Codling moth (*Cydia pomonella*) mating disruption outcomes in apple orchards

J.T.S. Walker¹, P.L. Lo¹, R.M. Horner¹, N.M. Park¹, J.G. Hughes² and T.M. Fraser²

¹*The New Zealand Institute for Plant & Food Research Limited, Private Bag 1401, Havelock North, New Zealand*

²*Fruition Horticulture, P.O. Box 966, Hastings, New Zealand*

Corresponding author: jim.walker@plantandfood.co.nz

Abstract New Zealand apple growers need to produce crops that satisfy conflicting export market requirements. Some markets want pest-free fruit, while others demand residue-free fruit. Pheromone mating disruption combined with the judicious use of insecticides enables crops to meet both demands. This study in 14 Hawke's Bay apple orchards showed that seasonal pheromone trap catch was reduced by 70%, from 40.1 codling moths/trap in the season before mating disruption was introduced to 11.7 moths/trap over the subsequent five seasons. In the same period, insecticide use reduced from 5.9 applications/season in 2006-07 to 2.3 in 2007-08 and 3.7 since 2008-09. The incidence of larvae in fruit where mating disruption operated averaged 0.01%, which was lower than in orchards using insecticides only. Damage increased from 2008-09 with greater reliance on codling moth granulosus virus over residual insecticides. Nevertheless, mating disruption with 3-4 insecticide sprays controlled codling moth to the high standard needed.

Keywords codling moth, mating disruption, trap catch, insecticides.

INTRODUCTION

New Zealand apple growers' access into many high-value markets is dependent on meeting stringent phytosanitary requirements. There is zero tolerance for live codling moth (*Cydia pomonella*) in New Zealand exports to Taiwan, China, Japan, Thailand and India. To achieve ongoing access to these markets, management of New Zealand apples is based on a regulatory 'codling moth sensitive market' programme (Anonymous 2013a). This programme is administered by Pipfruit New Zealand in accordance with protocols set by the Ministry for Primary Industries. It is a 'systems approach' to codling moth management that uses risk reduction practices, verified by traceability and

auditing of inputs to address the risk of infestation at all critical points in the production pathway.

Increasingly, apple growers must also balance the phytosanitary regulatory requirements of pest-sensitive markets with European supermarket demands for low-residue or residue-free fruit, such as those developed in the Apple Futures programme (Kaye-Blake & Zuccollo 2012). The New Zealand pipfruit Integrated Fruit Production (IFP) programme (Batchelor et al. 1997; Walker et al. 1997) proscribes the protocols for managing pests, such as population monitoring, spray thresholds and appropriate insecticides to apply.

Pheromone mating disruption has long been used in New Zealand apple orchards to manage

codling moth and leafrollers (e.g. Suckling & Shaw 1995). This technology is based on 'twist-tie' dispensers that release the male disruptive sex pheromone (codlemone) over a 5-6 month period. In conjunction with a codling moth monitoring programme and the judicious use of insecticides, mating disruption potentially enables crops to be produced that are both pest-free and residue-free. In New Zealand, the use of codling moth mating disruption has increased in the apple sector over the last 4 years; adoption is now estimated to be around 2,300 ha (~50% of the Hawke's Bay production area and ~25% nationally) as growers try to meet these conflicting market requirements. Implementation of mating disruption has decreased codling moth activity on treated orchards with resultant decreases in insecticide use. This paper quantifies these changes and the outcomes in terms of codling moth control on 14 Hawke's Bay orchards that have operated mating disruption programmes since 2007-08.

METHODS

A research partnership was developed with one Hawke's Bay supply group (Apollo Apples Ltd). The 14 apple orchards included here were those that used codling moth mating disruption continuously between 2007-08 and 2011-12, to help manage increasing moth activity in pheromone traps and the potential risk of crop infestation. Data for the 2006-07 season preceding the introduction of mating disruption are included for comparison.

Different brands of pheromone dispensers were used during the 5-year study period, but the codlemone pheromone loading was ~210 g/ha irrespective of dispenser type. All dispensers were installed according to recommendations (e.g. 1000/ha and early spring application to the upper tree canopy). In 2007-08, Isomate® C Plus (Shin-Etsu Fine Chemicals Ltd, Japan) dispensers were used. Nomate® CM (Scentry Biologicals, Billings, Montana, USA) dispensers were substituted for Isomate® C Plus in 2008-09 and 2009-10, while both dispenser types were used on different orchards in 2010-11. In 2011-12, all orchards were treated with a new codling

moth and leafroller disruptive dispenser (see Lo et al. 2013), Isomate 4Play™ applied at 800/ha.

Codling moth activity in the trial blocks was monitored using standard delta traps baited with standard pheromone caps (1 mg) in 2006-07 and from 2007-08 on with high dose (10 mg) pheromone caps as recommended for codling moth mating disruption (Thomson et al. 2001). Traps were placed in the upper 10-20% of the tree canopy and operated at one trap/2 ha, but from 2008-09 onwards, the trap density increased to one trap/ha following a change in the IFP programme requirements. Traps were checked and cleared weekly, while bases and caps were replaced 3- and 6-weekly respectively. A residual insecticide was applied to each orchard each year at the time point determined by codling moth BIOFIX + ~100 degree-days (Jones et al. 2008), usually in early November. Thereafter, all insecticide use within these orchards was based on pheromone trap catch and IFP thresholds for codling moth activity (Anonymous 2013a).

Fruit damage was assessed at harvest based on at least 100 fruit sampled per bin, with 10 bins sampled (a minimum of 1000 fruit) from each cultivar block (mostly 'Royal Gala', 'Braeburn' and 'Fuji'). Twenty-four to 35 blocks across these orchards were sampled each year for codling moth larval entry damage and/or any presence of live larvae. In the absence of untreated control orchards (i.e. no pheromone disruption), analysis was restricted to box plots of trends in mean values of trap catch, insecticide use and fruit damage at harvest.

RESULTS

Pheromone trap catches

The impact of mating disruption on codling moth trap catch is shown in Figure 1 for the 14 orchards where mating disruption was implemented each season between 2007-08 and 2011-12. The mean catch of codling moth in pheromone traps prior to the introduction of mating disruption was 40.1 moths and this decreased by ~70% to an average of 11.8 moths over the five seasons following its introduction. This contrasted with just ±7% variation in seasonal mean codling moth trap catch on untreated properties over

Figure 1 Mean seasonal codling moth trap catch on 14 Hawke's Bay orchards that have operated codling moth mating disruption since 2007-08 (no mating disruption in 2006-07). The box plot depicts the 25th and 75th percentiles, whiskers show the 10th and 90th percentiles, outliers are indicated by triangles. The horizontal line inside the box shows the median and the mean is represented by a circle.

the same period (J.T.S. Walker, unpublished data). More importantly, the variation in codling activity between properties treated with mating disruption was substantially reduced, which eased the management of codling moth while also reducing the potential fruit damage.

Insecticide programmes

Implementation of codling moth mating disruption also brought about a corresponding reduction in insecticide use for codling moth control on these 14 orchards (Figure 2). Prior to its adoption, mean insecticide use on 85 cultivar blocks was 5.9 applications and typically 5-7

Figure 2 Mean seasonal insecticide use for codling moth control on 14 Hawke's Bay orchards that have operated codling moth mating disruption since 2007-08 (no mating disruption in 2006-07). The box plot parameters are as for Figure 1. Values are the mean for all blocks (number in parentheses) monitored in that season, with blocks being based on cultivars and locations within each orchard.

sprays were used. This decreased by ~ 60% to 2-3 sprays in the first year of mating disruption (2007-08). Thereafter an average of 3.5-3.8 insecticide applications was made per block per year against codling moth.

The growers used predominantly residual sprays to control codling moth between 2006-07 and 2008-09 (Table 1). Subsequently, the number of residual applications fell while more biological insecticides (i.e. codling moth granulosis virus) were used. This non-residual product was used increasingly in mid-late summer, and for the last 2 years of the study it was the most commonly used insecticide against codling moth on these orchards.

Table 1 Average number and type of insecticide applications for codling moth control on 14 Hawke's Bay orchards treated with mating disruption since 2007-08.

Year	Residual ¹	Biological ²	Total
2006-07	5.0	1.0	5.9
2007-08	2.2	0.1	2.3
2008-09	2.9	0.8	3.7
2009-10	2.0	1.6	3.6
2010-11	1.0	2.3	3.4
2011-12	1.7	2.1	3.8

¹tebufenozide, methoxyfenozide or thiacloprid.

²codling moth granulosis virus.

Fruit damage at harvest

In the season before mating disruption was used (2006-07), the mean incidence of fruit damage by codling moth across all variety blocks was 0.1% and some damage was found on 38% of blocks (Figure 3). The incidence of damage decreased to ~0.03% in the first 2 years of mating disruption, and was recorded on about 20% of blocks. Subsequently, damage gradually increased back to the 2006-07 mean level and was found on 30-43% of blocks. No larvae were found in 24,000 fruit examined in the year preceding mating disruption, none in the first 2 years of mating disruption (52,000 fruit) and two in 102,000 fruit in the following 3 years.

DISCUSSION

Apple exporters need the flexibility to be able to send fruit to a variety of markets and consequently orchardists will aim to grow their higher value cultivars to the strictest phytosanitary standard. In the case of codling moth, this means having crops with no live larvae. A comparison with other orchards within the same supply group that had insecticide-only programmes following either IFP guidelines and/or 'codling moth sensitive market' programme requirements (Anonymous 2013a) sets a benchmark for the performance of mating disruption. Insecticide-only treated orchards

Figure 3 Percentage of harvested apples with codling moth damage and larval infestation on 14 Hawke's Bay orchards using codling moth mating disruption since 2007-08 (no mating disruption in 2006-07). The box plot parameters are as for Figure 1. Values are the mean for all blocks (number in parentheses) monitored in that season, with blocks being based on cultivars and locations within each orchard.

averaged 0.017% larval incidence (approximately one infested apple per ~6000 harvested fruit) (J.T.S. Walker, unpublished data), whereas orchards using mating disruption achieved a lower incidence of <0.01%. For markets with a nil tolerance for codling moth, the subsequent harvest and post-harvest risk mitigation measures as required in the codling moth sensitive market programme would remove or eliminate any blocks with damage from the programme and this would significantly decrease the risk of larval infestation even further.

This study has found that mating disruption supplemented with a reduced number of insecticide applications, matched or bettered the incidence of codling moth damage achieved on the same properties by insecticides alone. In particular, a very low incidence of damage was achieved in 2007-08 and 2008-09. During the last 3 years of the study, however, there was a trend for more damage and two larvae were found. The crucial factor behind the annual trend of damage was a change in insecticide programmes. At the start of the study period, there was a strong reliance on residual insecticides, such as tebufenozide, methoxyfenozide and thiacloprid, which provided long lasting control. This continued during the first 2 years of mating disruption, albeit with several fewer applications. The average number of insecticide applications increased in 2007-08 and 2008-09, which was prompted by a reduction in the cumulative catch threshold for codling moth in the 'Codling moth sensitive market' programme.

Of greater significance to both insecticide use and codling moth risk management was the supply group's adoption of the 'Apple Futures' low residue programme (Anonymous 2013b) in the 2009-10 season. Under this initiative, residual insecticide use for codling moth control in mid and late summer was replaced by codling moth granulosus virus, a non residual biological insecticide to ensure that harvested fruit had nil residues. The short period of residual control with this product requires more frequent applications (Authurs & Lacey 2004) and contributed to the greater variability in the number of insecticide applications used for codling moth control on these orchards since 2009. This virus is also slow acting and less effective in preventing

codling moth damage (Wearing 1993), so increased reliance on this product may also explain the greater variability in codling moth damage observed over that period.

Codling moth mating disruption significantly reduced both the numbers and variability of moths trapped in season-long monitoring programmes. Accordingly, it reduced both insecticide use and larval risk, but did not completely eliminate this risk in crops intended for markets with a nil tolerance for this pest. Growers using mating disruption therefore need to find the right balance between using residual and non residual insecticides. Firstly they need to meet the high standards of pest management demanded by codling moth sensitive markets, and secondly there is the requirement for nil or very low pesticide residues on fruit destined for residue-sensitive markets.

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