Science behind the Resistance Management Strategy for diamondback moth (*Plutella xylostella*) in Australian canola crops

Developed by the grains National Insecticide Resistance Management (NIRM) working group of the Grains Pest Advisory Committee (GPAC)

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Table 1. Background information on diamondback moth (DBM), *Plutella xylostella*

Attribute	**What is known about DBM?**	**References**	**Knowledge gaps**

Economic importance to grains	• DBM is a major pest of canola and mustard* crops, particularly at flowering and podding, and of brassica vegetable crops and forage brassicas.
	• Economic losses to the canola grains industry are considerable.
	• Economic impact varies across regions and years
	    o regions commonly affected by DBM include Eyre Peninsula SA and the northern wheatbelt of WA
	    o outbreak frequency generally 1 in 3-5 years
	• *P. australiana* recently described cryptic species. Economic status unknown.
		Furlong *et al.* 2008; Murray *et al.* 2013; Landry & Hebert 2013.	• Models to forecast intensity of seasonal outbreaks within districts and across regions.
			• Pest status and biology of *P. australiana*.

Mode of reproduction	• Sexual reproduction, nocturnal. • Males respond to sex pheromones released by receptive (calling) females. • Sex pheromone components characterized and available in commercial blends.	Talekar & Shelton 1993; Tamaki *et al*. 1977.	• The potential of mating disruption as a cost-effective DBM management tactic in vegetables. (Advantage to grains: reduce the selection rate for insecticide resistance in Australian DBM pops.)
Life cycle (incl. # generations)	• Australian climate supports DBM development and reproduction year-round (exception: some inland desert regions). • DBM typically completes 3-5 generations per canola growing season, 8-12+ generations pa in brassica vegetable crops. • DBM canola infestations generally peak in early-mid spring. By this time all life-stages overlap (making a difficult insecticide target).	Zalucki and Furlong 2011. Ridland & Endersby 2006.	• Accurate predictions of conditions leading to DBM outbreaks in canola.
Crop hosts	• Canola and mustard grain crops, brassica vegetable crops		• Dynamics of DBM movement

	and forage brassicas. • Significant canola compensation to DBM foliar damage, highlighting importance of thresholds.	Baker 1985.	between canola and other brassica crop sources. (Kym Perry PhD)
Non-crop hosts	• Brassicaceae weeds, e.g. Lincoln weed, mustard weed, turnip weed, Ward's weed, dog weed etc.. • Recorded on native *Lepidium hyssopifolium*, and likely to occur on other native Brassicaceae.	Common 1990.	• Role of weed hosts as local refugia for DBM and DBM parasitoid pops.
Distribution	• Cosmopolitan, greatest pest status in tropic-subtropic zone. Bioclimatic modelling illustrates the population-limiting effects of high rainfall and extreme temperatures, which can preclude year-round persistence in some global regions. • Locally, Australia wide; very common across all grain growing regions in WA, SA, VIC, NSW and QLD.	Zalucki *et al*. 2012; Furlong *et al*. 2013.	• Seasonal changes in DBM distribution including source/sink areas
Dispersal/movement	• DBM is a seasonal migrant, seeking new host sources when the current host patch senesces. • DBM flight activity in southern Australia increases in spring, before decreasing during summer. • In early winter young canola crops are colonized by DBM moths. The source(s) of these colonizers is often uncertain, but in many instances is thought to be local wild hosts (eg. southern Eyre Peninsula, SA, where insecticide resistance profiles of DBM on green-bridge weeds and volunteer canola match those of the local canola crops). • Genetic analysis shows no strong differentiation between populations of DBM across Australia, suggesting widespread gene flow across regions of Australia and/or that they were derived from a common ancestral source population (approx. 130 years ago).	Endersby *et al*. 2006; Furlong *et al*. 2008; Saw et al. 2006; Schellhorn *et al*. 2008; Schellhorn *et al*. 2008; Schellhorn *et al*. 2004	• Knowledge of dispersal ecology and sources of crop-colonizing DBM populations is required for reliable pest forecasting. • Though genetic studies have found evidence for frequent gene flow among DBM populations within individual regions (around the world), dispersal/migration routes remain to be identified. Newer molecular tools may provide more resolution in the near future.
Feeding behaviour & oviposition	• Chewing pest; larval feeding can cause extensive damage to canola foliage, inflorescences and pods.	Baker 1985; Cook *et al*. 2000;	• Refinement of economic thresholds for canola crops under

behaviour	• Older larvae feed on the underside of leaves, causing ragged holes and 'windows' with the upper leaf surface intact. • Canola has significant capacity to compensate for defoliation loss. However severe infestations can cause complete defoliation and substantial yield losses. • As flowering commences, DBM larvae can move to and cause loss of floral buds, flowers and young pods, and later cause scarring of the outer walls of maturing pods. The damage to these reproductive parts can reduce seed number & size. • Economic thresholds are available (based on 2000-02 WA studies.	Broad *et al.* 2008; Broad *et al*. 2008	different field scenarios.
Chemical controls	• Chemicals remain central to control in canola and also in the forage and vegetable brassica industries. • There are approximately 170 insecticide products registered in Australia for DBM control, but these are primarily from two old chemical groups - organophosphates and synthetic pyrethroids – to which DBM has evolved high levels of resistance. • Since 2012 two newer MOA insecticides have been registered for DBM control in canola crops (Group 5 spinetoram and Group 6 emamectin benzoate). (Spinetoram is also registered in forage brassicas.) • In addition to these two, another four newer insecticides with different MOA are registered for DBM control in brassica vegetable crops. • Globally, resistance to over 82 insecticide compounds recorded.	Furlong *et al*. 2008. Furlong *et al.* 2013.	• Need for more alternative chemistries. • Economic thresholds and/or predictive models. • Measurement of the cost-effectiveness of Bt spray control (direct control + beneficial preservation effect).
Biological control options	• Three parasitoids (*Diadegma semiclausum*, *Diadromus collaris* and *Cotesia plutellae*) have been successfully	Baker 1985;Furlong *et al*. 2008; Bianchi	• Monitoring tools so that beneficial levels can be factored into ET spray

	introduced to Australia for the biological control of DBM. • They supplement a range of native parasitoids (e.g. *Apanteles ippeus*, *Diadegma rapi*) and various polyphagous predators (e.g. nabid and pentatomid bugs, coccinellids, hemerobiid lacewings, lycosid and other spiders, etc.) that provide biotic regulation of DBM. • Epizootics of the fungal pathogen *Zoophthora radicans* can cause spectacular reductions in DBM pops in canola crops.	*et al*. 2009; Li *et al*. 2007; Hamilton *et al*. 2004; Hamilton *et al*. 2006.	decisions. • Host sources of beneficials, particularly parasitoid pops, which colonize canola crops.
Other control options	• Mating disruption using female sex pheromone. Potentially feasible for vegetable crops using new application technologies (eg. SPLAT®). Not presently being practiced or trialled in Australia. • Magnet® Attract-and-Kill technology (contains plant volatile moth attractants and the toxicant spinetoram). Being tested as a DBM control tactic.	Wu *et al.* 2012. Peter Gregg (UNE), pers. comm.	

* Mustard (*Brassica juncea*) is a less commonly grown brassica oilseed crop in Australia. In this table all further references to canola (*B. napus*) also apply to mustard.

Table 2. Products with label claims for diamondback moth control in Australia

IRAC MoA group	Insecticide category	Example trade names	Active ingredient	Registered crops and pastures
Group 1A	Carbamates	Carbaryl	carbaryl	Brassica vegetables
Group 1A	Carbamates	Lannate, Marlin	methomyl	Canola (WA only)
Group 1B	Organophosphates	Lancer, Orthene	acephate	Brassica vegetables
Group 1B	Organophosphates	Chlorpyrifos, Lorsban, Strike Out	chlorpyrifos	Canola, brassica vegetables, forage brassicas
Group 1B	Organophosphates	Diazinon, Diazol	diazinon	Canola, brassica vegetables
Group 1B	Organophosphates	Hy-mal, Fyfanon	maldison	Canola, brassica vegetables
Group 1B	Organophosphates	Phosdrin	mevinphos	Brassica vegetables
Group 1B	Organophosphates	Tokuthion	prothiofos	Brassica vegetables
Group 1B	Organophosphates	Lepidex	trichlorfon	Brassica vegetables
Group 2B	Phenylpyrazoles	Regent, Fipronil	Fipronil	Brassica vegetables
Group 3A	Pyrethroids	Fastac, Dominex Duo, Astound	alpha-cypermethrin	Canola, brassica vegetables, forage brassicas
Group 3A	Pyrethroids	Chix, Banshee	beta-cypermethrin	Canola, brassica vegetables
Group 3A	Pyrethroids	Scud Elite	cypermethrin	Canola, brassica vegetables
Group 3A	Pyrethroids	Decis Options, Ballistic Elite	deltamethrin	Canola, brassica vegetables
Group 3A	Pyrethroids	Trojan	gamma-cyhalothrin	Canola, brassica vegetables
Group 3A	Pyrethroids	Karate Zeon, Matador	lambda-cyhalothrin	Canola, brassica vegetables, forage brassicas
Group 3A	Pyrethroids	Sumi-alpha Flex	esfenvalerate	Canola, brassica vegetables
Group 3A	Pyrethroids	Ambush, Hellfire, Pounce, Axe	permethrin	Canola, brassica vegetables
Group 3A	Pyrethroids	Klartan, Mavrik	tau-fluvalinate	Brassica vegetables
Group 5	Spinosyns	Success Neo	spinetoram	Canola, brassica vegetables, forage brassicas
Group 6	Avermectins	Affirm, Proclaim	emamectin benzoate	Canola, brassica vegetables

Group 11A	Bacillus thuringiensis	Dipel, Delfin, Agree	B.t. subsp. kurstaki	Canola, brassica vegetables
Group 11A	Bacillus thuringiensis	Xentari	B.t. subsp. aizawai	Brassica vegetables
Group 13	Pyrroles	Secure	chlorfenapyr	Brassica vegetables
Group 22A	Oxadiazines	Avatar	indoxacarb	Brassica vegetables
Group 28	Diamides	Coragen	chlorantraniliprole	Brassica vegetables
Group 28	Diamides	Belt	flubendiamide	Brassica vegetables
Group 28/4A	Diamides / Neonicotinoids	Durivo	chlorantraniliprole & thiamethoxam	Brassica vegetables

Source: APVMA-Public Chemical Registration Information System Search (PubCRIS), Australian Pesticides & Veterinary Medicines Authority; accessed February 2016.

To summarize, although there are approximately 170 different products from ten different IRAC MoA groups registered for the control of DBM in Australia, there are only two synthetic insecticides (Group 5 spinetoram and Group 6 emamectin benzoate) and several *Bacillus thuringiensis* var. *kurstaki* products (Group 11A) that are currently registered for use in canola and capable of reliably providing efficacious control of DBM.

The synthetic pyrethroid (Group 3A) and organophosphate (Group 1B) products are generally ineffective because of the significant resistance to each of these Groups that occurs in virtually all DBM populations.

The strategy to manage the insecticide resistance risk associated with DBM chemical control in canola presented in this paper (Table 5) only includes the three currently registered and effective IRAC MoA groups, namely Groups 5, 6 and 11A.

Industry chemical use and secondary chemical exposure:

The DBM insecticide control practices presented in this paper are based on phone surveys of agronomists in SA, WA and VIC and the prior knowledge of the senior author.

DBM outbreaks are sporadic. They vary in frequency between canola growing regions, from one in every two to three years (eg. SW Eyre Peninsula of SA, northern wheatbelt of WA) to one in five or more years (e.g. cool, high rainfall zone districts of Victoria). The regions that experience the more frequent outbreaks are generally in the warmer, drier range of canola production, and these outbreaks are often associated with summer-autumn rains that support growth of 'wild' brassicas and early sowing. In years when a district experiences a DBM outbreak, typically 50% or more (at times up to 95%) of the canola crop in the district will be sprayed for DBM control, usually once but occasionally twice. Most DBM spraying occurs in early to mid-spring during flowering and pod formation and filling, but on occasion spray treatments are required to protect establishing crops from defoliation resulting from early DBM build-up.

Until the registration of two new chemistries in 2012 (Affirm® and Success Neo®), the choice and usage of insecticides for DBM control were almost universally a range of synthetic pyrethroid (SP) products, with occasional use of several organophosphates and *Bacillus thuringiensis* var. *kurstaki*. Over the past decade canola growers and agronomists have found that SP treatments, either alone or in OP-mixtures, do not effectively control DBM. Hence since 2012 SP usage for DBM control has been largely replaced by the newly-available Affirm® (Group 6 emamectin benzoate), which has the market advantage of being priced substantially lower than the other new product, Success Neo®(Group 5 spinetoram). It appears that only a few percent of DBM canola applications nationally are Success Neo® or *Bt* var. *kurstaki* products. *Bt* var. *kurstaki* products, which are an intermediate price between the two new synthetic insecticide products, are generally overlooked by agronomists and growers because of the perception that they are less efficacious compared to Affirm®.

Chemical usage against DBM in Australian canola is typically within label recommendations and usually only applied on a case-by-case basis following sweep-net monitoring and reference to ET guidelines.

Table 3. Current status of insecticide resistance in diamondback moth within Australia

Attribute	What is known?	References	Knowledge gaps
Resistance status	• Confirmed widespread and high-levels of resistance to pyrethroids (Group 3A) across Australian canola and vegetable production regions. • Confirmed widespread and moderate levels of resistance to organophosphates (Group 1B) across Australian canola and vegetable production regions. • Low-moderate levels of resistance to emamectin benzoate (Group 6) and several Group 28 insecticides are common across Australian canola and vegetable production regions. (The Group 28 resistance detected in DBM in canola crops is notable given nil canola usage.) • Nil/incipient resistance to spinetoram (Group 5), indoxacarb (Group 22A) and Bt var. kurstaki (Group 11A) in Australian canola production regions.	Baker and Kovaliski 1999; Endersby et al. 2011. G. Baker, K. Powis (unpubl. data).	• Current extent of resistance to new chemistries (Groups 5, 6, 13, 22A and 28) in vegetable production areas.
Mode of Action of resistance & cross-resistance	• Synthetic pyrethroids: mutations in the para-sodium channel (at *kdr*, *skdrl* and *cdr* loci, which cause target site modification) is the main resistance mechanism. Metabolic resistance (probably enhanced action of cytochrome P450 oxidases) is also evident. • Organophosphate resistance probably metabolic. • Group 6 and 28 resistance probably metabolic, with possible cross resistance component.	N. Endersby et al. (2011). G. Baker and K. Powis (unpubl. data).	• Possibility of metabolic cross-resistance between Groups 3A, 1B, 6 and 28.
Known fitness costs	• Field observations and Endersby study (which reported stable levels of field resistance over time) suggest no marked fitness costs associated with SP target site resistance. • Modest fitness costs associated with Group 6 and 28 metabolic resistance in lab.	N. Endersby *et al.* (2011). G. Baker and K. Powis (unpubl. data).	• Assessment of fitness costs.
Genetic basis for resistance	• Synthetic pyrethroids: not fully resolved, but may involve heterozygous (skdrl/cdr) fitness advantage. This would help		• Genetic basis of resistance to other mode of action

	maintain both resistant alleles in pops repeatedly exposed to pyrethroid spraying, especially if there is a fitness cost associated with either homozygote.		groups.
Origin of resistance	• SP and OP resistance likely to have resulted from gene-flow from vegetables and from local selection due to grain crop SP/OP use patterns. • Poor coverage and distribution of larvae throughout the canola canopy commonly results in sub-lethal dosing, which may exacerbate survivorship of resistant (heterozygote) individuals • Selection pressure for resistance to the new DBM insecticides (Groups 5, 6, 13, 22A & 28) is considered low in grains because of: o the low DBM spray frequency (low outbreak frequency, low number of sprays/canola crop in outbreaks), and o nil/minimal other registered uses in canola and other grain crops. • Hence resistance risk to these new DBM insecticides may be more dependent on non-grain use patterns (brassica vegetables and forage crops).		• Gene-flow between canola and other brassica crops (vegetables, forage).

Resistance management & minimisation strategy

The basis of this strategy is to minimise the selection pressure for resistance to the same chemical group across consecutive generations of diamondback moth (DBM) as a result of DBM chemical control in canola crops. The strategy includes three DBM chemical groups - the two synthetic insecticides Affirm® (Group 6) and Success Neo® (Group 5) and the biopesticide *Bacillus thuringiensis* var. *kurstaki* (Group 11A) - each of which provide efficacious field control. It excludes the old synthetic pyrethroid (Group 3A) and organophosphate (Group 1B) products because resistance to these products is ubiquitous in Australian DBM populations at levels that render them ineffective.

'Area-wide' adherence to a window strategy is likely to be a significant challenge while large cost discrepancies between the three available chemical groups continue to drive grower's choices, particularly during outbreaks.

Given that the susceptibility to Btk in screened Australian DBM populations has not declined despite the 45 year history of Btk registration for DBM control in Australian canola, vegetable and forage crops, the resistance risk to Btk products is considered to be low. Group 5 insecticides were first registered for control of DBM in Australian vegetables circa 1999-2000, and the Success Neo® registration was extended to include canola and forage crop use in 2012; however only incipient shifts in susceptibility to spinetoram have been detected thus far in DBM collected from canola (up until 2015) or vegetables (up until 2010), and given the current low use pattern for Success Neo® in Australian canola the resistance risk to Success Neo® as a result of canola use is likewise considered to be low. However there is a detectable shift in susceptibility to Affirm® in Australian DBM populations, and hence it is this Group 6 insecticide that is presently considered at greatest risk from resistance development. The relative contributions of selection pressure on Affirm® from its use in canola, versus Group 6 use in vegetable production, versus metabolic cross-resistance conferred from the use of other pesticides, remains unknown.

DBM appears to be a seasonal migrant in Australia. There is (limited) evidence of spring migrations of DBM; further, resistance profiles of DBM collected from weedy hosts and canola crops reveal similar insecticide resistance patterns on both host sources and across large geographic ranges, and genetic marker studies have revealed little genetic differentiation, each suggesting that a considerable degree of interbreeding and gene flow is occurring. DBM over-summer on irrigated brassica vegetable and forage crops and patches of rain-fed brassica weeds and volunteer canola. However the sources of the DBM that colonize winter-sown canola are not defined. Does significant DBM gene-flow from vegetable and forage crops to canola crops occur? Subject to the answer to this question, insecticide selection pressures on DBM in vegetable (and forage) crops may have significant bearing on the trajectory of insecticide resistance to the newer chemistries in DBM populations that colonize canola crops. And hence the capacity of this proposed resistance management strategy to limit the development of insecticide resistance in canola populations of DBM in future years may be as dependent on DBM management practices in vegetable (and forage) crops as it will be on canola grower compliance with the strategy.

The incorporation of IPM strategies for DBM management in canola is integral to underpinning a reduction in DBM insecticide use and thereby helping to minimize resistance selection pressures in canola crops.

Finally, there is clearly a need for new chemical options to control DBM in Australian canola crops, as the limited options currently available to growers make it difficult to use the alternation of chemical groups for long-term resistance management.

Resistance Management Strategy for Diamondback Moth (DBM) in Australian Canola

INTRA-SEASON MANAGEMENT

1. **Summer-Autumn: Pre-season**

Summer rainfall events can generate brassica 'green-bridge' growth, which can support DBM (e.g. volunteer canola, Lincoln weed, etc.).

In years when the brassica green-bridge is abundant and extends through March-April there is a higher risk of earlier and greater DBM colonization of canola crops, requiring increased attention to early crop monitoring. The DBM risk associated with summer-autumn green-bridge may also extend to higher DBM populations in the early spring. In districts that experience frequent DBM outbreaks and year-to-year carryover of DBM populations on local green-bridge growth, area-wide green-bridge control has the potential to benefit DBM management.

2. **Crop Stage: Pre-flowering**

Monitor at 3-4 week intervals from establishment using either visual inspection (up to the rosette stage) or a sweep net (stem extension onwards). See sweep net monitoring instructions below.

More frequent monitoring is advised in years when the DBM risk is greater, namely years with substantial green-bridge over summer and when dry conditions and/or above average temperatures occur during autumn and winter.

Grazing + Grain: Where possible manage DBM foliar feeding by strategic grazing.

> If unable to introduce stock to manage DBM, apply a Bt spray[ab] if the economic threshold (ET) is reached (refer to Thresholds table below).
>
> (Note that the same recommendations apply for forage brassicas.)

Grain only: If the economic threshold (ET) is reached apply a Bt spray[ab].

3. **Crop-Stage: Flowering/Podding (Grain only and Grazing+Grain crops)**

Monitor crops using a sweep-net at fortnightly intervals throughout flowering to windrowing/harvest (more frequently when weather dry and/or temperatures are above average).

> Sweep-net monitoring instructions: Take a minimum of 5 sets of 10 sweeps in several representative parts of the crop and calculate the average number of the larvae (caterpillars) per 10 sweeps. In addition to scoring the DBM larvae, record

the numbers of larvae of other moth pests (eg. native budworm, cabbage centre grub) and the numbers of DBM natural enemies (See natural enemy table).

If the DBM ET is reached (refer to the Thresholds table below) a spray treatment is recommended.

Spray product choice:

i) If controlling DBM alone, apply a Bt[c], Affirm[d] or Success Neo[d] spray.

ii) If controlling DBM and Helicoverpa larvae that are less than 8 mm length, apply a Bt[ce], Bt plus VivusMax[e], Affirm[d] or Success Neo[d] spray.

ii) If controlling DBM and Helicoverpa larvae* greater than 8 mm length, apply either an Affirm[e] or Success Neo[e] spray.

*Helicoverpa ET: 4-5 larvae per 10 sweeps.

Note good spray coverage is essential for achieving effective control of DBM, and because of dense canola canopies in spring require appropriate nozzle type, pressure and volumes[f].

Continue to monitor the DBM population and natural enemy activity post spraying.

In the unlikely situation that the DBM population again increases to the ET density, avoid consecutive use of the same product. E.g. Use Success Neo if Affirm was applied earlier, or vice versa.

INTER-SEASON MANAGEMENT

If DBM outbreaks that warrant spray treatment occur in consecutive years, in the second year avoid using the same product used in the previous year.

Insecticide Product Explanatory Comments:

[a]Bt products will conserve beneficials, which is particularly important early season. For winter-sown canola Bt products are suited to the relatively low UV conditions that prevail during pre-flowering. Also, Bt products benefit from the greater ease of coverage associated with the lesser canopy area of pre-flowering crops. We therefore recommend during pre-flowering to not use the two currently-available chemical insecticides, Affirm and Success Neo, and instead reserving them for use during flowering-podding if required.

[b]In some situations pre-flowering crops are infested by very dense DBM infestations, and a higher level of control may result from the use of a chemical insecticide rather than a Bt product. In these instances in fodder brassica crops Success Neo is the only registered chemical product. In graze+grain canola crops Success Neo may be preferred because it has shorter grazing WHP (7 day) than Affirm (14 days), and therefore more suitable if further grazing may be required in a short period of time. In grain crops either Affirm or Success Neo is recommended for use in these situations.

[c]Bt products will conserve beneficials, but are less suitable if the DBM larval density is rapidly increasing above the ET. If a Bt spray was applied earlier during pre-flowering, the rationale for advising a repeat use of a Bt spray rather than an Affirm or Success Neo spray is to avoid 'flaring' DBM and other pests (e.g. aphids), and because this repeat Bt spray still presents a low resistance selection risk given the low frequency of DBM outbreaks in Australian canola.

[d]Affirm or Success Neo are considered more suitable for treatment of rapidly increasing DBM populations, as they each have greater persistence under field conditions in spring compared to Bt products. However both Affirm and Success Neo are toxic to parasitoid wasps and nabid predatory bugs, and highly toxic to bees (follow the 'Protection to Honey Bees' guidelines on the label).

[e]Bt products require optimal conditions and small-sized larvae (no greater than 8mm) for native budworm control. A mixture of Bt and Vivus Max is a biological pesticide option for native budworm control.

[f]To achieve the necessary canopy penetration and coverage for late season DBM control use water volumes of no less than 100 L/ha (ground applied) . Air-induction nozzles or flat fan nozzles greater than 110-03, spaced at 50 cm, producing a medium spray quality have provided good control of DBM in canola crops and reduce drift when effective products at label rates are used.

Synthetic pyrethroid (SP) and organophosphate (OP) products are not recommended for DBM control at any crop stage, because resistance to these products is widespread in Australian DBM and results in poor control, typically 20-30% control with SP's and 30-50% control with OP's. Note that because of their broad-spectrum activity, SP and OP sprays for the control of other canola pests (e.g. aphids) will kill most natural enemy groups, and hence increase the risk of flaring a DBM outbreak.

The carbamate methomyl is registered for DBM control in Western Australian canola; while there is no carbamate resistance data available for Australian DBM, OP-carbamate cross-resistance has been reported in overseas populations of DBM.

Economic Threshold (ET) Table:

Crop stage	Moisture stress	DBM threshold
Rosette*	N	50% leaf area damaged
Pre-flowering stem extension	Y	30 larvae per 10 sweeps
Pre-flowering stem extension	N	50 larvae per 10 sweeps
Early to mid-flowering*	N	>50 larvae per 10 sweeps
Mid to late-flowering*	N	>100 larvae per 10 sweeps
Pod maturation*	N	200 larvae per 10 sweeps

*Moisture stress is not listed for these growth stages, but note that moisture-stressed crops are more susceptible to insect damage. A lower threshold may be used if extended dry periods are expected. (Source: adapted from GRDC Diamondback moth Fact Sheet)

Common Natural Enemies of DBM:

Group	What to look for?	Impact on DBM
Parasitoids	The adult wasp parasitoids are small (3-5 mm). The main species is Diadegma (see photo of adult).  Note the unparasitized DBM pupae are tapered (upper photo) and easily distinguished from the parasitized DBM pupae, which are capsule shaped (lower photo).  	Diadegma wasps lay eggs in the second instar DBM larvae, kill the host and emerge from their cocoon. Parasitism of 40-60% is often observed, and can significantly reduce DBM densities.
Lacewings	Brown lacewing larva. 	Contribute to supressing low-moderate DBM populations. Will feed on DBM eggs, larvae and pupae.
Ladybirds	Both ladybird adults and larvae attack DBM 	Contribute to supressing low-moderate DBM populations.
Spiders	Numerous species of spiders inhabit crops. 	Will feed on eggs, larvae, pupae and adults
Damsel bugs	Adults (left), wingless nymphs (right) feed on eggs, larvae, pupae and adults	

	 	
Fungal disease	DBM larvae killed by *Zoophthora* fungal disease  	Outbreaks of the fungal disease *Zoophthora radicans* can cause greater than 90% reduction in DBM population density following a period of warm temperatures, rainfall and high humidity. Diseased larvae become yellow, sluggish and swollen before dying. Dead larvae are white, brittle, flat and covered with fungus.

General principles to avoid or minimise resistance development:

- Avoid repeated use of insecticides from the same IRAC mode of action chemical group against DBM or other pests, as this will increase selection pressure for resistance development, not only in DBM but other species;
- Where possible, avoid use of SP's and OP's for control of spring pests, and instead use target-specific "soft chemicals" such as pirimicarb for aphids and *Bt* for caterpillars;
- Ensure the target pest is correctly identified to ensure the most effective insecticide and rate is used. Misidentification and incorrect insecticide selection results in poor control and contribute to selection for resistance;
- Assess DBM and beneficial populations by fortnightly sweep-net monitoring to determine if chemical control is warranted. Use spray thresholds to ensure spray decisions are warranted;
- Do not re-spray a crop in the same season where a known spray failure has occurred using the same product or another product from the same insecticide group, or if a spray failure has occurred where the cause has not been identified; arrange for a DBM sample to be tested for resistance to the product used;
- Comply with all directions for use on product labels;
- Ensure spray rigs are properly calibrated and sprays achieve good coverage, particularly in crops with a bulky canopy;
- If growing forage brassicas, manage DBM by grazing or use of Btk.

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