps baited with ethyl ester lures loaded with 1.0, 3.0, and 10.0 mg caught significantly more males than traps baited with 1.0 and 10.0 µg lures and more total moths than traps baited with the 1.0 µg lure. Significant differences were found in the catch of female moths among the kairomone lures ($F = 7.19$; df = 5, 42; $P < 0.001$) (Table 1). Lures loaded with 1.0 – 10.0 mg ethyl ester caught significantly more female moths than lures loaded with 1.0, 10.0, and 100.0 µg (Table 1).

Table 1.
Attractiveness of ethyl (*E*,*Z*)-2,4-decadienoate (Et-*E*,*Z*-DD) lures compared with sex pheromone lures in 'Bartlett' pear orchards, 1999.

		Mean cumulative capture ± SE of codling moth per trap[1]		
Exp.[2]	Lure, loading	Males	Females[3]	Total
1	Et-*E*,*Z*-DD, 1.0 µg	0.50 ± 0.38d	0.38 ± 0.18b	0.88 ± 0.52d
	Et-*E*,*Z*-DD, 10.0 µg	1.25 ± 0.59cd	0.75 ± 0.31b	2.00 ± 0.85cd
	Et-*E*,*Z*-DD, 100.0 µg	3.13 ± 0.88bc	1.00 ± 0.50b	4.13 ± 0.99bcd
	Et-*E*,*Z*-DD, 1.0 mg	4.50 ± 0.93b	3.13 ± 1.01a	7.63 ± 1.61bc
	Et-*E*,*Z*-DD, 3.0 mg	5.25 ± 1.10b	3.25 ± 0.75a	8.50 ± 1.46b
	Et-*E*,*Z*-DD, 10.0 mg	5.50 ± 0.99b	4.75 ± 0.90a	10.25 ± 1.71b
	Sex pheromone, N.A. [3]	28.00 ± 5.20a	-	28.00 ± 5.20a
2	Et-*E*,*Z*-DD, 1.0 mg	2.33 ± 0.80c	0.89 ± 0.54a	3.22 ± 1.01c
	Et-*E*,*Z*-DD, 10.0 mg	1.78 ± 0.49c	0.89 ± 0.35a	2.67 ± 0.82c
	Et-*E*,*Z*-DD, 40.0 mg	8.33 ± 1.73b	1.00 ± 0.47a	9.33 ± 2.13b
	Sex Pheromone, N.A. [3]	21.78 ± 4.98a	-	21.78 ± 4.98a

[1] Column means within each experiment followed by a different letter are significantly different at $P < 0.05$, Fisher's LSD.
[2] Experiment 1 was conducted from 21 May –22 June and experiment 2 was conducted from 30 June – 27 July 1999.
[3] Not available. Proprietary loadings in the L2™ and Megalure™ sex pheromone lures used in experiments 1 and 2, respectively have not been published (Trécé Inc., Salinas, CA).

Significant differences in the catch of male (F = 12.08; df = 3, 32; P < 0.0001) and total moths (F = 15.37; df = 3, 32; P < 0.0001) among the ethyl ester and sex pheromone lures were also found in experiment 2 (Table 1). The sex pheromone lure caught significantly more males and total moths than any of the three doses of the ethyl ester tested. The 40.0 mg ethyl ester lure caught significantly more males and total moths than the 1.0 and 10.0 mg lures. No significant differences in the catch of female moths occurred among doses of the ethyl ester in this experiment (F = 0.02; df = 2, 24; P = 0.98).

Optimizing the lure dose of propyl (*E*,*Z*)-2,4-decadienoate. Significant differences were found in the mean captures of males (F= 3.91; df = 4, 45; P < 0.01) and total moths (F = 3.23; df = 4, 45; P < 0.05) among different doses of the propyl ester and the 3.0 mg ethyl ester lure (Table 2). The highest dose of the propyl ester (40.0 mg) caught significantly more males and total moths than the other lures. No difference was found among lures in the catch of female codling moth (F = 2.29; df = 4, 45; P = 0.07).

Comparison of kairomone and sex pheromone lures. During the first generation flight in 2002 there was no difference in moth catch among the sex pheromone and kairomone lures (F = 0.97; df = 3, 36; P = 0.42). However, there was a significant difference among lures in the first detection of moth flight (F = 4.39; df = 3, 36; P < 0.01). The first adult codling moth caught by the 3.0 mg ethyl ester lure was on average nearly 2 wk later than the other lures (Table 3). The high-dose kairomone and sex pheromone lures did not differ in their detection of the start of codling

Table 2.
Evaluation of the attractiveness of ethyl (*E,Z*)-2,4-decadienoate (Et-*E,Z*-DD) and propyl (*E,Z*)-2,4-decadienoate (Pr-*E,Z*-DD) lures in ten Bartlett pear orchards from 9 May to 5 July 2001.

		Mean cumulative capture ± SE of codling moth per trap[1]		
Lure	Loading (mg)	Males	Females	Total
Pr-*E,Z*-DD	1.0	2.3 ± 0.6b	0.8 ± 0.3a	3.1 ± 0.6b
Pr-*E,Z*-DD	3.0	2.6 ± 0.6b	1.0 ± 0.3a	3.6 ± 0.8b
Pr-*E,Z*-DD	10.0	2.4 ± 0.4b	0.2 ± 0.1a	2.6 ± 0.4b
Pr-*E,Z*-DD	40.0	5.4 ± 0.9a	0.6 ± 0.3a	6.0 ± 1.0a
Et-*E,Z*-DD	3.0	3.5 ± 0.7b	0.2 ± 0.1a	3.7 ± 0.6b

[1] Column means followed by a different letter are significantly different at $P < 0.05$, Fisher's LSD.

Table 3.
The effectiveness of the ethyl (*E,Z*)-2,4-decadienoate (Et-*E,Z*-DD), propyl (*E,Z*)-2,4-decadienoate (Pr-*E,Z*-DD), and sex pheromone lures in monitoring first generation codling moth in ten 'Bartlett' pear orchards treated with sex pheromone, 22 April to 1 July 2002.

Lure	Loading (mg)	Mean ± SE cumulative moth catch per trap[1]	Mean ± SE weeks to first moth catch
Pr-*E,Z*-DD	40.0	9.4 ± 1.7a	3.1 ± 0.5a
Et-*E,Z*-DD	3.0	14.2 ± 3.6a	4.8 ± 0.2b
Et-*E,Z*-DD	40.0	15.4 ± 3.7a	2.2 ± 0.1a
Sex pheromone	N.A. [2]	24.8 ± 12.0a	3.0 ± 0.8a

[1] Column means followed by a different letter are significantly different at $P < 0.05$, Fisher's LSD.
[2] Not available. Proprietary loading in the Megalure™ high-dose sex pheromone lure has not been published (Trécé Inc., Salinas, CA).

moth's spring flight. A significant difference in the capture of codling moth adults was found among lures during the second generation in 2001 ($F = 4.06$; df = 3, 36; $P < 0.05$). The sex pheromone lure caught 4- to 13-times more moths than the various kairomone lures (Table 4). No differences in male, female, and total moth catch were found among kairomone lures in this test.

DISCUSSION

The hypothesis and rationale for the synthesis and testing of the un-natural synthetic propyl ester were the potential for its greater detectability, attractiveness, or capture activity in orchards where high levels of pear fruit damage are causing the precocious liberation of large, perhaps masking, amounts of the natural methyl and ethyl esters. However, our results with the propyl ester lures were inconsistent. The 40.0 mg propyl ester lure caught significantly more total moths and males than similar lures loaded with 1.0 – 10.0 mg and more than the 3.0 mg ethyl lure during May and

Table 4.

Evaluation of the attractiveness of the ethyl (*E,Z*)-2,4-decadienoate (Et-*E,Z*-DD), propyl (*E,Z*)-2,4-decadienoate (Pr-*E,Z*-DD), and a commercial sex pheromone lure in monitoring second generation codling moth flight in ten 'Bartlett' pear orchards treated with sex pheromone, 3 July to 15 August 2001.

		Mean ± SE cumulative moth catch per trap[1]		
Lure	Dose (mg)	Males	Females	Total
Pr-*E,Z*-DD	40.0	3.5 ± 1.9b	3.5 ± 1.9a	7.0 ± 4.5b
Et-*E,Z*-DD	3.0	3.0 ± 1.0b	3.1 ± 1.8a	6.1 ± 2.7b
Et-*E,Z*-DD	40.0	2.0 ± 0.5b	1.4 ± 0.6a	3.4 ± 0.9b
Sex pheromone	N.A.[2]	26.9 ± 9.3a	-	26.9 ± 9.3a

[1] Column means followed by a different letter are significantly different at $P < 0.05$, Fisher's LSD.

[2] Not available. Proprietary loading in the Megalure ™ high-dose sex pheromone lure has not been published (Trécé Inc., Salinas, CA).

June in 2001, yet from July to mid August in 2001 and from late April through June in 2002 traps baited with the 40.0 mg propyl lure did not catch more moths than the 3.0 mg ethyl ester lure. Thus no clear advantage in using the propyl ester versus the ethyl ester was demonstrated in these studies.

The effect of increasing the loading rate of the ethyl ester was also inconsistent among experiments. No significant difference in moth catch was found in traps baited with 1.0 – 10.0 mg ethyl ester in late May to June in 1999, but the 40.0 mg lure caught significantly more total moths and males than either the 1.0 or 10.0 mg lure during July. However, from July to mid August in 2001 and from late April through June in 2002 no difference in moth catch occurred in traps baited with either a 3.0 or 40.0 mg ethyl ester lure.

The 40.0 mg kairomone lures, however, were effective in detecting the beginning of the first generation moth flight in pear, whereas moth catch in traps baited with the 3.0 mg ethyl ester lure was delayed. Similar patterns of delayed first moth catch have been found with 3.0 mg ethyl ester lures in apple orchards (A.L.K., unpublished data), but not in walnut (Light *et al.* 2001). Accurate detection of the start of moth flight ("Biofix") is widely used to predict the start of egg hatch and in timing insecticide applications (Riedl *et al.* 1976). Thus, the 40.0 mg ethyl ester lure may be an improved kairomone lure to monitor early-season codling moth flight activity.

Traps baited with either kairomone were not as effective as traps baited with sex pheromone in capturing codling moth in all but one study (early season 2002 trial). This negative result was similar to other data collected with the 3.0 mg ethyl ester lure from 'Bartlett' orchards in the same fruit-growing region of WA (Knight *et al.* 2005). The relatively poor performance of the ethyl ester lure in both WA studies is in contrast to its higher performance than sex pheromone lures in CA 'Bartlett' orchards (Zoller and Zoller 2003). A major difference between the published WA and CA studies is the population densities of codling moth within the monitored orchards. Mean moth catch in sex pheromone-baited traps was >80 moths per trap per season in WA 'Bartlett' orchards (Knight *et al.* 2005) and >20 moths per trap over the one- to two-month studies reported here. Codling moth fruit injury occurred at levels >10.0% in many of these orchards. In comparison, mean cumulative moth catch in the sex pheromone-baited traps was 2.7 per season in CA 'Bartlett' orchards and fruit injury was <0.5%

(Zoller and Zoller 2003). A similar reduction in the attractiveness of the ethyl ester was found in the second generation of codling moth for apple orchards with high levels of fruit injury (Light *et al.* 2001). Additional studies are needed to refine under which field conditions the pear esters are likely to perform well, i.e. crop, cultivar, season, crop load, fruit maturity, and percent injured fruit (Knight 2002b). Comparing the statistical correlations of moth catch in sex pheromone- and kairomone-baited traps with egg density or levels of fruit injury versus the absolute counts would likely be more informative in developing an improved monitoring program for codling moth.

Similarly, interpretation of the numbers and timing of female moth capture is a unique feature of kairomone-baited traps that has not been fully utilized. Traps baited with ethyl ester typically catch from 40 – 60% female codling moth (Light *et al.* 2001), and similar data were reported across four pear cultivars in orchards with both low and high moth population densities (Knight *et al.* 2005). In our current study, female moths were caught in traps baited with either ester and across all lure-loading rates. Significantly more female moths were caught in traps baited with $\geq$1.0 mg ethyl ester than at the lower rates tested and no additional increase was found with lure loadings up to 40.0 mg. Results with the propyl ester were similar and no differences in female catch were noted between 40.0 mg ethyl and propyl lures. Establishing moth catch thresholds based on female codling moth density could be a useful approach to improve management of this pest, especially in sex pheromone-treated orchards (Knight 2002b). In addition, initiating predictive timing models of egg hatch based on a "Biofix" of first female moth catch could improve current models. Incorporating these kairomone-baited traps in the integrated management of codling moth will require additional testing and refinement.

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