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Ten years implementing codling moth mating disruption in the orchards of Washington and British Columbia: starting right and managing for success!

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Abstract: In 1991, Isomate C (Pacific Biocontrol Corp., Ridgefield, WA.) became the first commercial product registered by the United States EPA for control of codling moth. Currently, there are 5 products available including Isomate C+, CheckMate CM (Consep, Inc., Bend, OR), NoMate CM (Scentry, Inc., Billings, MT) and Disrupt CM (Hercon, Inc., Emigsville, PA). In Washington State in 1991, codling moth mating disruption (CMMD) was used on approximately 600 hectares. By 1999, use of CMMD had increased to approximately 25,000 hectares. In British Columbia, the efficacy of CMMD was first demonstrated in organic orchards in 1990. In 1999, Isomate C+ (currently the only registered product in Canada) was used on approximately 700 hectares. Research into new CMMD technologies including sprayable pheromones and large aerosol dispensers is underway in both countries. Due to increased regulatory restrictions of conventional insecticides and other factors, a large increase in the commercial use of CMMD is forecast for both countries. The careful selection of orchards and the adoption of a pheromone-based IPM approach can minimize the risk and control problems associated with CMMD. Most importantly in orchards with high resident populations, the application of supplemental insecticides and/or intensive sanitation is essential to achieve commercially acceptable levels of control. CMMD works best in orchards where the physical characteristics and environmental conditions ensure a uniform distribution of pheromone concentration. Dispensers should be deployed within 1 meter of the top of the canopy prior to spring emergence. Borders of pheromone-treated orchards are susceptible to high levels of codling moth infestation and growers generally treat the border areas with supplemental insecticides or an increased application rate of pheromone. Border problems can also be reduced by the area-wide application of CMMD technology. Monitoring codling moth adult activity in orchards treated with CMMD is difficult. Capture of moths in pheromone traps baited with 1 mg of codlemone is an unreliable indicator of efficacy. The sensitivity of pheromone traps can be improved by using traps baited with 10 mg lures and locating them in the upper part of the canopy. False negatives (no or low captures of moths in orchard sustaining economic damage) do occur even with the deployment of 10 mg-baited traps and it is important to interpret trap capture data carefully. Fruit should be inspected on a regular basis to ensure that economically acceptable levels of control are achieved. Economic studies show that the selective application of CMMD in conjunction with the judicious use of insecticides can be more cost effective than conventional programs. Other advantages of CMMD include enhanced levels of biological control, reduced costs associated with worker protection and labour management, and decreased potential for the development of insecticide resistance. Disadvantages of CMMD include the perceived high cost of the technology and its application, concerns over efficacy, the need for intensive monitoring and outbreaks of secondary insect pests. Continued research is required to identify the most effective pheromone blend relative to the delivery system. Greater knowledge of moth flight and mating behaviour relative to the dynamics of pheromone concentration within orchard canopies is essential. Increased understanding of the mechanisms of CMMD will aid in the design of more cost effective technology. The development of improved monitoring techniques in conjunction with the use of economic thresholds to determine the need for and timing of supplemental controls is essential. The continued adoption of CMMD will depend on how well it meets grower concerns about risk, efficacy and cost.

Keywords: *Cydia pomonella*, mating disruption

Introduction

Codling moth, *Cydia pomonella* L., is the key pest of pome fruit in Washington State (Beers & Brunner 1992) and British Columbia (Judd *et al*. 1997) and until recently has been primarily controlled by one or more applications of an organophosphate insecticide (Gut & Brunner 1998). Issues associated with the widespread use of organophosphates, including insecticide resistance (Varela *et al*. 1993), toxicity to natural enemies (Gut & Brunner 1998), worker safety and food residues (Brunner 1994), have provided the impetus to research and develop alternative control technologies. Research on the use of pheromone-mediated mating disruption technology for control of codling moth (CM) has shown considerable promise in various pome fruit production areas around the world (Rothschild 1980; Charmillot 1990; Thomson et al. 1999; Barnes & Blomefield 1997, Waldner 1997).

History of use in Washington and British Columbia

In Washington State, research into the use of pheromones to control CMbegan in 1987 (Howell *et al.* 1992). In small plots, levels of fruit damage in pheromone-treated plots relative to untreated controls were reduced by 80 to 90%. However, the authors cautioned that CMMD would not work well as a stand alone technology when CM populations were high and supplemental applications of insecticides would be necessary to ensure commercially acceptable control. In 1991, Isomate CTM (Pacific Biocontrol Corp., Ridgefield, WA.) became the first mating disruption product to be registered for control of codling moth in Washington State. In 1991, approximately 600 hectares of pome fruit in Washington State were treated with codling moth mating disruption (CMMD) (Thomson 1997). By 1999, the use of CMMD had increased to approximately 25,000 hectares and a substantial increase in use is forecast for 2000 (J. Brunner, P. communication). Currently, commercial products are available from Pacific Biocontrol, Ridgefield, WA (Isomate C+TM, Isomate CM/LRTM), Consep, Inc., Bend OR (CheckMate CMTM), Scentry, Inc., Billings, MT (NoMate CMTM) and Hercon, Inc., Emigsville, PA (Disrupt CMTM). In Washington State, (Alway 1998) surveyed 153 growers farming 4,655 hectares and found that92% of the growers used Isomate C+TM.

In British Columbia, research into the use of CMMD began in 1987 (Judd *et al*. 1992). The efficacy of CMMD was first demonstrated in commercial organic orchards in 1990 (Judd *et al*. 1997). Damage in 4 organic orchards was reduced from an average of 25% in 1989 to a mean of 0.7% during the 3 year period from 1990 to 1992. The 3 year mean % damage in an untreated control orchard during the same period was 48% (Judd *et al.* 1997). In 1991, 75 growers, representing 140 hectares of pome fruit, participated in a large-scale evaluation of CMMD. The median level of damage in pheromone-treated blocks was 0.42% and 0.88% in apple and pear orchards, respectively (Judd & Gardiner 1992). Isomate C+ was registered in Canada in 1994. In 1994 and 1999, CMMD (Isomate C+ is the only registered product in Canada) was used on approximately 100 and 700 hectares, respectively (G. Judd, P. communication). Use is forecast to increase to approximately 2,000 hectares in 2000. The large increase is due to the recommended use of CMMD in conjunction with insecticides by the Sterile Insect Release (SIR) program in British Columbia to help reduce regional CM populations (G. Judd, P. communication).

Selecting an orchard

The careful selection of orchards can minimize the risk and control problems associated with CMMD. High resident populations are the most important limitation to the successful use of CMMD In orchards with high resident CM populations, the application of supplemental insecticides (Gut & Brunner 1992) and/or intensive sanitation (Judd *et al*. 1997) is essential to reduce populations to levels low enough to achieve commercially acceptable control. In 1997 in Washington State, 153 growers farming 4,655 hectares were surveyed on the particulars of how they used CMMD (Alway 1998). In the first year, 95% of the growers applied at least 1 insecticide to supplement CMMD. In the second and third year , the percentage of growers applying at least 1 supplemental insecticide was reduced to 83% and 76%, respectively. Azinphos-methyl was the most frequently used supplemental insecticide, used by 90% of the growers. Growers in British Columbia have also used pre- and post-harvest fruit removal and tree banding to successfully lower CM populations to ensure the efficacy of CMMD (Judd *et al*. 1997). In addition, careful consideration should be given to the topography (slope), wind exposure and size and structure of the canopy (Thomson *et al*. 1999, Gut & Brunner 1994).

Applying dispensers

Pheromone dispensers should be deployed within 1 meter of the top of the canopy just prior to the start of CM flight (Gut & Brunner 1994). Research has shown that most CM mating activity occurs in the upper part of the canopy. For example, Riedl *et al*. (1979) showed that higher numbers of male CM were caught in lure-baited pheromone traps when traps were placed in the upper canopy. Weissling & Knight (1995) using a variety of techniques, including tethered virgin females, unbaited sticky traps and blacklight observation of released moths, showed that males and unmated females are mostly distributed in the upper canopy. Further, they demonstrated that when pheromone dispensers were placed at 2 meters, there was still mating of tethered females occurring at 4 meters.

The placement of dispensers at 4 meters further reduced the incidence of mating. The results strongly suggest that dispensers should be applied in the upper canopy to optimize the efficacy of CMMD.

Treating borders

Borders of pheromone-treated orchards are susceptible to high levels of codling moth infestation. In a 3 year study of the use of CMMD in 6 Washington apple orchards, Gut & Brunner (1998) found that approximately two-thirds of the CM damage occurred within 30 meters of the border. Knight *et al*. (1995) showed similar results. In a study of an orchard treated with CMMD, 65% of the fruit damage occurred along the border. Factors contributing to border infestations include the immigration of mated females from adjacent untreated orchards and reduced concentrations of pheromone in the border zone (Gut & Brunner 1998). Milli *et al.* (1997) showed that wind reduced pheromone concentrations for up to 15 meters from the edge of a CMMD treated orchard. This resulted in a border zone with potentially insufficient concentrations of pheromone to disrupt mating. Recommendations to reduce border infestations include increasing the application rate of dispensers in border areas and/or spraying the borders with insecticides (Gut & Brunner 1996). Given the cost of pheromone dispensers and questions regarding the effectiveness of higher application rates especially when CM populations are high (Gut & Brunner 1998), most growers in eastern Washington and British Columbia apply insecticides or remove infested as supplemental border treatments. Based on the work of Milli *et al*. (1997), supplemental controls should be applied to areas up to 15 meters from the edge. Border problems can also be reduced by treating adjacent orchards or wind breaks with pheromone dispensers and/or by the area-wide application of CMMD technology (Kogan 1994).

Area-wide use

The Codling Moth Areawide Management Program (CAMP) was initiated in 1993 by university and United State Department of Agriculture (USDA) scientists (Kogan 1994). The program was a joint effort between the University of California, Berkeley, California, Oregon State University, Corvallis, Oregon, Washington State University, Wenatchee, Washington and the United States Department of Agriculture/Agricultural Research Service, Wapato, Washington. The objective of the 5 year program was to implement an area-wide and multi-tactic pest management strategy that would effectively control CM while reducing the negative impacts of pesticide use on natural enemies of secondary pests, the environment and the farm workers (Kogan 1994). The major tactic for control of CM was CMMD. CM was chosen as it is the "key pest" of pome fruit orchards in western North America. Five area-wide projects comprising a total of 1,294 hectares in 3 western states were initiated in 1995 (Kogan 1996). By 1998, CAMP had expanded to over 6,000 hectares involving 17 sites (Alway 1998). CAMP has been very successful in demonstrating the effectiveness of the CMMD technique when used in an area-wide approach. Recently, the SIR Program in British Columbia recommended the use of CMMD in conjunction with insecticides to reduce moth populations to levels where the technique of releasing sterile insects can be effective. The area-wide use of CMMD and insecticides is expected over a large region comprising 2,000 hectares(G. Judd, P. communication).

Monitoring CMMD-treated orchards

Monitoring codling moth adult activity in orchards treated with CMMD is difficult. Pheromone traps should be uniformly distributed in the orchard at a density of 1 trap per hectare. Additional traps should be placed to monitored the borders and known "hot spots". Traps should be inspected at least once a week. Lures should be changed every 2 to 3 weeks or according to the manufacturer's recommendations. Capture of moths in pheromone traps baited with 1 mg of codlemone is frequently an unreliable indicator of efficacy (Thomson *et al.* 1999). Charmillot (1990) showed that the sensitivity of pheromone traps can be improved by using traps baited with 10 mg lures and locating them in the upper part of the canopy. False negatives (no or low captures of moths in orchards sustaining economic damage) do occur even with the deployment of 10 mg-baited traps and it is important to interpret trap capture data carefully. Welter *et al.* (1997) demonstrated that the effective active space (area of attraction) of lure-baited pheromone traps in CMMD treated orchards is less than 0.5 hectares. Therefore, it is essential that fruit be inspected on a regular basis to ensure that economically acceptable levels of control are achieved.

Economics of CMMD

A study of the economics of CMMD conducted in Washington State during 1991 and 1992, found that the cost of Isomate C technology when adjusted for materials, labour and machinery costs was $133.38 per hectare higher than a conventional insecticide program (Williamson *et al.* 1996). In the years following the registration of Isomate C, the higher costs provided a strong disincentive to the adoption of CMMD technology in Washington and British Columbia. However, the use of CMMD at reduced rates in conjunction with the judicious use of insecticides has made the economics more attractive to growers. In his survey, (Alway 1998) found that 73% of growers (153 growers farming 4,655 hectares) surveyed in Washington State deployed Isomate C+ at reduced rates. Connor (1999), in a study conducted between 1995 and 1998, compared the economics of Isomate C+ applied at reduced rates with conventional insecticide programs in Pacific Northwest apple and pear orchards. He found that the cost competitiveness of Isomate C+ was a function of CM population densities. Where CM populations were low (growers normally apply 2.5 insecticides or less for CM), he found that the use of Isomate C+ was not cost effective even when dispensers were applied at half the labelled rate of 500 dispensers per hectare. However, if CM populations were high (normally greater than 5 insecticides applied for CM), the use of Isomate C+ was more cost effective compared to conventional insecticide programs after 2 years. Growers implementing CMMD in orchards with moderate CM populations, would expect to net savings by years 3 and 4. He concluded that the decision by growers to adopt CMMD was equivalent to an investment decision in that the additional costs in the first years following the deployment of CMMD would be off-set by future savings (Connor 1999). Economic advantages of CMMD not factored in the above studies include reduced costs associated with worker protection and labour management in orchards and decreased potential for the development of insecticide resistance. Economic disadvantages not factored into the study include the need for intensive monitoring and outbreaks of secondary insect pests other than leafrollers.

Pheromone blends

Roelofs (1978) in his "Threshold Hypothesis" suggested that the efficacy of mating disruption would be enhanced by dispensing the complete blend. CM pheromone was first identified as (E,E)-8, 10-dodecadien-1-ol (Roelofs *et al*. 1971). Evidence for the presence and behavioural role of secondary components has been reported by many authors (Arn 1985; Bartell & Bellas 1981; El-Sayed *et al*. 1999; Rothchild *et al*. 1988; Witzgall *et al*. 1999). However, only one commercially available CMMD product incorporates the secondary components into the formulation (Thomson *etal*. 1999). Witzgall *et al.* (1999) suggested that the lack of efficacy of CMMD at high populations was due in part to the failure to dispense the complete blend of CM pheromone . Continued research is required to determine the importance of secondary components to the efficacy of CMMD. In addition, the importance of secondary components relative to the delivery system needs to be better understood . Research into new CMMD technologies including sprayable pheromones (G. Judd, P. communication) and large aerosol dispensers (Shorey & Gerber 1996) is underway in both Washington State and British Columbia.

Concluding remarks

Due to increased regulatory restrictions of conventional insecticides and other factors, a large increase in the commercial use of CMMD is forecast for both Washington State and British Columbia. The continued adoption of CMMD will depend on how well it meets grower concerns about risk, efficacy and cost. Greater knowledge of moth flight and mating behaviour relative to the dynamics of pheromone concentration within orchard canopies is essential and will lead to an increased understanding of the mechanisms of CMMD. This will aid in the design of more cost-effective CMMD technology. Extensive research is still needed to improve monitoring techniques and to develop economic thresholds to ensure commercially acceptable levels of control. The development and registration of new formulations will provide growers with more alternatives and the resulting competition should lower the price to the grower thus encouraging even greater adoption.

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