Development of multiple species mating disruption to control codling moth and leafrollers (Lepidoptera: Tortricidae)

P.L. Lo¹, J.T.S. Walker¹, R.M. Horner¹ and D.I. Hedderley²

¹The New Zealand Institute for Plant & Food Research Limited, Private Bag 1401, Havelock North 4157, New Zealand

²The New Zealand Institute for Plant & Food Research Limited, Private Bag 11600, Palmerston North 4442, New Zealand

Corresponding author: Peter.Lo@plantandfood.co.nz

Abstract Codling moth (*Cydia pomonella*) and leafrollers, principally lightbrown apple moth (*Epiphyas postvittana*), are key pests of apples. Pheromone mating disruption has until now required separate dispensers to be deployed for each pest group. With 600-1000 dispensers per ha for each species, application costs are a significant factor limiting the wider adoption of multi-species mating disruption in New Zealand apple orchards. The aim was to integrate the two disruption systems into a single dispenser, and evaluate its performance against that of separate dispensers, in paired block comparisons on four apple orchards. The three measures of effectiveness, pheromone trap catch, suppression of moth mating and fruit damage at harvest, all showed no statistical differences between the two treatments. The performance of the new combination pheromone dispenser was equivalent to that when the two dispensers were deployed separately.

Keywords Tortricidae, pheromone mating disruption, apple.

INTRODUCTION

Meeting stringent international phytosanitary requirements, together with increasing market demand for residue-free fruit, are serious challenges for New Zealand's pipfruit sector. Codling moth (*Cydia pomonella*) and several species of leafrollers are significant pests in New Zealand apple orchards and their presence in harvested fruit can lead to the rejection of consignments from high value, international markets. There is zero tolerance for codling moth in apples exported to Taiwan, China, Japan, Thailand and India, with control based on a regulatory programme. While a zero tolerance also applies for leafrollers in the USA, Mexico,

Thailand and India, their control is based on best practice recommendations rather than a regulatory programme. Control of both pests to meet these tolerances requires a high certainty of pest outcomes that ultimately determines ongoing access for New Zealand apples to these markets, and potential for future access to other high-value markets (e.g. South Korea).

Supplying fruit to Europe poses a different problem because, although their pest management requirements are easily achieved, their supermarket buyer programmes increasingly demand product with low or nil pesticide residues, that go well beyond the legal

requirements, the maximum residue levels (or MRLs), upon which human food safety is based. Furthermore, new far-reaching EU pesticide legislation may significantly limit pesticide availability and is likely to further restrict pesticide use on New Zealand apple crops. In short, the current position of crop protection in the \$NZ363 million (Plant & Food Research 2011) apple export sector is confronted by significant market incompatibility issues: the need for not only 'pest-free' but also 'residue-free' fruit.

Apple growers following the sector's Integrated Fruit Production (IFP) programme use pheromone traps to monitor both codling moth and leafroller activity, and respond with insecticides once specified moth activity thresholds are exceeded (Walker et al. 1998). While this approach has successfully reduced pesticide use, the use of sex pheromones incorporated into mating disruption technology offers growers the potential of a pest management system that results in either negligible, or no insecticide residues on harvested fruit.

Mating disruption is an effective strategy for lepidopteran control, but use of this technology by New Zealand growers has been traditionally low compared with that of growers in North America and many European countries. The primary issues affecting uptake include the cost of pheromone dispensers and their application, implementation issues and uncertainty that may affect phytosanitary outcomes and market access. Dispensers have been available for codling moth and three of the pest leafroller species present in New Zealand orchards: lightbrown apple moth (LBAM) (*Epiphyas postvittana*), brownheaded leafroller (*Ctenopseustis obliquana*) and greenheaded leafroller (*Planotortrix octo*). The cost of controlling even two of the four species with separate dispensers is, however, prohibitive. The recent development of a multi-species mating disruption dispenser against the three leafroller species above, called the 3NZLR dispenser (Suckling et al. 2012), has reduced the cost of this technology. The development of a combined codling moth and leafroller pheromone dispenser could further reduce both the production and the application costs, thereby promoting greater uptake of mating disruption.

There are several international examples where multiple species mating disruption systems have been developed for the simultaneous control of codling moth and leafroller species (e.g. Judd & Gardiner 2008).

The aim of this research was to compare the efficacy of a new combination mating disruption dispenser for both codling moth and the three New Zealand leafroller species (marketed as Isomate 4play™, Etec Crop Solutions), against the separate pheromone dispensers for the two groups. The most widespread pest leafroller in New Zealand is LBAM and it was this species that was tested. The primary purpose of these trials was to ensure that there was no 'cross-talk' or interference between the two pheromone blends when operating in the same space with the combined dispenser and to evaluate the implications of combining disruption on insecticide use and pest management outcomes.

MATERIALS AND METHODS

Trial design

Two plots on each of four orchards in Hawke's Bay were randomly allocated a treatment, either the combination or standard pheromone dispensers. Treated plots were 1.5–3.2 ha in size and each plot was comprised of 1–3 apple cultivars. In total there were 18 cultivar blocks within the eight treatment plots. Seven of these blocks were Gala type apples and the rest were the later harvested cultivars 'Fuji', 'Pacific Queen', 'Scifresh' (Jazz™) and 'Braeburn'.

Pheromone dispensers

The new combination codling moth and leafroller mating disruption dispensers comprised a single-species codling moth dispenser (Isomate®CPlus) and a 3NZLR dispenser (both Shin Etsu Fine Chemicals Ltd) that were fused together. Their performance was compared against that of another single-species codling moth dispenser already being used on the orchards (NoMate® CM, Scentry Biologicals) and the multi-species leafroller dispenser (3NZLR). The combination and NoMate CM dispensers were put out in mid October 2010, followed by the 3NZLR dispensers in early November 2010.

The combined pheromone formulation was applied at 800 dispensers/ha, compared with 1000 and 600 dispensers/ha for Isomate®CPlus and 3NZLR respectively. The amount of codling moth pheromone in the combined dispenser was increased to give an equivalent quantity per hectare as that in the Isomate®CPlus dispenser. The amount of leafroller pheromone was also adjusted to account for the different application rates and date of application. The combined dispenser was put out a month earlier than is usual for 3NZLR dispensers.

Treatment evaluation

The effectiveness of the treatments was evaluated in three ways: pheromone trap catch, suppression of virgin female moth mating and the incidence of codling moth and leafroller fruit damage at harvest. In each orchard, high-dose pheromone 10X caps (1 mg for codling moth and 1.05 mg for LBAM) were used to monitor male moth activity from November 2010 to March 2011. Codling moth traps were attached to bamboo poles and placed in the upper canopy (~3.5 m high), with two traps 40 m inside and four perimeter traps (one on each side) per plot. LBAM were monitored using four perimeter traps per plot placed in the lower canopy (~1.5 m high) (Walker et al. 2011). Traps were inspected and cleared weekly, sticky bases were changed every 3 weeks and pheromone lures were replaced 6-weekly.

Single virgin female moths were tethered onto paper placed inside delta pheromone trap bodies that served as mating stations (Walker et al. 2011). This was conducted between December 2010 and February 2011 for codling moth, and in February and March 2011 for LBAM. In each plot, four stations were placed on outside trees along each perimeter, while eight traps were placed at least 40 m from a plot edge. Tethered moths were also placed in two non-pheromone-treated orchards that had a minimal or no insecticide programme, to compare the frequency of mating in a control group. After being left out for 3 days the moths were dissected to determine their mating status. Fruit damage at harvest was assessed by sampling 100 fruit from each of 10 field bins per cultivar block in each plot.

Insecticide programmes and data analysis

An insecticide was applied at a pre-determined point, BIOFIX +~100 growing degree days (J.T.S. Walker, unpublished data), to coincide with codling moth egg hatch as recommended by the IFP guidelines. Insecticides for codling moth and leafrollers were subsequently applied only when trap catch thresholds were exceeded (Anonymous 2012). If either codling moth or leafroller thresholds were exceeded on an orchard, then both pheromone treatment blocks were sprayed with an insecticide.

Data were summarised by property, treatment (dispenser type), month and location (interior or perimeter of plot). For pheromone trap catches a generalized linear mixed model (GLMM) with a Poisson distribution was fitted to the mean count per trap per week. The virgin female moth data were analysed using a binomial generalized linear model (GLM). The incidence of fruit damage was analysed by fitting a Poisson GLM (codling moth) or a GLMM with a Poisson distribution (LBAM). Initially GLMMs were fitted for both species, but for codling moth the property to property random effect was not significant, and so a GLM could be fitted.

RESULTS

Pheromone trap catch

The overall average weekly moth catch was similar (codling moth $P=0.556$, LBAM $P=0.469$) for plots treated with combination or standard dispensers, although there was some orchard to orchard variation (Figure 1). Average catches varied monthly for both species, but the trends were similar for each type of dispenser (Table 1). Perimeter traps caught more moths than internal traps (codling moth $P<0.001$, LBAM $P=0.003$; data not shown).

Virgin female moth mating

A total of 334 codling moths was placed in dispenser-treated plots and the mating status of 270 moths was able to be determined. Another 67 moths (44 status-determined) were placed in untreated orchards. The respective figures for LBAM were 269 (231) and 86 (54).

Figure 1 Average codling moth and lightbrown apple moth catch per trap per week in 2010-11, on four Hawke's Bay apple orchards (A-D) comparing plots treated with combination dispensers against blocks treated with NoMate® CM and 3NZLR dispensers for codling moth and leafrollers respectively.

A similar proportion of female moths in combination and standard dispenser plots were mated for both codling moth (~4%, $P = 0.683$) and LBAM (~5%, $P = 0.520$) (Figure 2). More mating occurred on the perimeter of blocks than internally ($P=0.030$ for codling moth, $P=0.009$ for LBAM) for both dispenser types. In contrast, approximately 40% of codling moth and LBAM were mated in the untreated orchards.

Incidence of fruit damage at harvest

A very low incidence of fruit damage occurred in all except one plot, and damage in the two dispenser treatments was not significantly different for codling moth ($P=0.654$) or leafrollers ($P=0.074$) (Figure 3). Only for LBAM

Figure 2 Percentage of tethered virgin female moths mated on the perimeter or 40 m inside plots treated with combination or standard pheromone dispensers. The percentage of moths mated in two orchards without mating disruption is shown for comparison. Below each column is the number of moths where it could be determined if they had mated or not.

at orchard D was there a large difference in fruit damage between the two treatments. Codling moth damaged fruit was found in three of the four combination dispenser plots and a single codling moth larva was also recovered from two plots. In contrast, codling moth damage was found in only one of the four plots treated with standard dispensers and no larvae were found.

Insecticide use

All 18 cultivar blocks received the early-season spray recommended by the IFP programme. Thereafter, 11 blocks on three orchards received no other insecticides for lepidopteran control, while one block was sprayed once more. On the fourth orchard, the six blocks were sprayed

Table 1 Monthly average codling moth and lightbrown apple moth trap catch per week in Hawke's Bay apple orchards treated with combination and standard (NoMate® CM or 3NZLR) pheromone dispensers during 2010-11. Values are the mean for four orchards.

	Codling moth		Lightbrown apple moth	
	Combination	NoMate	Combination	3NZLR
November	0.00	0.08	-	-
December	0.13	0.18	0.23	0.18
January	0.20	0.46	0.34	0.35
February	0.67	0.66	0.40	0.53
March	0.11	0.10	1.43	2.06

Figure 3 Percentage of fruit at harvest with codling moth and lightbrown apple moth damage and larvae from four Hawke's Bay apple orchards treated with combination and standard pheromone dispensers during 2010-11. The number of fruit examined is shown below each column.

twice more for codling moth, and three blocks of later varieties also received one leafroller-specific insecticide.

DISCUSSION

Before any new control measure can be used in a regulatory pest management programme, it is essential to demonstrate that its efficacy is at least equivalent to that of standard treatments. It was possible that having two pheromone blends in close proximity (as in the combination dispenser) could have caused interference to the response of male moths, with a consequent loss of mating disruption efficacy. However, there was no evidence of any interference to mating disruption of codling moth or LBAM in these trials.

It was shown by three distinct measures that the performance of the combination dispensers was comparable to that of the two dispensers separately. There were similar numbers of both species trapped in the two dispenser treatments. The suppression of trap catch is a consequence of the deployment of pheromone dispensers. It would have been useful to compare moth catch between treated and untreated plots, which is one measure of the dispenser effectiveness (i.e. trap 'shut-down'). However, this was not feasible because commercial orchardists cannot leave blocks untreated.

The mating or non-mating of virgin female moths within pheromone-treated orchards is a direct measure of the potential effectiveness of mating disruption. In this trial, the incidence of virgin female moth mating was similar for both dispenser types. It is well known that the protective 'pheromone cloud' is more susceptible to wind around the edges of treated areas, and this effect was seen in the higher proportion of moths mated in perimeter stations compared with internal ones. The overall proportion of mating for both species was ~90% lower than in untreated orchards, which was an excellent result. This proportion would be expected to increase as treated areas became larger and the risk from external immigration of moths is reduced.

The incidence of fruit damage at harvest from both codling moth and leafrollers was impressively low in both treatments, particularly given the few insecticides applied. The combination dispensers, supplemented with one insecticide application in most blocks, limited damage or larval infestation to approximately 0.1% or lower for both codling moth and leafrollers. Even on late harvested varieties such as 'Fuji' and 'Braeburn', the number of lepidopteran insecticide applications was usually one and no more than four.

Codling moth and leafroller mating disruption potentially provides control of these important phytosanitary pests, with minimal use of insecticides and a greatly reduced risk of associated residues on fruit at harvest. A serious limitation to its greater use has been the high cost of this technology. In 2009, dispensers for codling moth and LBAM cost approximately \$500 and \$350 per ha respectively. In addition, installation costs of about \$60 per ha for each dispenser, brought the annual cost of both codling moth and leafroller mating disruption to close to \$1000 per ha. Such a cost was prohibitive when an insecticide-based programme for their control was in the range of \$500-750 per ha. Installation of a single disruption system (e.g. codling moth) is also challenged by the necessity to continue insecticide applications for leafroller control. Not all growers need to control the four species covered by the combination dispenser. For example in Nelson, the great majority of growers

only need to control LBAM, because populations of codling moth and native leafrollers are much lower than in Hawke's Bay.

A major advantage of the combined dispenser was that it reduced the total time required for dispenser application of the two pheromone blends by more than 50% compared with single dispenser applications (1000/ha for codling moth and 600/ha for leafrollers). This multiple species approach to control substantially reduced the need for specific treatments for either codling moth or leafrollers, with 11 of the 18 cultivar blocks used in this study achieving acceptable control of both species with just one insecticide application all season. Extending the use of mating disruption to the complex of pest leafroller species provides a real opportunity to significantly reduce insecticides for tortricid pest control and provides an opportunity to further reduce the presence of insecticide residues on harvested fruit. Importantly, this new technology provides growers with the flexibility to grow fruit for both 'pest-free' and 'residue-free' markets.

ACKNOWLEDGEMENTS

This research was funded by the Ministry for Primary Industries' Sustainable Farming Fund, Pipfruit New Zealand Incorporated and Etec Crop Solutions Ltd. We thank Apollo Apples Ltd for providing orchard trial sites and applying the pheromone dispensers. The combination and 3NZLR dispensers were supplied by Shin-Etsu Fine Chemicals Ltd, Japan. Moth pupae were supplied by Anne Barrington, while Cathy McKenna and Peter Shaw (all Plant & Food Research) made useful comments to a draft manuscript.

REFERENCES

- Anonymous 2012. New Zealand Pipfruit-Integrated Fruit Production manual©. Pipfruit New Zealand, Hastings, New Zealand.
- Judd GR, Gardiner MT 2008. Efficacy of Isomate-CM/LR for management of leafrollers by mating disruption in organic apple orchards of western Canada. *Journal of the Entomological Society of British Columbia* 105: 45-60.
- Plant & Food Research 2011. FreshFacts. New Zealand Horticulture. 2011. New Zealand Institute for Plant & Food Research Limited, Auckland, New Zealand. (www.freshfacts.co.nz, accessed 10 April 2013). 32 pp.
- Suckling DM, McLaren GF, Manning LM, Mitchell VJ, Attfield B, Colhoun K, El-Sayed AM 2012. Development of single-dispenser pheromone suppression of *Epiphyas postvittana*, *Planotortrix octo* and *Ctenopseustis obliquana* in New Zealand stone fruit orchards. *Pest Management Science* 68: 928-934.
- Walker JTS, Wearing CH, Bradley SJ, Shaw PW, Burnip GM, Tomkins AR, Richardson CA, Hodson AJ 1998. Integrated Fruit Production (IFP) for New Zealand pipfruit: evaluation of pest management recommendations. *Proceedings of the 51st New Zealand Plant Protection Conference*: 166-172.
- Walker JTS, Rogers DJ, Lo PL, Suckling DM, El-Sayed AM, Fraser TM, Horner RM 2011. Use of mating disruption for control of New Zealand leafrollers in apple orchards. *New Zealand Plant Protection* 64:215-221