Codling Moth (Lepidoptera: Tortricidae) Control by Dissemination of Synthetic Female Sex Pheromone

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ABSTRACT Permeation of a synthetic pheromone mixture through an isolated Asian pear orchard provided excellent control of the codling moth in the Sacramento Valley of California during a 2-yr period. The synthetic pheromone mixture was applied in 1,050 plastic twist-tie dispensers and at the rate of 100 g codlemone, 50 g dodecanol, and 10 g of tetradecanol per hectare. Female codling moth antennae give electroantennogram responses to these compounds.

KEY WORDS Insecta, codling moth, mating disruption, electroantennogram

THE CODLING MOTH, *Cydia pomonella* (L.), is a key pest of apples, European pears, Asian pears, and some varieties of Persian walnuts and Japanese plums (Barnes 1991). Relatively broad spectrum insecticides have maintained control of codling moth in California, although insecticide resistance has been encountered (Barnes & Moffitt 1963, Welter et al. 1991). Also, when insecticides are used there is concurrent suppression of natural enemies of other orchard arthropods. This frequently causes existing problems with other pests to increase and new pest problems to appear. This situation has recently been exacerbated by withdrawal of partially selective insecticides from the marketplace. For example, phosalone (registration withdrawn in the United States) has been useful in selective control of codling moths in walnut orchards, because it does not interfere with rapid reestablishment of an effective parasite of the walnut aphid, *Trioxys pallidus* Haliday (Riedl et al. 1979). Consequently, development of alternative control methods would be desirable.

Putman (1963) reported an unpublished observation by his colleagues in which caged virgin codling moth females attracted mates. He also made the prescient observation that "if the male-attracting pheromone secreted by the female could be chemically identified and synthesized, it might be useful for detecting very low infestations, or even for preventing copulation by saturating the environment" (p 51). Barnes et al. (1966) described the codling moth female sex pheromone gland, and soon thereafter Roelofs et al. (1971) provided the first evidence that a major component of the pheromone is (E,E)-8,10-dodecadien-1-ol (codlemone), along with a method for its synthesis. Riedl et al. (1986) reviewed the use and standardization of trapping systems for monitoring male codling moths using codlemone. Control by false trail following—i.e., mass trapping of males—has been successful only when the ratio of traps to females strongly favors the traps. This has been observed only in isolated orchards with low populations (Madsen et al. 1976).

A thorough review of factors pertaining to suppression of codling moth by permeating synthetic pheromone through the air is provided by Rothschild (1982). The development of a procedure for control of the codling moth by this method, using codlemone, is reported by Charmillot (1990) in Switzerland where the moth has one full generation and a partial second generation. In a two-generation-per-year area in Oregon, Moffitt & Westigard (1984) found promising suppression of light codling moth populations in pear orchards, using three- to five-broadcast applications of hollow fibers containing codlemone. If mating disruption is successful in pear orchards in the western United States, it would have the advantage of controlling this key pest while allowing natural enemies, otherwise suppressed by insecticides, to suppress other pests such as pear psylla and spider mites (Westigard & Moffitt 1984).

Compounds other than codlemone have been identified in the female codling moth pheromone gland (Einhorn et al. 1984, Arn et al. 1985). Behavioral responses by the male to the natural pheromone are greater than those to codlemone (Einhorn et al. 1984). Enhanced behavioral responses may be attributed to dodecanol (Arn et al. 1985) and to dodecanol and tetradecanol (Bar-

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tell et al. 1988). In the latter study, responses by field-collected males equivalent to the natural pheromone were observed when codlemone, dodecanol, and tetradecanol were present in ratios of 1.0, 0.6, and 0.2, respectively.

An orchard trial was conducted to determine if, under conditions of orchard isolation but with significant, recorded initial populations, control of the codling moth could be consistently achieved in the Central Valley of California by dissemination of a three-component synthetic pheromone, using commercially available dispensers.

Although pheromone permeation may chiefly act by disruption of communication that suppresses pheromone-trail following and mating, conceivably there may be some effect on female moths as well. Although females of >300 species in six lepidopterus families are nonresponsive to the sex pheromone they produce in behavioral or electrophysiological trials (Light & Birch 1979), there are exceptions. Female antennae of the cabbage looper, *Trichoplusia ni* (Hübner) (Light & Birch 1979); the pink bollworm, *Pectinophora gossypiella* (Saunders) (Cook et al. 1978); and the spruce budworm, *Choristoneura fumiferana* (Clemens) give electroantennogram responses to their sex pheromone, and the latter species shows behavioral responses (Palaniswamy & Seabrook 1978). As a first step in determining whether codling moth pheromone may have some effect on females, female antenna were tested in coupled gas chromatography–electroantennography observations.

Materials and Methods

The study was conducted in an Asian pear orchard located near Capay, Calif. (Sacramento Valley), and isolated by 3.2 km from other orchards. No insecticides had been applied in the orchard. It consisted of 75 trees of the 'Hosui' variety, 325 'Shinseiki' and 20 '20th Century' pollinizors planted 4.26 m^2 over 0.8 hectare. Fruit damage figures for 'Shinseiki' include both of the latter two varieties, which are harvested together. The orchard is planted on slightly sloping ground. 'Shinseiki' is ordinarily harvested in the first half of August, when only part of the flight activity of second-brood moths has taken place. 'Hosui' fruits are harvested later in August, even into early September, and are more subject to infestation by third-brood larvae.

The background of codling moth infestation in the orchard follows. The orchard came into partial bearing in 1986 and <1% of fruit were infested by codling moth at harvest. The next year, by now in full bearing, an attempt was made to maintain a low population in this orchard by trapping males, using 10 Pherocon IC traps (Trece, Salinas, Calif.) baited with 1 mg of codlemone per trap. Traps were installed 14 March 1987, before moth emergence, and renewed three times at 6-wk intervals. Trapping surfaces were renewed six times, as needed. Trap catches tripled from 40 to 113 between the first and partial-third generations, and 3.1% fruit loss resulted at harvest. The fruit loss data were derived from an account based on all fruit as described below.

Treatment in 1988. In the 1st yr of the pheromone-permeation trial, laminated-plastic pheromone dispensers (Pacific BioControl, Davis, Calif.) were used, containing 540 mg of synthetic pheromone compounds in the following proportions: codlemone, 63%; dodecanol, 31%; and tetradecanol, 6%, plus 60 mg of antioxidants and other stabilizers. These were installed, one unit in every other tree, in the upper one-third of the north side of the tree on 27 March and 11 July. This provided approximately 50 g of codlemone, 25 g of dodecanol, and 5 g of tetradecanol from 150 emitters per hectare in each application.

Treatments in 1989 and 1990. In the 2nd and 3rd yr of the orchard trial, plastic-tube, twist-tie dispensers were used (Shin-Etsu Chemical, Tokyo, Japan). The tubes contained 157 mg of the three-component synthetic pheromone mixture in the same proportions as noted above, plus 23 mg of antioxidants and other stabilizers (Pacific Bio-Control, Davis, Calif.). They were installed once, in the upper one-third of the northeast quadrant of the trees at the rate of two per tree, with three per tree on the trees of the two outside rows. This amounted to ≈100 g of codlemone, 50 g of dodecanol, and 10 g of tetradecanol in 1,050 dispensers per hectare, discounting the extra dispensers on the outside rows.

Five pheromone traps, as described above, were installed at the time of installation of the pheromone release units to monitor their attractiveness to male moths under the conditions of the trials. These were renewed once after 8 wk.

Each year all dropped fruit were counted (5–10 per tree) and larval entries were recorded from 20 trees divided proportionately among varieties. At harvest, which took place in a series of picks, packed boxes were recorded by number of fruit packed per box and by variety. All cull fruit were counted and examined by variety for larval entry. The resulting data were collated to provide the level of infestation of the entire crop.

On 20 July 1990, a corrugated cardboard band, 10-cm wide and with open flutes, was stapled, open flutes against the bark, around the trunk of 20 trees selected at random. Each was protected from larval predation by birds by stapling fly screen loosely over them. To sample the moth population, two 175-W mercury vapor lamps were placed separately on tripods on 8–by–8 white sheets on the ground and powered by a portable generator. Lamps were operated from dusk to 2300 hours on 20 August 1989.

Table 1. Percent infestation at harvest by codling moth in Asian pears following season-long dissemination of three-component synthetic female sex pheromone, Capay, Calif.

Pear	1988[a]	1989[b]	1990[c]
Shinseiki	5	1.3	0.2
Hosui	17	2.1	0.5

[a] Ribbed, plastic pheromone dispensers installed in every other tree, 16 March and 11 July. Total crop = 33,806 fruit.
[b] Plastic, twist-tie (Shin-Etsu) dispensers, two per tree, installed 27 March. Total crop = 38,637.
[c] Plastic, twist-tie (Shin-Etsu) dispensers, two per tree, installed 25 March. Total crop = 38,790.

Coupled gas chromatography–electroantennogram detection (GC–EAD) analyses were conducted with codling moth antennae taken from male and female moth specimens from a laboratory colony reared on apple thinnings and derived from the USDA–ARS Yakima laboratory strain. Antennae were carefully pulled out of the head, and the antennal tip was cut off. Antennae were suspended from drops of Ringer's solution between two chloridized silver-wire electrodes. Antennal signals were amplified with a custom-built amplifier, as previously described (Millar et al. 1987).

A Hewlett-Packard 5890 GC (Avondale, Penn.) equipped with a DB-5 column (30 m by 0.32 mm) (J & W Scientific, Folsom, Calif.) was used for the analyses. The GC column effluent was split (1:1) with a direct-connect X-cross glass connector (Alltech Associates, Deerfield, Ill.). Electroantennogram and GC signals were recorded simultaneously with a matched pair of Hewlett-Packard 3394 recording integrators.

Dodecanol, tetradecanol, and E8,E10-dodecadienol were obtained as a mixture by cutting open one of the Shin-Etsu dispensers. The mixture was diluted to a concentration of 1 mg/ml in hexane before use in GC–EAD trials.

Results

In 1988, use of laminated plastic dispensers on every other tree, renewed once, failed to provide satisfactory control (Table 1). The higher average infestation level of 'Hosui' (17%) reflected its greater exposure to the third brood. Three 'Hosui' trees harvested last (15 August) had 30.5% infested fruit.

A single installation of twist-tie dispensers provided successful control in 1989. Less than 2% of the fruits were infested. No males were caught by monitoring traps for ≈120 d (9 August) after placement of the traps. At the end of 120 d, harvest was underway. By 20 August, 50% of the female moths collected at UV lamps were mated (n = 12).

In 1990, codling moth infestation was further suppressed to 0.5% or less on the earlier varieties (Table 1). Two male moths were caught in the monitoring traps before harvest. Corrugated cardboard bands, were removed from the trunks of 20 trees on 31 October 1990. These contained only four diapausing larvae.

The results of the electroantennogram study were as follows. First we observed that male antennae responded well to codlemone in our experimental set-up. We then observed GC–EAG responses by antennae from three different females to codlemone, dodecanol, and tetradecanol.

Discussion

Perhaps the most important aspect of the methods of a trial of pheromone permeation for codling moth control is the design of the orchard experiment. A reliable trial has four characteristics: (1) isolation from immigrating gravid females, (2) a known background of moth populations, (3) lack of interference by other control methods, and (4) continuity year after year in the same location. The Asian pear orchard used and the trial reported had all these characteristics.

Success in suppression of codling moth infestations by pheromone permeation was achieved under the conditions of this experiment. It is apparent that isolation is relatively essential for a valid trial of such an air-permeation system. Otherwise, mated females dispersing from adjacent orchards or adjacent areas within a trial orchard may create uncontrolled infestations of considerable magnitude, particularly where three generations occur. As well, codling moth infestation varies from one part of an orchard to another. The requirement of isolation and the existence of variable distribution of infestation within an orchard inherently prevents the use of a true check. However, the potential of the codling moth as a pest has repeatedly been observed. Without control, its populations are eventually limited by other factors, but at a high level of damage (Geier 1964, Glass & Lienk 1971). An experiment demonstrating sequential suppression year after year would provide evidence of effectiveness as a method of control. A relatively low population in the experimental orchard at the outset should improve the chances of satisfactory suppression and lessen the chance of mate finding through means other than pheromone-trail following. Perhaps the most difficult criterion to meet in an examination of the effectiveness of pheromone permeation is lack of interference by use of insecticides in the trial orchard.

When moth infestation is high in an orchard, it is frequently observed (M.M.B., unpublished data) that larval infestations are somewhat higher on border rows, as though arboreal moths tend to remain within a canopy. This suggests that, in trials of pheromone permeation, experimental

blocks should extend to borders, rather than be confined to an area within an orchard. However, if insecticide use borders the trial block directly, then an insecticide regime should be used which provides moth mortality to suppress ingress of gravid females into the pheromone-treated area. Because female antennae possess the sensory elements to respond to the three major elements of her sex pheromone, the role of these pheromone constituents in female behavior should be investigated.

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