A Comparison of Gray Halo-butyl Elastomer and Red Rubber Septa to Monitor Codling Moth (Lepidoptera: Tortricidae) in Sex Pheromone-Treated Orchards

ALAN L. KNIGHT

YAKIMA AGRICULTURAL RESEARCH LABORATORY, AGRICULTURAL RESEARCH SERVICE, USDA 5230 KONNOWAC PASS RD. WAPATO, WA 98951

ABSTRACT

The emission rate, isomeric stability, and relative attractiveness of field-aged gray halo-butyl elastomer and red rubber septa loaded with 4.0 and 10.0 mg of (*E*,*E*)-8,10-dodecadien-1-ol (E8,E10-12:OH, codlemone), the major sex pheromone component for codling moth, *Cydia pomonella* L., were evaluated. Initially, field-aged red septa loaded with 10.0 mg had significantly higher emission rates than gray septa loaded with 4.0 mg codlemone. Emission rates of codlemone decayed over time from both lures and were similar for lures aged 28-42 d in the field. Isomerization of E8,E10-12:OH occurred rapidly in red septa but did not occur in the gray septa. Moth capture in traps baited with either lure type aged in the field did not differ initially (0 and 7 d), but were significantly lower in traps baited with 14, 28, and 42 d-old red versus gray septa. Significant differences observed in the attractiveness of these two types of field-aged lures were primarily due to changes in their isomeric purity and not to differences in their emission rate. Increasing the codlemone load of gray septa up to 20.0 mg did not improve the performance of lures in sex pheromone-treated orchards. All lures were effective for 10 wk. Loading gray septa with 50.0 mg codlemone increased lure attractiveness and extended its longevity to 16 wk. Proprietary gray septa loaded with a high rate of pheromone and replaced once per season were more attractive than the standard 10.0 mg loaded red septa replaced three times in a sex pheromone-treated orchard.

Key words: *Cydia pomonella*, codling moth, sex pheromone, monitoring, lures

INTRODUCTION

Codling moth, *Cydia pomonella* L., is the major direct pest of pome fruits and walnut throughout the world (Shel'deshova 1967). Following the identification of the sex pheromone of codling moth, (*E,E*)-8,10-dodecadien-1-ol (E8, E10-12:OH, codlemone) (Roelofs *et al.* 1971), moth catches in pheromone baited traps have been widely used to establish action thresholds (Riedl and Croft 1974) and to track the seasonal timing of key population events (Riedl *et al.* 1976). Traps baited with red rubber septa impregnated with codlemone have been the most widely used dispenser system (Riedl *et al.* 1986). Lure loadings between 0.1 and 1.0 mg codlemone have provided optimal attraction (Maitlen *et al.* 1976, Culver and Barnes 1977, McNally and Barnes 1980, Kehat *et al.* 1994).

Maitlen *et al.* (1976) characterized the first-order release characteristics of codlemone from red rubber septa under controlled laboratory conditions (23 °C). Based on both analytical and biological studies they determined that a 1.0 mg lure should maintain a maximum level of attraction for up to four wk. Their calculations suggested that a 5.0 mg loading would remain effective for >4 months. Riedl *et al.* (1986) used the half-life calculations of Maitlen *et al.* (1976) to predict that red rubber septa loaded initially with 1.0 mg codlemone should be effective for up to 11 wk (based on maintaining a residual pheromone content >0.1 mg). This predicted long field-life of the red rubber septa was demonstrated by McNally and Barnes (1980). Field-aged lures loaded with 1.0 mg codlemone were equally effective as new lures

for up to 16 wk. However, Culver and Barnes (1977) found that the attractiveness of 1.0 mg lures dropped significantly after 2-3 wk in the field. Riedl *et al.* (1986) hypothesized that this large difference observed in the longevity of field-aged red rubber septa might be due to changes in the manufacturer's formulation. Subsequent field studies found that both the emission rate and the attractiveness of red rubber septa declined rapidly after two wk (Kehat *et al.* 1994).

Concurrent with the rapid adoption of sex pheromone dispensers for mating disruption of codling moth during the 1990's was the use of monitoring lures loaded with higher rates of codlemone (Charmillot 1990). Red rubber septa loaded with 10.0 mg codlemone have been the most common lure used in sex pheromone-disrupted orchards in western North America (Knight 1995a, Judd *et al.* 1996, Gut and Brunner 1998). Lures with high loads of codlemone have allowed pest managers to track the population density and phenology of codling moth within sex pheromone-treated orchards. Current monitoring recommendations of sex pheromone-treated orchards with 10.0 mg red septa suggest changing lures every 2-3 wk (Gut and Brunner 1996). The short life of these high load lures was hypothesized to be due to the depletion of codlemone under high summer temperatures (Gut and Brunner 1995), similar to the results reported from Israel with standard lures (Kehat *et al.* 1994). This frequent replacement schedule for lures combined with a higher density of traps has increased the cost of monitoring sex pheromone-treated orchards relative to conventional orchards (Knight 1995a).

The chemical instability of many sex pheromones can severely limit the longevity of lures (House *et al.* 1998). The chemical sensitivity of codlemone, a conjugated diene alcohol, to heat, light, and air is particularly acute (Brown and McDonough 1986, Ideses and Shani 1988). Several biochemical pathways can degrade codlemone, including isomerization and oxidation to peroxides and furans (Millar 1995). Rapid isomerization of codlemone within rubber septa is catalyzed by the presence of sulphur and sunlight (Brown and McDonough 1986). Isomerization of codlemone within sulphur-cured rubber septa begins immediately (Vrkoč *et al.* 1988), and the three isomers may account for 20% of the content within seven days in field-aged lures placed within traps (Brown and McDonough 1986). Chemical protection of codlemone can be accomplished with the addition of UV stabilizers and antioxidants (Ideses and Shani 1988, Millar 1995) or by the use of other lure substrates. For example, the isomerization of codlemone was 4.7 fold slower within phenolic resin-cured, gray halo-butyl elastomer lures versus the red rubber septa (Brown and McDonough 1986).

The isomeric purity of codlemone is an important factor affecting a lure's performance. Various crude mixtures of the three geometrical isomers of codlemone decreased the attractiveness of codlemone when incorporated together within red rubber septa-baited traps (Roelofs *et al.* 1972). A chemical equilibrium blend of the four isomers (61% *EE,* 5% *ZZ*, 14% *ZE*, and 20% *EZ*) significantly reduced the flight response of males in flight tunnel tests versus pure codlemone (McDonough *et al.* 1993). El-Sayd *et al.* (1998) found that the single addition of the *Z,E* isomer to codlemone synergized the response of codling moth in a flight tunnel, but moth capture in traps was not affected in a subsequent field study. In contrast, the addition of 20% *E,Z* isomer strongly depressed male responses both in a flight tunnel and to traps placed in the field.

The objective of this study was to evaluate the effects of emission rate and isomeric purity of codlemone on the attractiveness of lures for codling moth. Herein are reported the emission rate and isomeric purity of field-aged red rubber and gray halo-butyl elastomer septa. The relative attractiveness of lures was evaluated in a series of field trials within sex pheromone-treated apple orchards. Subsequent field tests evaluated the optimal loading rate of gray septa for season-long monitoring of codling moth in sex pheromone-treated orchards.

MATERIALS AND METHODS

Preparation of lures. Gray halo-butyl elastomer septa (No. 1888, size No. 1) and red, natural rubber septa (No. 1171, size 1F) were used in all tests (West Co., Phoenixville. PA). Septa were extracted in hexane for 24 h, dichloromethane for another 24 h, and then air-dried for 48 h prior to loading. E8,E10-12:OH (97% purity, Aldrich Chemical, Minneapolis, MN) was added to the cup portion of the septa in a 200-μl aliquot of dichloromethane, followed by another 200 μl of dichloromethane to ensure penetration of the material. Initial studies found that a maximum of 4.0 mg codlemone could be loaded in gray septa using this technique. Codlemone crystallized on the surface of these lures at higher loadings. Thus, red and gray septa were loaded with 10.0 and 4.0 mg E8,E10-12:OH, respectively. Septa were kept frozen at –15 °C prior to use.

Evaluation of field-aged septa. Prepared septa were field-aged by pinning lures inside of non-sticky Pherocon IC wing traps (Trécé Inc., Salinas, CA) hung at 2.0 m height in the canopy of an unsprayed apple orchard (Yakima, WA). Eight septa of one type were placed 4.0 cm apart inside of traps, and pinned 1.5 cm above the traps' bottom surfaces on 8 July 1995. Nine lures of each type were randomly collected at weekly intervals (0, 7, 14, 21, 28, 35, 42 and 49 d field exposure) for subsequent field testing and chemical analyses.

The average daily emission rate of lures during each time interval was estimated by differential residual analysis (difference between the mean sex pheromone content at the beginning of the time period and the residual values at the end of the time period). Four septa of each type from each date were extracted with 50 ml dichloromethane by shaking lures in a flask for 1 h. The extract was further diluted in dichloromethane and heptane and analyzed with a Hewlett-Packard Model 5880 GC with flame ionization detection (Hewlett Packard, Mountain View, CA) and equipped with a 60 m by 0.32 mm i.d. Supelcowax capillary column (Supelco Inc., Bellefonte, PA) with splitless injection. The oven program used for analysis was: 60 °C for 2 min; ramping at 20 °C/min to 154 °C for 17 min; and a 5-min purge at 210 °C. Recovery rates for E8,E10-12:OH averaged 97 – 102%. The isomeric purity of dispensers was confirmed with a GC- mass spectrometer (Hewlett-Packard model 5970 GC coupled with a HP 5970 mass detector).

The attractiveness of the field-aged septa (0, 7, 14, 21, 28, 35 and 42 d) was evaluated in a commercial apple orchard in July 1996 treated with 1,000 polyethylene dispensers (Isomate-C+, Pacific Biocontrol, Vancouver, WA) per ha. Polyethylene dispensers were loaded with 182.0 mg of a three-component sex pheromone for codling moth (60:34:6 blend of E8, E10-12:OH: dodecanol: tetradecanol). Treatments were arranged in a complete randomized block design. On each date (17, 24 and 31 July and 7 and 14 August) one replicate of each lure type and age was tested. Traps were hung on trees at a height of 3.0 m and spaced 30 m apart.

Unsexed sterile moths were obtained from the codling moth mass-rearing SIR facility in Osoyoos, British Columbia. Moths were sterilized with gamma radiation (33 krad) from a $Cobalt^{60}$ source (dose rate of 1,150-1,320 rad/min) and held at 0 to 2 °C before field release. The sterilized moths had been marked with a red internal dye during larval mass-rearing. Three hundred sterilized codling moths were released around each trap at the beginning of each test by tapping chilled moths out of petri plates onto both the foliage of trees and on the ground within 10 m of each trap. Traps were checked after six nights and only counts of sterilized moths were recorded. Treatments were re-randomized prior to the start of the next replicate.

Optimizing the attractiveness of gray septa. Studies were conducted to evaluate the optimal loading rate of gray halo-butyl septa for use in sex pheromone-treated orchards. Gray septa were loaded with varying rates of E8, E10-12:OH (4.0, 10.0, 20.0, and 50.0 mg) by Trécé Inc. (Salinas, CA) personnel using a proprietary technique. Lures were placed in specialized wire hangers and field-aged within an apple orchard situated near Fresno, CA on

12 April 1998. Five lures of each loading rate were collected weekly for 16 wk and kept at –15.0 °C. Field trials to evaluate the attractiveness of these lures were conducted in an apple orchard in Moxee, WA beginning on 19 August and continuing for five wk. One replicate of each lure loading and age was placed in a Pherocon IC trap in a completely randomized 30 x 30 m grid and hung at 3.0 m in the canopy. Each week 300 sterilized moths were released within 20 m of each trap. Traps were checked after six nights and treatments were re-randomized.

Seasonal comparison of commercial lures. The two proprietary high-load gray septa, CM Megalure™ and the conventional-load CM L^{2TM}, and the standard CM 10X red rubber septa (Trécé Inc., Salinas, CA) were field tested in an apple orchard treated with 1,000 Isomate C+ dispensers per ha from 18 May to 17 August 1999 near Moxee, WA. Lures were placed in Pherocon VI delta traps and eight replicates of each lure type were evaluated in a completely randomized 20 x 20 m grid. Moths were collected and counted, trap liners were replaced, and traps were rotated one position each week. All three septa types were replaced on 6 July. Additionally, the10X septa were replaced on 8 June and 26 July.

Statistical analyses. Linear regression analysis was used to fit the emission rate and changes in the % *E,E* isomer as a log decay curve with days aged in the field (Analytical Software 2000). The effects of field aging and dispenser type on moth catch were tested with analysis of variance (ANOVA). Moth count data were transformed (square root [x + 0.05]) to remove heterogeneity of variances before analysis. Means were separated in significant ANOVAs with Fisher's LSD. Differences in emission rate and isomeric purity on specific ages for different dispensers were evaluated with Student t-tests. Linear regression of moth catch on emission rate and % *E,E* isomer were also conducted. The effect of dispenser age and their initial loading rate for gray septa were evaluated with ANOVA. Specific comparisons were made for 4.0,10.0, and 20.0 mg loads. These data were subsequently grouped and compared with moth catch by 50.0 mg lures. The attractiveness of three proprietary lures was evaluated during the season using ANOVA both on individual dates and for each moth generation.

RESULTS

Emission characteristics. The emission rate from new red rubber septa was nearly five-fold higher than from new gray halo-butyl dispensers (Fig. 1a). The emission rate for each dispenser fit a log decay curve with number of days aged in the field; gray lure: $t = -4.9$, df = 26, $P < 0.001$); and red lure: $t = -8.5$, df = 26, $P < 0.001$. Red septa retained a significantly higher emission rate than gray septa for dispensers aged up to 21 d in the field (t values > 3.45, df = 7, $P < 0.05$). The emission rate for the two dispensers aged from 28-42 d were not significantly different ($P > 0.05$).

The isomeric purity of codlemone loaded in new dispensers was > 96% in both septa types (Fig. 1b). The percentage of the *E,E* isomer remained unchanged in gray septa aged in the field, $t = -1.2$, df = 26, $P = 0.24$. In comparison, the percentage of the *E,E* isomer declined over time in the red septa, $t = -4.6$, df = 26, $P < 0.001$. The combined percentage of the *E,Z* and *Z,E* isomers increased to nearly 20% after 2 wk and 30% after 4 wk.

Field aging (0 – 42 d) of lures was not a significant factor affecting lure attractiveness ($F = 1.47$; df = 6, 56; $P = 0.21$) (Table 1). However, significant differences in the attractiveness of the two lures were found ($F = 9.90$; df = 1, 56; $P = 0.003$). No significant interaction between lure type and age was detected ($P = 0.43$). Gray septa were significantly more attractive than red septa for lures aged for 14 and 42 d (Table 1). Fourteen day-old red lures had nearly three times the emission rate of gray lures (0.22 vs. 0.07 mg/d) ($t = -4.86$, df = 5, $P = 0.003$), and a significantly lower isomeric purity (82.1 vs. 96.2% *E,E* isomer) ($t = 3.47$, df = 5, $P = 0.03$). The emission rates of 42 d-old red and gray lures were low (0.1 mg/d) and

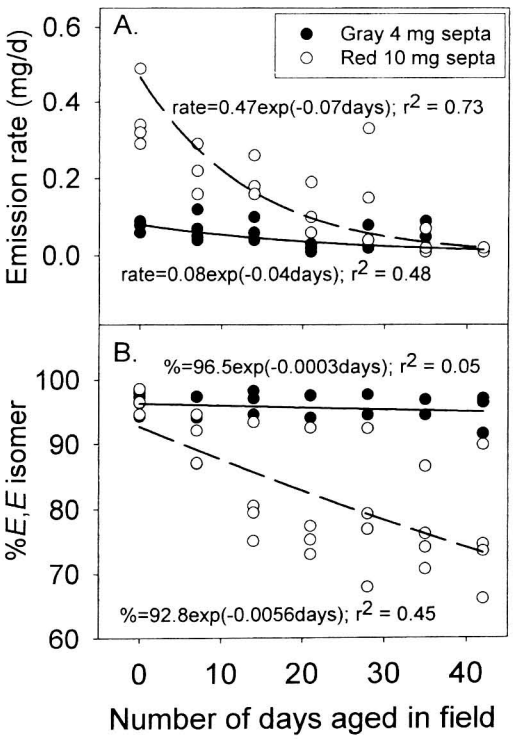

Figure 1. Emission rate (**A**) and percentage of the *E,E* isomer (**B**) from field-aged gray halo-butyl elastomer and red rubber septa loaded with 4.0 and 10.0 mg codlemone, respectively. Some data points overlap, n = 4 per date.

Table 1

Attractiveness of field-aged gray halo-butyl elastomer and red rubber septa loaded with codlemone tested during July 1996.

Days aged in the field prior to test	Mean no. (SE) moths per trap		Statistical analysis	
	Red septa	Gray septa	t-value	P-value
0	6.4 (2.1)	5.8 (2.6)	-0.05	0.96
7	8.2 (3.6)	11.6 (3.5)	0.83	0.43
14	1.6 (0.6)	11.6 (3.8)	2.93	0.02
21	3.0 (1.0)	7.4 (3.4)	0.60	0.56
28	1.0 (0.3)	8.2 (2.5)	2.21	0.05
35	2.6 (1.2)	5.2 (2.2)	0.42	0.68
42	2.2 (0.5)	7.0 (1.8)	2.39	0.04

Red rubber septa and gray halo-butyl elastomer septa were loaded with 10.0 and 4.0 mg codlemone, respectively.

did not differ between lure types (t = -0.28, df = 6, P = 0.79), but the percentage of the *E,E* isomer was again significantly different (76.0 vs. 94.2% for the red and gray lures, respectively, t = 3.48, df = 5, P = 0.03).

The mean number of moths caught per trap with either lure was not linearly correlated to emission rate (gray: t = -0.22, r^2 = 0.01, df = 5, P = 0.83; red: t = 1.49, r^2 = 0.31, df = 5, P =0.20) (Fig. 2a). A significant difference in moth catch was found between lure types when

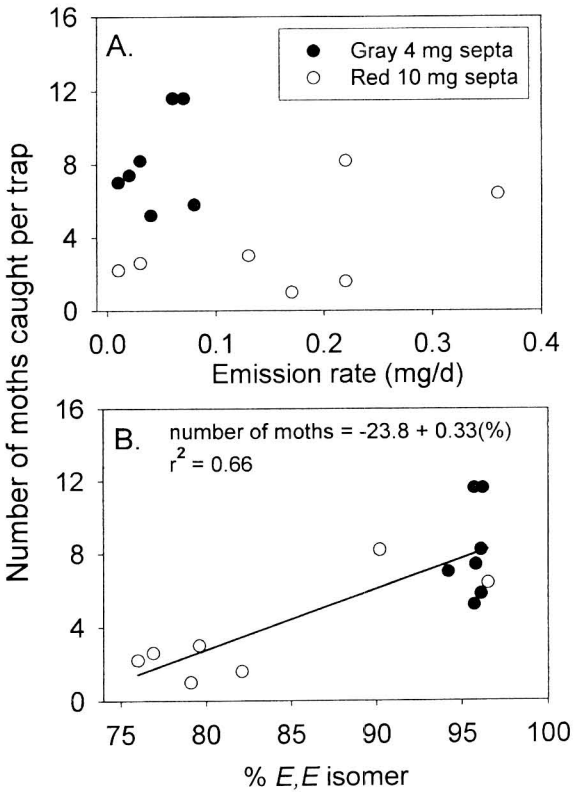

Figure 2. Number of moths caught per trap as a function of emission rate (**A**) and percentage *E,E* isomer (**B**) in gray halo-butyl elastomer and red rubber septa loaded with 4.0 and 10.0 mg codlemone, respectively.

the data were pooled across similar emission rates (gray septa 0.01 – 0.08 mg/d and red septa 0.01 – 0.13 mg/d), $t = 4.52$, df = 8, $P = 0.004$. Within this lure emission range, moth catch in traps baited with gray versus red septa was more than three-fold higher (Fig. 2a).

A significant linear relationship was found between mean moth catch and the percent *E,E* isomer for red septa, $t = 3.23$, df = 5, $r^2 = 0.68$, $P = 0.02$. No similar relationship was found for moth catch and percent *E,E* isomer for gray septa, $t = -1.18$, df = 5, $r^2 = 0.22$, $P = 0.29$. Combining the data for both lures generated a significant relationship between moth catch (y) and the percent *E,E* isomer (x): $y = -23.8 + 0.33x$, $t = 3.76$, df = 12, $r^2 = 0.66$, $P = 0.0003$. These data fall into two distinct groups based on the percentage of *E,E* isomer (Fig 2b). Lures containing > 90% *E,E* isomer caught on average four-fold more moths than lures emitting < 85% *E,E* isomer, $t = 5.69$, df = 12, $P = 0.001$.

Optimizing the Loading Rate of Gray Halo-butyl Septa. Dispenser age ($F = 5.03$; df = 7, 128; $P < 0.0001$) and pheromone loading ($F = 8.69$; df = 3, 128; $P < 0.0001$) of gray septa were both significant factors affecting moth catch (Table 2). The interaction between lure age and pheromone load was not significant ($P = 0.87$). A significant curvilinear decline in moth catch with lure age was detected with the nontransformed data, $F = 4.72$,; df = 1, 128 ; $P = 0.03$. Moth catch among the 4.0, 10.0 and 20.0 mg loads was not significantly different ($F = 0.17$; df = 2, 128; $P = 0.85$). Moth catch with the 50.0 mg lure was significantly different from the other three lure loads ($F = 25.75$; df = 1, 128, $P < 0.0001$) and declined linearly with age ($t = -2.71$, df = 37; $P = 0.01$). Moth catch by 50 mg lures aged for 2 wk was significantly greater than with older lures and a curvilinear relationship was suggested ($t = 1.96$, df = 37;

$P = 0.57$). Mean moth catch by gray lures loaded with 4.0 – 20.0 mg codlemone aged up to 10 wk did not differ significantly from moth catch by new 10X red rubber septa (Table 2; see means lacking asterisks). In comparison, moth catch by aged 50.0 mg gray septa did not differ from 10X red septa over the 16 wk.

Seasonal comparison of lures. The attractiveness of the two proprietary grey septa lures, CM Megalure™ and CM L²™, and the CM 10X red rubber septa did not differ until the third wk of the study (Table 3). During the third wk, moth catch was significantly higher in traps baited with the Megalure™, and the L²™ lure caught more moths than the 10X lure. The 10X lure was replaced on 8 June and no difference in the attractiveness of lures was found the following week (17 June) (Table 3). Mean moth catches in traps baited with the 10X lure were >75% lower than in traps baited with the Megalure™ for wk two and three (23 and 29 June) though not significantly different (P values = 0.07-0.08). After three wk the 10X lure caught significantly fewer moths than the Megalure™. All lures were replaced on 6 July and moth catch was again significantly lower in traps baited with the 10X vs. the Megalure™ after two wk (19 July). The 10X lure was replaced on 26 July and caught significantly fewer moths than the Megalure™ after two wk (10 August). The L²™ lure caught an intermediate number of moths in comparison with the other two lures throughout the season (Table 3).

Table 2

Comparison of mean (SE) captures of codling moth in sticky traps baited with halo-butyl gray septa loaded with varying amounts of codlemone in a sex pheromone-treated apple orchard in Moxee, WA.

	Pheromone Load (mg)			
Lure age (wk)	4.0	10.0	20.0	50.0
2	21.2 (12.7)	12.2 (4.7)	12.2 (8.0)	32.4 (7.1)
4	7.6 (2.1)	10.6 (6.0)	8.8 (3.7)	15.8 (6.3)
6	6.0 (1.6)	9.6 (3.3)	5.6 (2.5)	14.8 (2.2)
8	5.6 (3.7)	4.0 (1.9)	7.4 (3.2)	13.2 (4.0)
10	5.0 (1.4)	8.2 (2.0)	6.4 (4.2)	11.6 (5.5)
12	1.0* (0.3)	2.8* (1.2)	3.6* (2.4)	9.2 (4.2)
14	1.6* (0.8)	5.8 (2.0)	3.6* (1.0)	7.6 (3.2)
16	1.8* (0.8)	2.0* (0.7)	0.6* (0.4)	9.2 (4.8)

Mean catches followed by '*' were significantly different (t-test, df = 8, $P < 0.05$) from the mean (SE) catch with new, red rubber septa loaded with 10.0 mg E8,E10-12:OH, 20.2 (6.6) moths per trap.

DISCUSSION

The chemical instability of conjugated dienes, such as codlemone in sulphur-cured red rubber septa is well known (Brown and McDonough 1986, Ideses and Shani 1988, Vrkoč *et al.* 1988). Yet, despite this general knowledge, a red rubber septum has been the standard lure used to monitor codling moth for nearly 30 yr (Riedl *et al.* 1986). More recently, the use of a 10.0 mg red septa for monitoring codling moth in orchards treated with sex pheromone dispensers has been widely reported in North America (Knight 1995a, Judd *et al.* 1996, Gut and Brunner 1998) and Europe (Charmillot 1990). Gut and Brunner (1995) found that these high-load lures require frequent replacement and presumed this was caused by a rapid drop in their emission rates under sustained warm summer weather. Our data suggest that the 10X septa are attractive for 1- 2 wk; however, their rapid loss in attractiveness appears to be due to the degradation of codlemone and not to a reduction in their emission rate. Similar results emphasizing the importance of the chemical instability of conjugated dienes in rubber

Table 3

Seasonal comparison of three commercial lures (n = 8) rotated weekly within a 12 ha apple orchard treated with 1,000 Isomate C+ dispensers per ha.

Date traps checked	Mean catch (SE) Red septa 10X	Gray septa MegaLure™	Gray septa L²™	Statistical analysis $F_{2,21}$	P value
25 May	1.63 (0.68)	2.88 (0.95)	1.88 (0.58)	0.59	0.56
01 June	0.13 (0.13)	0.63 (0.18)	0.50 (0.27)	1.85	0.18
08 June	0.00* (0.00)a	2.25 (0.67)c	0.88 (0.23)b	11.00	<0.001
17 June	1.00 (0.33)	1.88 (0.40)	0.88 (0.64)	2.08	0.15
23 June	0.50 (0.27)	2.13 (0.67)	0.75 (0.49)	2.94	0.08
29 June	0.13 (0.13)	1.00 (0.38)	0.50 (0.19)	2.98	0.07
06 July	0.13* (0.13)a	1.25* (0.41)b	0.25* (0.16)a	4.95	0.02
Total 1st flight	**3.52 (0.82)a**	**12.02 (1.30)b**	**5.64 (1.03)a**	**12.81**	**<0.001**
12 July	1.75 (0.75)	1.63 (0.57)	3.00 (0.89)	0.98	0.39
19 July	0.00 (0.00)a	1.63 (073)b	0.38 (0.18)ab	4.69	0.02
26 July	0.13* (0.13)a	4.25 (1.26)b	4.38 (1.84)b	6.02	0.01
03 August	3.25 (0.98)	4.50 (1.69)	5.00 (0.89)	0.60	0.56
10 August	3.13 (1.48)a	16.13 (3.89)b	6.75 (1.51)a	8.74	0.002
17 August	2.38 (1.69)a	10.75 (2.74)b	7.00 (3.70)ab	3.45	0.05
Total 2nd flight	**10.64 (2.52)a**	**38.89 (6.17)c**	**26.51 (4.85)b**	**4.18**	**0.03**

Traps were placed in the orchard on 5 May in a completely randomized 20 x 20 m grid. Traps were moved one position within the grid each week. Lures of each type were replaced on dates designated with a '*'. Data were transformed (sqrt(x+0.5) and subjected to ANOVA. Weekly means followed by a different letter were significantly different, $P < 0.05$, Fishers LSD.

substrates were found with red rubber septa loaded with (*E,E*)-8,10-dodecadien-1-yl acetate, the sex pheromone for the pea moth, *Cydia nigricana* (F.) (Horák *et al.* 1989).

The inhibitory effects of the isomeric blend of 8,10-dodecadien-1-ol on the attraction of codling moth was first shown by Roelofs *et al.* (1972) and later by McDonough *et al.* (1993). El-Sayd *et al.* (1998) demonstrated that this inhibitory effect was due to the presence of the *E,Z* isomer. McDonough *et al.* (1993) suggested that this reduction in attractiveness would be amplified in the high load lures used to monitor sex pheromone-treated orchards unless codlemone was stabilized. Isomerization of codlemone can be minimized by adding antioxidant or antiultraviolet components (Millar 1995) or by avoiding substrates containing sulphur (Brown and McDonough 1986). Horák *et al.* (1989) increase the longevity of lures for pea moth by using rubber substrates cured with organic peroxides instead of sulphur. Brown and McDonough (1986) found that isomerization of codlemone in gray halo-butyl elastomer septa was 4.7-fold slower than in red rubber septa. The gray halo-butyl septa appears to be a more effective lure than the red rubber septa for monitoring codling moth in sex pheromone-treated orchards due to this reduced rate of isomerization of codlemone.

The optimal loading rate of gray septa to monitor codling moth is difficult to determine from these studies. Moth catch as a function of lure age was curvilinear across the range of sex pheromone loads tested, with the highest moth counts for each pheromone load being found in traps baited with two-wk-old lures. Gray septa loaded with 4.0 – 50.0 mg codlemone all effectively monitored codling moth for at least 10 wk. The 50 mg lure caught significantly more moths than the other three lures, and its attractiveness most closely matched the mean moth catch by new 10X red septa over a 10 wk period. Residual studies of septa aged at 24 °C in the laboratory demonstrated that the half-life of codlemone in gray septa is 2.6-fold longer than in red septa (unpublished data). The emission rate of alcohol sex pheromones from

rubber septa has been shown to be proportional to the amount of pheromone present, i.e., first-order process (Butler and McDonough 1981). Therefore, one can estimate that the emission rates from gray septa loaded with 26 mg and a red septa loaded 10 mg codlemone should be roughly equivalent.

Replacing the standard red rubber septa with the gray halo-butyl lure appears to be a promising alternative for monitoring codling moth in sex pheromone-treated orchards. However, this switch may require some changes in the established action thresholds for supplemental insecticide sprays during both generations. Current recommendations provide a narrow range (2.5-fold) of cumulative moth catch to trigger the need for supplemental sprays (Gut and Brunner 1996). In comparison, cumulative catches of codling moth by the Megalure™ were more than three-fold higher than with the 10X red lure during both moth flights despite frequent lure replacements of the red septa (Table 3). Development of a codling moth lure that can minimize the occurrence of 'false negatives' (absence of moth catch despite the occurrence of fruit injury) is likely more important than having to change the catch threshold for applying supplemental controls. Previous studies have examined the effects of trap placement (Knight 1995b) and the proximity of the monitoring trap to the sex pheromone dispenser on lure performance (Knight *et al.* 1999). Optimizing the use of the gray septa to provide long-lasting effective monitoring in sex pheromone-treated orchards may require further refinements. Alternatively, development and testing of new lure substrates and attractants could further minimize the risks associated with the use of sex pheromones to manage codling moth.

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