Update on Diamondback Moth (*Plutella xylostella*) insecticide resistance and the vegetable brassica insecticide management strategy

G.P. Walker[1], F.H. MacDonald[1], S.I. Davis[2] and T.J.B. Herman[3]

[1]*The New Zealand Institute for Plant & Food Research Limited, Private Bag 92169 Auckland 1142, New Zealand*
[2]*LeaderBrand Produce Ltd, PO Box 648, Gisborne 4040, New Zealand*
[3]*Fruitfed Supplies, PO Box 322, Hastings 4156, New Zealand*

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

Abstract The susceptibility of field populations of diamondback moth (DBM), *Plutella xylostella,* to lambda-cyhalothrin, methamidophos, spinosad and indoxacarb collected from the four major brassica-growing regions has been assessed approximately every two years from 1997 to 2008. Recent results indicate that populations from all regions have increased their resistance to lambda-cyhalothrin, but there is little or no resistance to spinosad and indoxacarb and reduced resistance to methamidophos. This mitigation of resistance in DBM is attributed partly to a decade-long regional adherence by the vegetable industry of, in particular, rotating spinosad with indoxacarb in a two-windows-per-year rotation strategy. The original insecticide resistance management rotation strategy had to be updated to incorporate chlorantraniliprole registered as a foliar spray, and recently a mixture of chlorantraniliprole and thiamethoxam as a seedling drench. Seedling drenches have been removed from the two-window strategy used for foliar sprays, with drenches now aligned with periods targeting the highest pest pressure, allowing mode of action (MoA)-free periods and rotation of different MoA insecticides to mitigate any resistance build-up in DBM.

Keywords Diamondback moth, *Plutella xylostella*, insecticide resistance, insecticide resistance management rotation strategy.

INTRODUCTION

Over the last twenty five years, researchers and the vegetable industry have developed, implemented and advanced an integrated pest management (IPM) programme for vegetable brassicas in New Zealand (Berry et al. 2000; Walker et al. 2009). The first implementation period was prompted by the build-up of resistance in diamondback moth (DBM), *Plutella xylostella* to a standard pyrethroid, lambda-cyhalothrin. Resistance reached levels in three regions equivalent to those associated with control failures in North America (Cameron & Walker 1998). The levels of resistance recorded for the standard organophosphate, methamidophos, were also likely to cause control failures (Cameron et al. 1997). The implementation phase of this IPM programme also included the publication of the first version of the IPM manual for vegetable brassicas that included an insecticide resistance management rotation strategy (Berry et al. 2000). This strategy recommended that insecticides be applied only in response to pest populations exceeding the specific action thresholds for cabbage, cauliflower and broccoli, and that Bt (*Bacillus thuringiensis*) products be applied to early crop stages. Then, when applications of insecticides were required for control of lepidopteran pests, the strategy relied on the use of spinosad (Success™ Naturalyte™) in the first part of the season from September to late January (the early 'window'), at which time growers should stop using spinosad and change to using indoxacarb (Steward®) from the beginning of February onwards (Berry et al. 2000; Walker et al. 2011). These dates divide the year equally into the same number of DBM generations, normally six generations, based on heat unit accumulations. Walker et al. (2004) reported that the

vegetable industry accepted recommendations that long-term mitigation of insecticide resistance in DBM required regular monitoring of trends in resistance to the most commonly used insecticides in the major vegetable brassica-growing regions. These surveys were supported by industry initiatives, including funding from agrichemical companies for surveys on the status of susceptibility of DBM populations to the newly registered products spinosad and indoxacarb. The trends in resistance were monitored by comparing susceptibilities with those of a standard susceptible laboratory colony which has been maintained at Mt Albert Research Centre, Auckland, without exposure to any insecticides since 1993 (Walker et al. 2011).

This IPM programme was updated in 2009 (Walker et al. 2009). However, the insecticide resistance management rotation strategy for control of DBM now requires further modification. An informal DBM insecticide resistance management working group was formed in 2009, consisting of the senior authors and New Zealand-based managers of the agrichemical companies that had insecticides registered for use in control of DBM in vegetable brassicas. This group liaised with regional grower representatives and the Brassica Crop Advisory Group of Vegetables New Zealand, to update the insecticide rotation strategy. This group also liaised with representatives of the New Zealand Pesticide Resistance Management Committee and the international Insect Resistance Action Committee (IRAC) Diamide (Group 28) working group.

The aim of this paper is to report on the current status of insecticide resistance in DBM in New Zealand and to document the updated resistance management rotation strategy.

CURRENT STATUS OF INSECTICIDE RESISTANCE IN DIAMONDBACK MOTH IN NEW ZEALAND

Recently, Plant & Food Research published the results of surveys of the levels of resistance in DBM collected from the key regions where vegetable brassicas are grown - Pukekohe, Gisborne, Horowhenua and mid Canterbury (Walker et al. 2011). Results indicated that populations from all regions have increased their resistance to lambda-cyhalothrin (Karate® Zeon), the standard pyrethroid tested, but there was little or no resistance to spinosad (Success™ Naturalyte™) and indoxacarb (Steward®) and reduced resistance to the organophosphate, methamidophos. The highest level of resistance to lambda-cyhalothrin was 885 times in a population sourced from Pukekohe (compared with the susceptible reference colony), but DBM showed high levels of resistance to pyrethroids in all of the surveyed regions. The results also indicated that resistance was variable not only between regions but also within regions (Walker et al. 2011). DBM resistance to lambda-cyhalothrin was significantly higher in South Auckland than elsewhere and resistance to this product has been increasing over time (Walker et al. 2004; Walker et al. 2011). This problem may well be due to continued use of this product for control of other insect pests in the warmer, northern regions of New Zealand, where the noctuid species *Thysanoplusia orichalcea* and *Helicoverpa armigera* are important caterpillar pests in summer and autumn crops (Walker et al. 2009). Lambda-cyhalothyrin is also used in this region to control infestations of *Thrips tabaci* (onion thrips) in leafy vegetable crops (Young 2012).

THE INSECTICIDE RESISTANCE MANAGEMENT ROTATION STRATEGY FOR DIAMONDBACK MOTH

Resistance in DBM to insecticide classes other than the pyrethroids appears to have been well managed over the last decade because of the country-wide adoption of an insecticide resistance management rotation strategy (Walker et al. 2004; Walker et al. 2011). This strategy depended on growers on a regional basis following IPM practices and using action

thresholds to minimise spraying insecticides. When applications of insecticides were required, the two-window strategy was used, with products positioned for use either in an early- or a late-window period, with growers changing to an insecticide from a different group (with a different mode of action) at the end of each window period. We believe this practice is the reason resistance in DBM has not developed to spinosad and indoxacarb in New Zealand. This strategy has had to be modified with the advent of new insecticide products, particularly to accommodate the use of pre-transplant drenches. The updated strategy is presented in Table 1. Table 2 presents a list of registered products and groups of insecticides used against brassica pests, their resistance grouping and activity profiles.

Table 1 Diamondback moth insecticide resistance management rotation strategy for vegetable brassicas (updated March 2012).

INSECTICIDE USE WINDOWS:						
Sep.-Nov.	Dec.-Jan.	Feb.	Mar.	Apr.	May	Jun.-Aug.
DIAMIDE/NEONICOTINOID INSECTICIDES						
Transplant drench **OR:**	chlorantraniliprole + thiamethoxam (Durivo™)[1] imidacloprid (Confidor®)					
Foliar spray	chlorantraniliprole (Coragen™)[2]					
OTHER INSECTICIDE GROUPS[3]						
Apply insecticides only in response to scouting thresholds						
Bacillus thuringiensis (Bt)[4]						
indoxacarb (Steward®)	spinosad (Success™ Naturalyte™) fipronil (Ascend®) synthetic pyrethroids[5,7]					
organophosphates[6,7]						
pymetrozine (Chess®) (for aphids only)	pirimicarb (for aphids only)[7]					

[1] Coragen and Durivo have an active ingredient (chlorantraniliprole) in common. If Durivo is used (as a transplant drench), it should not be followed with Coragen on that crop.
[2] Coragen can be used (as a foliar spray) in the period 01-Dec, to 30-April, but not on crops treated with Durivo (as a transplant drench).
[3] From any one insecticide group, use a maximum of two consecutive applications (less than 15 days apart) in the life of a single crop.
[4] Apply Bt to small larvae on small plants.
[5] There is resistance to synthetic pyrethroids in some populations of diamondback moth (DBM). The use of this group should be avoided in areas where resistance is known to exist. Consult your local pest control advisor before use.
[6] Organophosphates are best used sparingly either against high infestations of early season seedling pests or as an end of crop 'clean-up' application.
[7] Green peach aphid, *Myzus persicae*, and onion thrips, *Thrips tabaci*, are known to be resistant to broad-spectrum insecticides in New Zealand. Unnecessary application of these groups should be avoided as much as possible.

Table 2 A list of registered products and groups of insecticides used against brassica pests, their Insect Resistance Action Committee (IRAC) resistance grouping and activity profiles against diamondback moth (DBM) and other key pests.

Product(s)	Active ingredient/group	IRAC resistance group	Activity against key brassica pests		
			DBM & other caterpillars	Aphids	Thrips
Durivo™	chlorantraniliprole+ thiamethoxam	28+4A			
Confidor®	Imidacloprid	4A			
Coragen®	chlorantraniliprole	28			
Steward® 150 SC	Indoxacarb	22A			
Chess® WG	Pymetrozine	9B			
Success® Naturalyte®	Spinosad	5			
Ascend®	Fipronil	2B			
Various	synthetic pyrethroids	3A			
Various	organophosphates	1B			
Various	Pirimicarb	1A			

Activity against brassica pests:

= label claim

= known activity

= no activity known

DISCUSSION

The new strategy has been designed to ensure that diamides are not used all year round, in order to preserve the effectiveness of these products for as long as possible. The window for use of Durivo™ drench has been moved to cover the main part of the year where DBM is an issue i.e. drenching transplants from 1 December to 31 March (approximate harvest period 1 February to 30 June). This revised window has been designed so that there is an adequate window for at least the season's first generation of DBM to be completed in a diamide-free period. In the absence of Durivo-drenched plants, the foliar spraying of chlorantraniliprole (Coragen®) may be used within the same window period as for Durivo. However, Coragen should never be applied to plants drenched with Durivo.

Compared with the former strategy, the two 'soft' DBM insecticides indoxacarb (Steward) and spinosad (Success Naturalyte) have been transposed between the early and late windows. This means that spinosad will be used in the late season when its activity against thrips (as well as caterpillars) would be more useful. It is recommended that growers adopt this practice in other IPM programmes that use these two insecticides.

The new strategy has been designed assuming that the industry will retain the ability to use organophosphates as a "break group" for resistance management when required. Low use of organophosphates over recent years has resulted in a decline in organophosphate resistance in New Zealand populations of DBM (Walker et al. 2011), illustrating the importance of having multiple groups of insecticides available for effective resistance management. The current main uses of organophosphates are in transplant nurseries (as a replacement for groups that will be subsequently used in the field) and as late-season short withholding period clean-up applications. Other uses are against occasional establishment pests (such as wheat bug, thrips, greasy cutworm, leaf miners and springtails). It is recommended that

organophosphates should be used only when there is a real need, with a maximum of two consecutive applications on a single crop. This should restrict organophosphates to a single pest generation in any location. If they are used in this way, it is considered that there is no need for a particular window for organophosphates. This will allow their use for crop clean-up, rotation breaks or their availability to address issues such as leaf miners in leafy brassicas, which can occur at any time and where organophosphates are an effective insecticide group.

Management of diamondback moth and other key pests in vegetable brassicas

Growers should monitor plants to ensure insecticides are applied only when necessary. The IPM programme developed by Plant & Food Research includes a cost-effective crop scouting system and action thresholds for cabbage, cauliflower and broccoli crops (Walker et al. 2009). If the action thresholds for caterpillar pests are exceeded, growers should rotate insecticide groups in accordance with the national rotation strategy outlined above.

Growers throughout the country need to conform to this rotation strategy so that DBM populations do not develop resistance to any particular insecticide group. By rotating between different MoA groups of insecticides, any localised population that is developing resistance to a particular MoA will be reduced by the application of another group (MoA) of insecticide. The long-term sustainability of the updated IPM programme for vegetable brassicas relies on all brassica growers minimising insecticide use and using this updated insecticide rotation strategy.

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