**FINAL PROJECT REPORT**

**Project Title:** New attractants for monitoring, MD, and mass trapping of codling moth


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**Total Project Request:** **Year 1:** $53,000 **Year 2:** $56,000

**Other funding sources:** California Pear Research Commission **Awarded Amount:** **$10,000**

**Notes:** Trécé Inc. provided the lures used in the project *gratis* (value estimated at $30,000).

**Total Project Funding**: $70,000

**Budget History:**

| Item | Year 1: 2019 | Year 2: 2020 |
|---|---|---|
| **Salaries** | - | 19,500 |
| **Wages** | - | 6,500 |
| **Equipment** | - | - |
| **Supplies** | - | 15,500 |
| **Travel** | $-18,000 | 10,500 |
| **Total** | $18,000 | $52,000 |

Funds ($35,000) approved for Dr. Knight in 2019 were withdrawn by the Commission and only funds for travel of the three co-PIs were paid. Funds in 2020 were paid in full to Drs. Knight, Basoalto and Preti ($6,500 each for supplies), and $4,000 was returned by Dr. Mujica.

**Objectives:**

1. Evaluate the effectiveness of a new commercial non-pheromone lure (MegaLure 4K) comprised of pear ester, nonatriene, linalool oxide and acetic acid in apple and pear orchards.
2. Evaluate 19 other plant volatile blends compared with the 4K blend.
3. Evaluate the use of the 4K lure to establish codling moth Biofix.
4. Evaluate the addition of attractive plant volatiles to improve mating disruption.
5. Evaluate the use of female removal with the 4K lure to manage codling moth in apple and pear.

**Significant Findings:**

- A new more attractive blend for male and female codling moth consisting of plant and microbial volatiles was discovered and commercialized as the MegaLure 4K.
- Field trials showed that the 4K lure catches ca. 3-fold more females than any previous lure.
- The new PVC Combo lure used with acetic acid was much more effective than the previous septum lure used by the Industry for the past 15 years.
- The addition of sex pheromone to the 4K lure (5K) increased males but decreased female catches.
- All of the new PVC lures were effective for at least 8 weeks.
- The 4K lure outperformed the standard Combo septum lure when traps were placed at head height, and catches were greater if the trap was placed higher in the canopy.
- Establishing a Biofix to predict egg hatch with either Combo-P with acetic acid or 4K lures and with either total moth or female counts were equally effective.
- Adding acetic acid co-dispensers next to MD dispensers loaded with sex pheromone, pear ester, and one of two plant volatiles increased moth catches within replicated plots. No difference in levels of fruit injury occurred at mid-season.
- Several plant volatiles were found to decrease moth catches when added to the pear ester, nonatriene, and acetic acid lure set. These were associated with rosy apple aphid feeding, i.e., one orchard in 2019 with extremely high levels of RAA damage had an unexplained lack of codling moth injury and a record high level of virgin codling moth females trapped.
- Four volatiles were found to be effective as substitutes for linalool oxide in the four-component blend. Further studies are ongoing in Chile and planned for 2021 to develop alternative blends.
- The most effective trap for female codling moth with the new PVC Combo-P + AA lure set was a bucket trap with a green top and clear bottom. Orange delta traps outperformed the clear and green bucket traps. Standardization of how to use milk jug traps needs more work.
- Small, inexpensive solar-powered UV lights added to traps significantly increased catches of codling moth, oriental fruit moth, eye-spotted budmoth, and oblique banded leafroller including increase in females from 2-10-fold.
- Adding the UV light to delta traps baited with the OFM Dual lure significantly increased both OFM and CM catch and may allow the trap to be used for both species.
- 25 and 16 paired studies were conducted in apple and pear, respectively; to evaluate the effectiveness of a female removal strategy during 2019-20.
- Levels of codling moth injury were reduced on average by 56% with the use of 24 traps per acre across these 41 studies. Levels of injury reductions were similar in apple and pear.
- Female removal works best in combination with mating disruption because a higher proportion of unmated females are trapped.
- Trap density can be increased to at least 40 per acre without trap competition. Recommendations for 2021 using the Combo-P+AA lure are 50 traps per acre.
- Traps (50 per acre) baited with the 4K lure were placed in the 1.6-acre corner of a conventional orchard next to a bin pile stacked in August removed 1,770 females, and only a few injured fruits occurred on the row bordering the bins.

**Results:** Traps captured large numbers of codling moth during the lure evaluation trial in 2019 (Table 1). All three PVC lures outperformed the standard Combo-septum lure. The 4K and 5K lures captured significantly more females than either combo lures. The addition of PH in the multi-component PVC lure significantly reduced the capture of females

**Table 1.** Mean (± SEM**)** cumulative captures of codling moth from 4 May to 22 July 2019 in orange delta traps baited with combinations of sex pheromone and pear ester (Combo lures in either the standard grey septa or a new PVC matrix) and two new PVC lures loaded with pear ester, nonatriene, and linalool oxide (4K) or with this plus sex pheromone (5K), N = 8.

| | Mean (± SEM) moth capture per trap | |
|---|---|---|
| Lure | Total | Females |
| Combo – septum + AA | 94.6 ± 9.5 a | 39.1 ± 4.4 a |
| Combo – PVC + AA | 281.0 ± 19.9 b | 52.0 ± 5.2 a |
| 4K – PVC + AA | 244.3 ± 17.8 b | 136.6 ± 9.2 c |
| 5K – PVC + AA | 233.6 ± 16.3 b | 80.1 ± 4.8 b |
| ANOVA: df = 3, 28 | $F$ = 42.40, P < 0.001 | $F$ = 39.15, P < 0.001 |

The new 4K lure was significantly more attractive than the standard Combo septa lure over the course of the season in 10 pear orchards monitored in California during 2020 (Table 2). However, it was not more effective than the use of the Combo-P lure with the AA co-lure added in a 6-week pear trial in the Delta region. Both data sets showed that placing traps higher in the canopy is advantageous, but overall, the non-pheromone 4K lure can be used at head height instead of the standard use of the Combo lure placed high to monitor codling moth. Similar supporting datasets were generated in 2019 in Oregon and Washington but are not shown due to space limitations (see previous report).

**Table 2.** The influence of trap height on the capture of codling moth with either MegaLure 4K or the Combo-S or Combo-P +AA lure set in Bartlett pear, California, 2020.

| Lake County and other Areas 6 April – 21 Sept Mean (SE) catch | | Sacramento-Delta Region 9 April – 16 May Mean (SE) catch | | |
|---|---|---|---|---|
| Lure/height | Total | Lure/height | Females | Total |
| Combo – low, 6’ | 2.3 (1.5)b | Combo-P+AA – low 6’ | 11.0 (4.4) | 30.0 (6.5) |
| Combo – high 13.5’ | 6.7 (4.1)b | Combo-P+AA – high 10’ | 15.5 (4.3) | 44.8 96.6) |
| 4K – low 6’ | 9.5 (4.0)ab | 4K – low 6’ | 17.0 (3.1) | 27.0 (2.0) |
| 4K – high, 13.5’ | 37.7 (17.0)a | 4K high, 10’ | 22.5 (6.0) | 38.3 (8.3) |
| ANOVA | $F_{3, 36}$ = 7.37 | ANOVA | $F_{3, 36}$ = 1.07 | $F_{3, 36}$ = 1.63 |
| | $P$ = 0.0006 | | $P$ = 0.40 | $P$ = 0.23 |

Canopies averaged 14-16’ in the two studies.

The green/clear bucket trap caught significantly more total moths than the other two bucket traps and similar numbers to the orange delta (Table 3). However, the green/clear bucket caught significantly more females than any other trap. Interestingly, the proportion of females was similar among traps baited with the 4K lure, but both the clear and the green/clear bucket outperformed the orange delta and all-green bucket when baited with the Combo-P+AA lure set. During 2019 the milk jug trap outperformed all of these traps over a short trial period with extremely high moth catch, i.e., 500 moths per trap. However, in 2020 the milk jug traps in the first half of the season did not work well as the liquid often spilled and lure placement and potential degradation of the lures became an issue. Thus, milk jugs were not included in the 2020 trap study.

A core goal of our research developing new, more attractive blends for codling moth over the past 20 years has been to increase catches of females. Female-based monitoring has been shown to provide a more direct prediction of key life history events, *i.e.*, egg hatch and to establish action thresholds used to trigger supplemental insecticide sprays. The higher female moth catches with the 4K increases this opportunity. Studies found that the use of the 4K versus the Combo septum increased the ability to set a Biofix. However, the use of the new Combo-P with an acetic acid co-lure also allowed a Biofix to be set. No improvement was found in predicting egg hatch with these two lures using either sustained male or female catches during 2020.

**Table 3.** Comparison of codling moth catches in four trap types baited with either Combo-P or the 4K lure in apple, Washington 2020.

| Trap | # traps | Lure | Mean (SE) catch per trap [a] Males | Females | Total | Proportion females [b] |
|---|---|---|---|---|---|---|
| Orange delta | 64 | 4K | 3.5 (0.4)Ab | 3.9 (0.3)Ba | 7.3 (0.6)Ab | 0.53a |
| | 47 | Combo-P | 14.0 (1.3)Aa | 1.6 (0.2)Bb | 15.6 (1.4)Aa | 0.10c |
| Clear bucket | 51 | 4K | 1.6 (0.2)Bc | 3.2 (0.4)Ba | 4.9 (0.6)Bb | 0.65a |
| | 35 | Combo-P | 6.5 (1.5)Bb | 3.7 (0.8)Bb | 10.2 (2.4)Ba | 0.36b |
| Green bucket | 7 | 4K | 0.9 (0.3)Bbc | 1.7 (0.5)Ca | 2.6 (0.6)Bb | 0.65a |
| | 15 | Combo-P | 3.7 (1.2)Bbc | 0.6 (0.3)Cb | 4.3 (1.5)Ba | 0.14c |
| Green top/ clear bucket | 25 | 4K | 3.2 (0.6)Abc | 6.9 (1.4)Aa | 10.1 (1.9)Ab | 0.68a |
| | 14 | Combo-P | 10.0 (1.4)Aa | 5.2 (1.0)Ab | 15.2 (2.3)Aa | 0.34b |
| ANOVA: | Trap: df = 3, 250 | | $P < 0.0001$ | $P < 0.0001$ | $P < 0.0001$ | |
| | Lure: df = 1, 250 | | $P < 0.0001$ | $P < 0.001$ | $P < 0.001$ | |
| | Trap*Lure: df = 3, 250 | | $P < 0.05$ | $P = 0.06$ | $P = 0.26$ | |

The greatly improved attraction of the 4K lure for female codling moth now provides an opportunity to develop more effective 'lure and kill' strategies to manage populations. However, concerns about lure performance over extended periods, chemical stability, cost of active materials, and potential registration difficulties suggested that additional volatiles should be evaluated in combination with pear ester, acetic acid, and nonatriene.

Studies examined whether one or more host plant volatiles could be substituted for linalool oxide in the 4K blend to increase moth catches. Nineteen pome fruit and walnut volatiles were evaluated in a series of field studies in apple. The volatiles are not identified prior to the acceptance of the manuscript for publication due to the wishes of several coauthors. Several compounds were found to significantly lower total or female catches when added to the 3K blend (Table 4). These data suggested that the anomalous results obtained in an apple block heavily impacted by RAA (several of these compounds known to be released by aphid feeding) could account for the observed lack of fruit injury and record high levels of virgin females despite high codling moth pressure which unexpectedly occurred. Other substituted compounds did not increase moth catches (Table 5), and a few added compounds were found to provide a good substitute for linalool oxide in the 4K blend (Table 6). However, no volatile substitution improved the performance of the 4K blend. Our interesting results suggest that further evaluations of more complex blends and variable component ratios and emission rates should be conducted.

**Table 4** Summary of mean (+ SEM) of adult *Cydia pomonella* caught in orange delta traps baited with a ternary combination of pear ester, (*E*)-4,8-dimethyl-1,3,7-nonatriene, and acetic acid and quaternary bends with various volatiles, N = 8 lure replicates.

| Trial | | Mean ± SEM moth catch per trap | | |
|---|---|---|---|---|
| # | Volatile added | Females | Males | Total |
| 1 | - | 9.6 ± 2.5 ab | 2.0 ± 0.4 ab | 11.6 ± 2.7 ab |
| | 1 | 1.8 ± 0.5 c | 1.0 ± 0.4 b | 2.8 ± 0.8 c |
| | 2 | 1.3 ± 0.6 c | 1.1 ± 0.5 b | 2.4 ± 0.8 c |
| | 3 | 2.8 ± 0.8 c | 1.9 ± 0.4 ab | 4.6 ± 0.9 bc |
| | 4 | 4.0 ± 0.9 bc | 2.3 ± 1.0 ab | 6.3 ± 1.7 bc |
| | 5 | 1.3 ± 0.5 c | 0.9 ± 0.4 b | 2.1 ± 0.8 c |
| | 6 | 2.5 ± 1.1 c | 2.6 ± 1.0 ab | 5.1 ± 1.8 bc |
| | Linalool oxide (4K) | 14.1 ± 2.6 a | 5.0 ± 1.4 a | 19.1 ± 3.8 a |
| | ANOVA, df = 7, 56 | $F = 11.10$, $P < 0.0001$ | $F = 2.87$, $P = 0.012$ | $F = 8.21$, $P < 0.001$ |

**Table 5** Summary of mean (+ SEM) of adult *Cydia pomonella* caught in orange delta traps baited with a ternary combination of pear ester, (*E*)-4,8-dimethyl-1,3,7-nonatriene, and acetic acid and quaternary bends with the addition of a fourth volatile, N = 8-10 lure replicates.

| Trial | | Mean ± SEM moth catch per trap | | |
|---|---|---|---|---|
| # | Volatile added | Females | Males | Total |
| 2 | - | 4.6 ± 0.6 a | 2.0 ± 0.3 a | 6.6 ± 0.8 a |
| | 7 | 4.9 ± 0.8 a | 2.8 ± 0.4 a | 7.7 ± 1.1 a |
| | Linalool oxide (4K) | 5.9 ± 0.9 a | 3.2 ± 0.5 a | 9.1 ± 1.2 a |
| | RCB ANOVA, df = 2, 85 | $F = 0.92$, $P = 0.401$ | $F = 2.18$, $P = 0.120$ | $F = 2.03$, $P = 0.138$ |
| 3 | - | 3.7 ± 0.7 a | 1.8 ± 0.3 a | 5.5 ± 0.9 a |
| | 8 | 5.3 ± 1.2 a | 2.7 ± 0.5 a | 8.0 ± 1.5 a |
| | Linalool oxide (4K) | 4.9 ± 0.9 a | 3.1 ± 0.6 a | 8.0 ± 1.4 a |
| | RCB ANOVA, df = 2, 57 | $F = 0.50$, $P = 0.601$ | $F = 1.45$, $P = 0.244$ | $F = 2.01$, $P = 0.143$ |
| 4 | - | 5.5 ± 0.8 b | 1.9 ± 0.4 a | 7.4 ± 1.0 b |
| | 9 | 5.2 ± 0.9 b | 3.6 ± 0.8 a | 8.8 ± 1.5 b |
| | Linalool oxide (4K) | 9.4 ± 1.1 a | 4.1 ± 0.8 a | 13.6 ± 1.5 a |
| | RCB ANOVA, df = 2, 50 | $F = 6.77$, $P = 0.003$ | $F = 2.04$, $P = 0.141$ | $F = 5.62$, $P = 0.006$ |
| 5 | - | 4.1 ± 1.2 b | 1.4 ± 0.3 a | 5.5 ± 1.2 b |
| | 10 | 6.3 ± 1.5 ab | 4.3 ± 1.1 a | 10.5 ± 2.0 ab |
| | 11 | 6.4 ± 1.6 ab | 3.8 ± 1.1 a | 10.1 ± 2.5 ab |
| | Linalool oxide (4K) | 10.9 ± 1.9 a | 3.5 ± 1.2 a | 14.4 ± 2.4 a |
| | ANOVA, df = 3, 28 | $F = 3.05$, $P = 0.045$ | $F = 1.53$, $P = 0.230$ | $F = 3.41$, $P = 0.031$ |
| 6 | - | 6.6 ± 0.9 a | 2.5 ± 0.8 ab | 9.1 ± 1.4 a |
| | 12 | 5.4 ± 1.2 a | 1.8 ± 0.5 ab | 7.1 ± 1.1 a |
| | 13 | 5.9 ± 2.4 a | 1.1 ± 0.4 b | 7.0 ± 2.4 a |
| | 14 | 8.4 ± 1.3 a | 2.6 ± 0.5 ab | 11.0 ± 1.5 a |
| | Linalool oxide | 8.9 ± 1.8 a | 3.5 ± 0.8 a | 12.4 ± 2.3 a |
| | ANOVA, df = 4, 35 | $F = 1.43$, $P = 0.245$ | $F = 2.71$, $P = 0.046$ | $F = 2.07$, $P = 0.106$ |

**Table 6** Summary of mean (+ SEM) of adult *Cydia pomonella* caught in orange delta traps baited with a ternary combination of pear ester, (*E*)-4,8-dimethyl-1,3,7-nonatriene, and acetic acid and quaternary bends with a fourth volatile added, N = 8-10 lure replicates, trials conducted on 2-4 dates.

| Trial | | Mean ± SEM moth catch per trap | | |
|---|---|---|---|---|
| # | Volatile added | Females | Males | Total |
| 7 | - | 4.8 ± 0.6 b | 1.8 ± 0.3 b | 6.6 ± 0.8 b |
| | 15 | 7.0 ± 0.8 ab | 4.7 ± 0.9 a | 11.7 ± 1.6 a |
| | Linalool oxide (4K) | 7.8 ± 0.9 a | 3.5 ± 0.6 ab | 11.2 ± 1.3 a |
| | RCB ANOVA, df = 2, 73 | $F$ = 4.42, $P$ = 0.015 | $F$ = 5.11, $P$ = 0.008 | $F$ = 6.58, $P$ = 0.002 |
| 8 | - | 5.5 ± 0.6 b | 2.2 ± 0.4 a | 7.7 ± 0.8 b |
| | 16 | 8.9 ± 1.0 a | 3.7 ± 0.6 a | 12.6 ± 1.5 a |
| | Linalool oxide (4K) | 7.2 ± 0.8 ab | 3.5 ± 0.5 a | 10.6 ± 1.2 ab |
| | RCB ANOVA, df = 2, 73 | $F$ = 4.83, $P$ = 0.011 | $F$ = 2.99, $P$ = 0.057 | $F$ = 4.83, $P$ = 0.011 |
| 9 | - | 3.7 ± 0.5 b | 1.6 ± 0.2 b | 5.3 ± 0.6 b |
| | 17 | 5.5 ± 0.8 a | 3.4 ± 0.6 a | 8.9 ± 1.2 a |
| | Linalool oxide (4K) | 5.9 ± 0.8 a | 2.9 ± 0.5 ab | 8.9 ± 1.1 a |
| | RCB ANOVA, df = 2, 111 | $F$ = 3.25, $P$ = 0.042 | $F$ = 3.25, $P$ = 0.042 | $F$ = 5.24, $P$ = 0.007 |
| 10 | - | 3.8 ± 0.6 b | 1.7 ± 0.3 a | 5.5 ± 0.7 b |
| | 18 | 6.8 ± 1.1 a | 2.8 ± 0.5 a | 9.6 ± 1.4 a |
| | Linalool oxide (4K) | 6.5 ± 1.0 a | 3.2 ± 0.6 a | 9.7 ± 1.3 a |
| | RCB ANOVA, df = 2, 83 | $F$ = 4.38, $P$ = 0.016 | $F$ = 2.23, $P$ = 0.114 | $F$ = 5.73, $P$ = 0.005 |
| 11 | - | 6.6 ± 0.7 a | 2.4 ± 0.5 b | 9.1 ± 0.9 a |
| | 19 | 8.8 ± 1.3 a | 5.1 ± 0.8 a | 13.9 ± 1.8 a |
| | Linalool oxide (4K) | 8.6 ± 1.0 a | 4.1 ± 0.7 ab | 12.7 ± 1.5 a |
| | RCB ANOVA, df = 2, 50 | $F$ = 1.09, $P$ = 0.343 | $F$ = 4.34, $P$ = 0.018 | $F$ = 2.47, $P$ = 0.095 |

Another approach to increase the catch of female codling moths is to add an inexpensive solar-powered UV light to the trap. Lights were obtained directly from China as "Mosquito Zappers" for $4/unit. We tested three types of solar lights in 2020 with the bisexual lures I have developed for codling moth, oriental fruit moth, eye-spotted budmoth, and several leafroller species. The smaller light was discontinued due to poor reliability of the product. The addition of either of the two larger UV lights increased codling moth catch ca. 2-fold (Table 7). However, previous studies in Chile with UV lights on milk jugs increased catch 5-fold. New ongoing studies in Chile are comparing UV lights placed on several trap designs. Also, data is being developed on the reliability and longevity of these lights when used within orchard canopies.

**Table 7.** Comparison of codling moth catches in delta traps baited with 4K lure in traps with two different sizes of solar-powered UV lights added, Washington 2020.

| Light/ date | Lure | UV added | Males | Females | Total |
|---|---|---|---|---|---|
| Medium UV light | 4K | Yes, N = 25 | 10.6 (1.4)a | 10.0 (0.8)a | 20.6 (1.9)a |
| | | No, N = 47 | 7.4 (0.8)b | 6.8 (0.5)b | 14.2 (1.0)b |
| 7 July – 20 July | ANOVA df = 1, 70 | | $F$ = 6.06 | $F$ = 11.13 | $F$ = 12.68 |
| | | | $P$ < 0.05 | $P$ < 0.01 | $P$ < 0.001 |
| Large UV light | 4K | Yes, N = 27 | 23.1 (1.8) | 14.1 (1.2)a | 37.1 (2.5)a |
| | | No, N = 13 | 21.7 (3.3) | 8.7 (1.1)b | 29.4 (4.0)b |
| 7 July – 20 Aug. | ANOVA df = 1, 38 | | $F$ = 1.11 | $F$ = 7.57 | $F$ = 5.11 |
| | | | $P$ = 0.29 | $P$ < 0.01 | $P$ < 0.05 |

Interestingly, results were obtained in our 2020 studies with OFM in two apple orchards using the UV lights added to delta traps (Table 8). First, adding the UV light significantly increased male and female OFM catch, 2- and 3-fold, respectively. Second, we saw that delta traps with the UV light became effective (nearly 6-fold increase) in catching both sexes of CM (Table 8). These total counts were about half of what was caught in a single delta trap baited with the 4K lure for CM in each orchard, but the numbers of females caught were similar. It appears that the attraction of both CM sexes to the light partially overcomes any short-range repellency of the OFM sex pheromone blend normally has for codling moth. This result suggests that the OFM Dual lure could be used effectively to monitor both pests and supports the development of 'Smart traps' to remotely monitor both key pests.

**Table 8.** Comparison of moth catches in delta traps with or without a solar UV light attached in two apple orchards situated near Sunnyside, WA, baited with the OFM Combo lure from 15 July to 24 August 2020. N = 10

| Pest | Trap | Males | Females | Total |
|---|---|---|---|---|
| OFM | Solar UV | 114.1 (12.2)a | 33.3 (4.5)a | 147.4 (13.0)a |
| | No solar | 50.1 (4.7)b | 10.2 (0.7)b | 60.3 (5.1)b |
| ANOVA df = 1, 17 | | $F = 28.73$ | $F = 45.62$ | $F = 45.00$ |
| | | $P < 0.0001$ | $P < 0.0001$ | $P < 0.0001$ |
| CM | Solar UV | 13.2 (2.1)a | 15.3 (0.8)a | 28.5 (1.9)a |
| | No solar | 2.6 (0.5)b | 2.7 (0.8)b | 5.3 (1.2)b |
| ANOVA df = 1, 17 | | $F = 31.44$ | $F = 98.61$ | $F = 125.79$ |
| | | $P < 0.0001$ | $P < 0.0001$ | $P < 0.0001$ |

The major effort of this project was to evaluate the use of traps baited with these new lures to remove female codling moth and thus reduce levels of fruit injury. Studies were successful in both apple and pear in 2019 and 2020 in the USA and in 2020 in Italy (Tables 9, 10). Over 1,000 traps were deployed during both years. Levels of fruit injury reductions with the trap deployments averaged 56% over all studies and ranged up to 75%. Other factors, such as lure, trap, and duration of trials varied over the course of these studies. Dissections of codling moth during 2019 provided an interesting view of the importance of mating disruption (Table 11). Proportions of female codling moth that were mated was reduced with mating disruption by < 15%. Multiple matings by females was more strongly impacted by deploying mating disruption, in agreement with our previous studies. Data from 2020 are still being gathered from Drs. Mujica and Basoalto.

**Table 11.** Summary of the mating success of female codling moth collected from orchards either untreated or treated with sex pheromone dispensers or sex pheromone/pear ester dispensers, 2019.

| Treatment | Number of blocks | 1st generation Proportion Mated F | 1st generation Proportion Multiple-mated females | 2nd generation Proportion Mated F | 2nd generation Proportion Multiple-mated females |
|---|---|---|---|---|---|
| Untreated | 9 | 0.77 | 0.17 | 0.88 | 0.41 |
| Sex pheromone dispensers/aerosols | 7 | 0.58 | 0.03 | 0.73 | 0.12 |
| Sex pheromone / pear ester dispensers | 6 | 0.70 | 0.04 | 0.72 | 0.05 |

**Discussion:** Interesting developments occurred during 2020 beyond our variable levels of hibernation due to the virus. First, the MegaLure 4K was not allowed in organic orchards in 2020, but this appears to be unclear based on my own correspondence, and it should be available for at least monitoring in 2021. Meanwhile, studies are underway to develop more organic-friendly formulations with the same plant compounds but from natural sources. However, FMD-FR studies planned for 2021 are based on the use of the Combo-P+AA lure set in green/clear buckets. Second, during 2020 I learned that milk jugs can be used inappropriately and are not as effective as other traps when they are misused. One issue is the deterioration of the liquid due to excessive captures of nontargets (flies) that could repel moths. The problem may also be associated with the positioning of the lures near the 2" holes cut into the jug allowing direct exposure to UV light and higher wind velocity which might deplete the lures faster. A third idea for their poor performance in my studies is that having the AA lure placed near the sex pheromone containing lure (Combo-P) in these traps may generate codlemone acetate which is a known repellant. Previous studies suggesting that milk jugs were a cost-effective trap design were only conducted over 10-14 d and apparently, I was mistaken about their utility over longer periods of use. In WA, I switched all my jug traps to orange deltas in June. However, at least one pear grower used milk jugs with Combo-P+AA lures in 2020 to clean up a severe codling moth problem overwintering from 2019. She placed the lures directly under the cap of the jug, unlike what I typically did with lures hanging down near the holes in the trap.

Studies conducted in August in WA apple identified a bucket trap with a green top and a clear bottom as a much more effective trap than the all-clear or an all-green bucket trap in terms of both catch size and a much higher proportion of females trapped. This new result suggests that the Combo-P+AA lure could be used in organic orchards in 2021, but likely at a higher density (ca. 50/acre) using green/clear traps.

The use of female removal was shown to be an effective component of an integrated program to manage codling moth. Significant reductions in fruit injury were demonstrated with female removal in Italy, California, Oregon, and Washington. FR should be most effective if females can be removed before they mate or lay eggs. We found that FR removed a somewhat higher proportion of unmated female codling moth in orchards treated with mating disruption. During 2020 the addition of small solar-powered UV lights added to delta traps significantly increased female moth catches of codling moth and oriental fruit moth. Studies with these units are continuing in South America to develop more expertise with their reliability and effectiveness. Thus, it is likely that the Combo-P+AA lure can be used with the solar-powered UV lights to improve the effectiveness of MD-FR for codling moth. The lights also made the OFM Dual lure much more attractive for both oriental fruit moth and codling moth creating an opportunity to monitor both pests together with standard traps or with remote 'Smart traps'.

Growers are fully aware that MD does nothing to prevent mated females from entering an orchard and laying eggs. Thus, our current recommendation is to continue to use green/clear bucket traps along borders of orchards adjacent to unmanaged sources of codling moth and to reduce populations of female codling moth with clusters of traps placed within hot spots, such as borders, near bin piles, and any uphill edges of blocks with a history of pest injury. One of the most remarkable experiences of my 30-year career with CM management occurred in 2020 in a conventional apple block. I placed 80 orange delta traps at a high density (50/acre) baited with the 4K lure in the corner of this orchard next to where a bin pile was established in early August. Over the next 6 weeks we removed 1,800 females from this corner of the orchard, and only a few apples were damaged and only on the outside row at harvest. I have no explanation for where these moths came from except the bin pile, and I am amazed that the crop could be saved using MD/FR!

**Table 9** Summary of codling moth "female removal" field trials conducted during 2019.

| Year – trials<br>Crop / country | Treatments<br>1st / 2nd flight | # moths caught per trap | Prop. females | Prop. unmated females | Prop. fruit injury | # moths caught per trap | Prop. females | Prop. Unmated females | Prop fruit injury |
|---|---|---|---|---|---|---|---|---|---|
| 2019<br>N = 8 Apple orchard pairs USA | PH/PE+AA / 4K | 20.1 (3.1) | 0.25 (0.04) | 0.36 (0.05) | 0.019b (0.008) | 14.9 (4.9) | 0.50 (0.05) | 0.36 (0.06) | 0.024b (0.010) |
| | No traps | - | - | - | 0.031a (0.012) | - | - | - | 0.048a (0.013) |
| **Summary** | **502 traps** | **10,090 moths** | **3,362 females** | **Paired t-test $t_7$ = 6.85, $P$ = 0.0002** | | **7,480 moths** | **3,734 females** | **Paired t-test $t_7$ = 3.78, $P$ = 0.007** | |
| 2019<br>N = 8 Apple orchard pairs USA | PH/PE+AA / 5K | 19.4 (3.7) | 0.46 (0.08) | 0.31 (0.03) | 0.015b (0.006) | 13.3 (2.1) | 0.69 (0.08) | 0.18 (0.04) | 0.045b (0.023) |
| | No traps | - | - | - | 0.031a (0.010) | - | - | - | 0.086a (0.036) |
| **Summary** | **423 traps** | **8.206 moths** | **3,775 females** | **Paired t-test $t_7$ = 4.88, $P$ = 0.002** | | **5,626 moths** | **3,882 females** | **Paired t-test $t_7$ = 3.53, $P$ = 0.010** | |
| 2019<br>N = 5 Pear orchard pairs USA | PH/PE+AA / 5K | 7.2 (3.4) | 0.41 (0.08) | 0.32 (0.05) | 0.030b (0.019) | 4.5 (1.6) | 0.58 (0.08) | 0.09 (0.05) | 0.039b (0.020) |
| | No traps | - | - | - | 0.062a (0.040) | - | - | - | 0.111a (0.047) |
| **Summary** | **156 traps** | **1,123 moths** | **461 females** | **Paired t-test $t_4$ = - 3.37, $P$ = 0.028** | | **702 moths** | **407 females** | **Paired t-test $t_4$ = 2.80, $P$ = 0.049** | |

**Table 10.** Summary of codling moth 'female removal' field trials conducted during 2020

| Year – trials<br>Crop / country | Treatments<br>1st / 2nd flight | # moths caught per trap | Prop. females | Prop. unmated females | Prop. fruit injury | # moths caught per trap | Prop. females | Prop. Unmated females | Prop fruit injury |
|---|---|---|---|---|---|---|---|---|---|
| 2020<br>N = 9 Apple<br>orchard pairs<br>USA | -/ 4K | - | - | - | - | 19.9 (6.5) | 0.45 (0.02) | 0.38 (0.02) | 0.015 (0.006)b |
| | No traps | - | - | - | - | - | - | - | 0.071 (0.036)a |
| **Summary** | **641 traps** | **-** | **-** | **-** | **-** | **12,756 moths** | **5,740 females** | **Paired t-test $t_8$ = 3.69, $P$ = 0.006** | |
| 2020<br>N = 6 Pear<br>orchard pairs<br>USA | PH/PE+AA / 4K | 20.3 (7.2) | 0.52 (0.02) | 0.23 (0.03) | 0.004b (0.002) | 10.6 (2.7) | 0.55 (0.05) | 0.35 (0.03) | 0.052b (0.034) |
| | No traps | - | - | - | 0.010a (0.005) | - | - | - | 0.113a (0.039) |
| **Summary** | **132 traps – 1st<br>306 traps – 2nd** | **8.206 moths** | **3,775 females** | **Paired t-test $t_2$ = 2.89, $P$ = 0.034** | | **3,244 moths** | **1,784 females** | **Paired t-test $t_7$ = 3.53, $P$ = 0.007** | |
| 2020<br>N = 5 Pear<br>orchard pairs<br>Italy | 4K | 5.3 (0.8) | 0.43 (0.03) | 0.17 (0.03) | 0.015b (0.007) | 7.1 (0.8) | 0.61 (0.04) | | 0.063b (0.020) |
| | No traps | | | | 0.019a (0.009) | | | | 0.094a (0.02) |
| **Summary** | **258 traps** | **4,512 moths** | **1,940 females** | **Paired t-test $t_4$ = 3.30 , $P$ = 0.046** | | **1,832 moths** | **1,117 females** | **Paired t-test $t_4$ = 4.65 $P$ = 0.019** | |

## Executive Summary

**Project title:** New attractants for monitoring, MD, and mass trapping of codling moth

**Key Words:** plant volatiles, fruit injury, *Cydia pomonella*, oriental fruit moth, mating disruption

**Abstract:** The serendipitous development of the 4K lure for codling moth occurred through a collaborative synthesis of world-wide expertise. Its discovery gives us the ability to monitor codling moth without the use of sex pheromones and thus avoid any disruption of traps in orchards treated with variable levels of mating disruption technologies. The 4K lure provides us the ability to seasonally track female codling moths and improve predictive timing models for key phenological events. The attractiveness of the 4K lure allows traps to be placed at a more user-friendly height in the canopy and the lure is effective for at least 8 weeks. Ongoing studies have identified other host plant volatiles that can be used to create additional effective blends. The addition of UV light to traps baited with the 4K lure creates new opportunities to catch more moths, thus improving our ability to monitor and remove female moths from our orchards. The power of this dual modality can also be used for monitoring and female removal of other tortricid pests, such as oriental fruit moth, eye-spotted bud moth, and leafrollers. Development of optimized non-saturating trap-lure combinations allows us to use the power of the 4K lure to remove substantial numbers of both virgin and mated resident and immigrant female codling moths from our orchards before they lay eggs. Studies conducted over the past two years in apple and pear have consistently shown that female removal strategies can be effective in reducing levels of fruit injury by > 50%. Female removal should be used with mating disruption to increase the removal of unmated females. This MD-FR approach when used for orchards' borders and surrounding bin piles can serve as a key bulwark to protect the orchard from immigrant moths. Future studies building upon these initial findings will strive to increase this impact. Much has been accomplished and more fine tuning is needed by growers and farm managers to deploy and integrate this useful tactic into their programs.