Insecticide Resistance Management Strategies

Developed by the CropLife Australia Insecticide Resistance Management Review Group

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INTRODUCTION

The CropLife Australia Insecticide Resistance Management Review Group (IRMRG) has drafted insect resistance management strategies in conjunction with growers, researchers and agronomists to minimise the development of insect resistance to insecticides. These strategies provide growers with guidelines for insecticide use (and other methods) for sustainable insect control.

PRINCIPLES OF RESISTANCE MANAGEMENT

Insecticide or acaricide resistance management strategies seek to minimise the selection for resistance to any one type of insecticide or acaricide. This requires an understanding of insecticides as they are grouped according to similarity of Mode of Action (MoA) in controlling insects and mites.

In practice, sequences or rotations of compounds from different MoA groups provide an effective approach to resistance management. In practice, sequences or rotations of compounds from different MoA groups provide an effective approach to resistance management. These MoA groups are shown in the **Mode of Action Classification for Insecticides Table.**

EFFECTIVE RESISTANCE MANAGEMENT STRATEGIES USE ALTERNATIONS OR SEQUENCES OF DIFFERENT MODES OF ACTION

The objective of Insecticide Resistance Management is to prevent or delay resistance developing to insecticides, or to help regain susceptibility in insect pest populations in which resistance has already arisen. IRM is important in maintaining the efficacy of valuable insecticides. It is usually easier to prevent resistance occurring than it is to reactively regain susceptibility.

Insecticide applications are often arranged into MoA spray windows or blocks that are defined by the stage of crop development and the biology of the pest(s) of concern. Local expert advice should always be followed with regard to spray windows and timings. Several sprays of a compound may be possible within each spray window but it is generally essential to ensure that successive generations of the pest are not treated with compounds from the same MoA group.

WHAT IS RESISTANCE?

Resistance to insecticides and acaricides may be defined as '*a heritable change in the sensitivity of a pest population that is reflected in the repeated failure of a product to achieve the expected level of control when used according to the label recommendation for that pest species*'.

Resistance arises through the over use or misuse of an insecticide or acaricide against a pest species and results in the selection of resistant forms of the pest and the consequent evolution of populations that are resistant to that insecticide or acaricide.

MODE OF ACTION, TARGET-SITE RESISTANCE AND CROSS-RESISTANCE

In the majority of cases, not only does resistance render the selecting insecticide ineffective but it often confers cross-resistance to other chemically related compounds. Compounds within a specific chemical group usually share a common target site within the pest, and thus share a common Mode of Action (MoA). It is common for resistance to develop that is based on a genetic modification of this target site. When this happens the compound loses its pesticidal efficacy. Because all compounds within the chemical sub-group share a common MoA, there is a high risk that the resistance will automatically confer cross-resistance to all the compounds in the same sub-group. It is this concept of cross-resistance within chemically related insecticides or acaricides that is the basis of the Mode of Action classification.

ALTERNATION OF CHEMISTRY

Constant use of insecticides from one chemical grouping (MoA) will increase the risk of rapid build-up of resistance to that chemical group. Alternate use of chemical groups with different MoAs will slow down the process of selection for resistance.

USE OF CULTURAL PRACTICES

Incorporation of cultural techniques for controlling an insect pest will reduce selection pressure from the insecticides. Any resistance management strategies should incorporate all available methods of control for the insect pest concerned.

UNDERSTANDING OF THE INSECT/MITE LIFE CYCLE

A good understanding of the life cycle of the pest is essential so that control methods can be effectively targeted. An insecticide or acaricide should always be targeted at the pest growth stage that is most susceptible for that insecticide or acaricide.

APPLICATION

Label Recommendations

Insecticide labels have been carefully developed to ensure the most effective control of the pest. The label should at all times be carefully read and adhered to.

Rates

Full recommended rates of registered insecticides should always be used to ensure the most effective control of the pest.

Coverage

The majority of insecticides require good coverage of the target area to ensure the best possible chance of contact and subsequent control of the pest.

RESISTANCE MANAGEMENT STRATEGY DESIGN

Crop/Pest or Regional Strategies

The strategies below are provided on a CROP by PEST basis (eg. Tomato - Heliothis). However, in horticultural and agricultural areas often a range of crops are grown that are attacked by a range of pests.

In many cases, a specific MoA insecticide can be used across this range of crops to control multiple pests that have the ability to move from crop to crop. There is interaction between intensive horticulture and broadacre farming, as with Diamondback Moth (DBM) in Brassica vegetables and resistance strategies that could be compromised by widespread use of insecticides for DBM control in canola.

Also, the pest complex for a specific crop will vary within production regions, especially between Northern and Southern Australia.

For this reason, CROP by PEST strategies can be flawed and further Insecticide Resistance Management (IRM) advice for specific pests should always be sought on a local basis.

An alternative to the CROP by PEST strategy is that of “Regional strategies” such as those for Cotton, Brassicas and the Southern NSW and Northern Victorian IRM strategy for grain and annual horticultural crops”.

These regional or specific crop strategies are located on the CropLife Australia website.

The overall Resistance Management Strategy of avoiding overuse of individual Modes of Action insecticides should be followed, not just on a specific crop and pest but on a broad perspective of crops and pest complex.

ADDITIONAL INFORMATION

Further information on Insecticide Resistance, Management Strategies and Insecticide Mode of Action can be found on the International IRAC (Insecticide Resistance Action Committee) website **www.irac-online.org.**

Crop(s) : Banana

Insect(s) : Banana Weevil Borer

Components of the strategy:

1. Use only clean planting material.
2. If replanting into an old banana block allow at least 6 months fallow after old banana material has rotted down.
3. Remove weeds and trash around banana stools to allow maximum effectiveness of insecticides and reduce sheltering sites for weevils application of insecticide to trash may lead reduced control of banana weevil borer.
4. Cut up fallen and harvested pseudostems to reduce weevil breeding sites.
5. Monitor regularly for banana weevil borer activity by trapping (when adult weevils are active) or conduct corm damage ratings.
6. Only use insecticides when populations reach or exceed accepted threshold levels. Refer to local DPI guidelines.
7. Only use insecticides at the registered rate of application and apply at times when the particular product will have the maximum impact, i.e. use contact insecticides only when weevil borer adults are active.
8. Use insecticides only in the years indicated in the following diagrams.
9. Consider the impact of the use of other pesticides for other insects or nematodes on banana weevil borers.

The following diagram is an alternative Resistance Management Strategies depending on which product(s) is chosen for banana weevil borer control.

Crop(s) : Banana (cont.)

Insect(s) : Banana Weevil Borer (cont.)

STRATEGY

Group*	Chemical Sub-Group	Chemical Example	Year 1 Use	Year 2 Use	Year 3 Use	Year 4 Use	Year 5 Use	Year 6 Use
1A or 1B	Carbamates Organophosphates	Oxamyl or Cadusafos, chlorpyrifos,prothiofos, terbufos	**YES**	**NO**	**YES**	**NO**	**YES**	**NO**
2B	Phenylpyrazole (Fiproles)	Fipronil	**YES**	**NO**	**YES**	**NO**	**YES**	**NO**
3A	Synthetic pyrethroids	Bifenthrin	**NO**	**YES**	**NO**	**YES**	**NO**	**YES**
4A	Neo-nicotinoids	Clothianidin, imidacloprid	**NO**	**YES**	**NO**	**YES**	**NO**	**YES**

**Refer:* *CropLife Australia Insecticide Resistance Management Review Group Mode of Action Classification for Insecticides*

1. The resistance management strategy may start at any point in the product group rotation.
2. The product(s) used in any one year should not be followed by product(s) from the same insecticide group in the following year.
3. Products from different insecticide groups other than those shown in the diagram above should not be applied for banana weevil borer control in the same year.
4. If products from Group 1A or 1B (oxamyl, cadusafos or terbufos) are being used for nematode control in a block of bananas, then products from these groups should not be used for banana weevil borer control in the following year.
5. Where there is evidence of banana weevil borer resistance to a product or group of products, these should not be used again for banana weevil borer control until there has been use of products from other Insecticide Mode of Action groups for a period of at least 2 years.
6. Soil applications of bifenthrin or fipronil or stem injections of clothianadin or imidacloprid for rust thrips control should be considered as applications for banana weevil borer control in terms of the resistance management strategy. Do not follow the use of the these products for rust thrips control in one year with the same product(s) or product group(s) for control of banana weevil borer in the following year.

Crop(s) : Sorghum, Maize, Summer Grain Legumes

Insect(s) : Heliothis/Cotton bollworm/Native budworm (*Helicoverpa* spp.)

<table>
<tr><th>Stage I</th><th>Stage II</th><th>Stage III</th><th>Stage IV</th></tr>
<tr><td colspan="4">NUCLEAR POLYHEDROSIS VIRUS (NPV)</td></tr>
<tr><td></td><td colspan="3">INDOXACARB – Max of 1 per crop per season from Dec 15th. Only to be used in mungbeans, soybeans, azuki beans.</td></tr>
<tr><td colspan="2"></td><td colspan="2">SYNTHETIC PYRETHROIDS – Max of 2 per crop per season from Jan 15th.</td></tr>
<tr><td colspan="3"></td><td>CARBAMATES/ OPS – Max of 3 per crop per season from Feb 1st.</td></tr>
<tr><td></td><td>Dec 15th</td><td>Jan 15th</td><td>Feb 15th</td></tr>
</table>

For additional information refer: *Cotton and the Regional Southern NSW-Northern Victoria IRM strategies on the CropLife Australia website.*

Note: to conserve "beneficials" delay the use of carbamate and synthetic pyrethroid insecticides for as long as possible.

Guidelines:

1. In maize the critical stage of infestation is during silking. Infestation could extend through to when the grain in cobs begins to harden although spraying for Heliothis is generally not required after silking is complete.
2. In sorghum the critical stage of infestation is during flowering and milky dough stage. Infestation could extend through to when the grain begins to harden.
3. Monitor pest levels and do not spray unless pest thresholds are reached.
4. Do not use consecutive applications of products from the same chemical group in Stages II and III.
5. Sorghum, maize and grain legumes are often grown in areas where cotton is grown and product selection should be mutually compatible.
6. Sorghum, maize and summer grain legume grain or forage is often fed to livestock. Recognition of possible insecticide residue in forage and possible animal residues resulting from consumption is critical especially for produce destined for export markets.
7. Post-harvest cultivation to destroy pupae, as practised in cotton crops, should also be practised in sorghum, maize and grain legume crops.

Crop(s) : Brassica

Insect(s) : Diamondback Moth

Refer to the separate Diamondback Moth (DBM) strategies for -

1. **Queensland**
2. **New South Wales, Victoria, South Australia**
3. **Western Australia**

Further DBM resistance management information is available on website:

http://www.sardi.sa.gov.au/pestsdiseases/horticulture/horticultural_pests/diamondback_moth/insecticide_resistance_management

Guidelines:

Strategies are based on:

1. Distinct windows split at times of peak DBM population and which divide the brassica growing periods in each of the regions.

2. Alternating insecticide groups (changing groups) at the nominated date (ie. new use window).

3. Consultation with local industry advisers to set the regional window dates.

4. Using Bacillus thuringiensis (Bts) in earlier crop stages to encourage beneficials.

5. Monitoring pest levels and not spraying unless pest thresholds are reached.

6. NOT using mixtures of insecticides for controlling DBM.

7. Good crop hygiene such as the use of clean seedlings.

Crop(s) : Various

Insect(s) : Green Peach Aphid

Guidelines:

1. Rotate between registered insecticides that have different modes of action (eg. Group 1, Group 4,Group 9, and Group 23).

2. Do not apply consecutive applications of insecticides that have the same mode of action within and between seasons.

3. The Modes of Action (groups) and registered insecticides for control of green peach aphid are listed below.

Group*	Chemical sub-group	Example chemical
1A	Carbamates	pirimicarb
1B	Organophosphates	methamidophos
4A	Neo-nicotinoid	imidacloprid
9B	Pymetrozine	pymetrozine
23	Spirotetramat	spirotetramat

***Refer:** *CropLife Australia Insecticide Resistance Management Review Group Mode of Action Classification for Insecticides*

Notes:

1. There is known cross-resistance between Groups 1A and 1B. Rotate between Group 1 and Group 4A, 9B and 23.

2. Seek advice from the manufacturers and/or government advisory services to determine local resistance levels for particular Group 1, Group 4, Group 9 and Group 23 insecticides.

3. Do not exceed the maximum number of applications permitted on the insecticide label.

4. When using insecticides/miticides to control other pests, consider the chemical group in relation to contributing to resistance development of Green Peach Aphid.

Crop(s) : Sweet Corn

Insect(s) : Heliothis / Native Budworm (*Helicoverpa* spp.)

Region	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
North QLD North WA	No crop		NPV1 B.t. methomyl SP's emamectin		NPV B.t. methomyl SP's spinosad			NPV methomyl emamectin			B.t. SP's	No crop
South QLD South WA	NPV B.t. carbamates SP's spinosad emamectin		NPV B.t. methomyl SP's emamectin			No crop			NPV B.t. spinosad		NPV B.t. methomyl SP's	
NSW/ VIC	NPV B.t. carbamates SP's spinosad emamectin		NPV B.t. carbamates SP's		No crop					NPV B.t. carbamates SP's emamectin		
TAS	NPV B.t. carbamates SP's emamectin			No crop							NPV B.t. carbamates SP's spinosad	
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec

For further information :*Refer to both the Cotton and the Regional Southern NSW-Northern Victoria IRM strategies on the CropLife Australia website.*

Guidelines:

1. The critical stage of infestation is during silking. Even low levels of heliothis infestation are unacceptable at the silking stage. Because sweet corn is less attractive to heliothis before flowering and it is picked soon after silking is completed, there is a relatively short period of protection required.
2. Use of biological insecticides, Bt and Nuclear Polyhedrosis Virus (NPV), in the early stages of crop development is encouraged
3. Monitor crops regularly, at least weekly during silking and do not spray unless pest thresholds are exceeded.
4. Labels of new products place a limit on the number of applications. If further control is required on one planting, chemicals from different mode of action groups within the same window should be used.
5. Do not retreat a spray failure with a product from the same chemical group.
6. Do not use mixtures of insecticides for controlling heliothis.
7. Cultivation after harvest to destroy pupae will greatly assist in managing heliothis.
8. Seek local advice on pest incidence and on the risk of resistance developing from insecticide programs used to control heliothis in crops other than Sweet Corn.

Crop(s) : Tomato

Insect(s) : Heliothis/Tomato Budworm (*Helicoverpa* spp.)

Guidelines:

1. Monitor pest levels and do not spray unless pest thresholds are reached.

2. Do not apply products outside their window of application for that chemical group.

3. Integrate both chemical and non-chemical means of control as part of the overall control strategy. Examples are the use of predators/parasites and relevant cultural practices (crop hygiene, rotation of planted areas, and strategic time of planting.

4. Seek local advice on pest incidence and the risk of resistance development from insecticide programs used to control Heliothis in other crops or to control other pests

5. When using insecticides/miticides to control other pests on tomato, consider the chemical group in relation to contributing to resistance development of Heliothis.

Crop(s) : Potato

Insect(s) : Potato Moth (Leafminer)

Group*	Chemical sub-group	Example chemical
1B	**Organophosphates**	acephate, azinphos-methyl, methamidophos, diazinon, dichlorvos
1A	**Carbamates**	carbaryl, methomyl
3A	**Pyrethroids**	permethrin
5	**Spinosyns**	spinosad, spinetoram
28	**Diamides**	Chlorantraniliprole, Flubendiamide

***** *Refer: CropLife Australia Insecticide Resistance Management Review Group Mode of Action Classification for Insecticides*

Guidelines:

1. Monitor pest levels and do not spray unless pest thresholds are exceeded.

2. Rotate insecticide groups and do not use two consecutive applications of products with the same Mode of Action.

3. Integrate both chemical and non-chemical means of control as part of the overall control strategy. Examples are the use of predators/parasites and relevant cultural practices (crop hygiene, rotation of planted areas, and strategic time of planting).

Crop(s) : Pasture/Winter Crops

Mite : Redlegged Earth Mite (RLEM)

Guidelines:

Rotate insecticide groups.

Do not apply consecutive sprays of products from any one insecticide group

Crop Stage	Group*	Chemical Sub-group	Example chemical
Seed Treatment (or in-furrow)	4A *or* 1B *or* 2B	Neo-nicotinoids *or* organophosphates *or* phenylpyrazoles	Imidacloprid dimethoate fipronil
Bare Earth (Pre-emergent)	1B *or* 3A	organophosphates *or* synthetic pyrethroids	omethoate bifenthrin
Early Season (Autumn when limited green growth)	3A *or* 1B	synthetic pyrethroids *or* organophosphates	alpha-cypermethrin chlorpyrifos
Spring	1B *or* 3A	organophosphates *or* synthetic pyrethroids	Omethoate gamma-cyhalothrin

***Groups are the International Resistance Action Committee Insecticide Groups based on mode of action of the insecticides - refer MoA tables.**

If both autumn and spring applications are needed, alternate between synthetic pyrethroids and organophosphates

Timing of Sprays

1. Monitor Redlegged Earth Mite (RLEM) activity carefully and only treat if damage has reached threshold levels.
2. One well timed spray in Autumn or Spring will maximise effectiveness of treatment.

Placement of Sprays

1. Apply perimeter sprays where infestations are concentrated on the edge of fields.
2. Use blanket sprays where appropriate.

Crop(s) : Pasture/Winter Crops (cont.)

Mite : Redlegged Earth Mite (RLEM) (cont.)

Guidelines: (cont.)

Cultural Practices

1. Heavy grazing or cutting for hay or cultivation will reduce mite numbers.
2. Develop damage thresholds.
3. Rotate crops and pastures that are more tolerant to the pest.
4. Encourage predator survival by judicious use of insecticides.
5. Control alternative hosts such as Capeweed and Paterson's curse.

Crop(s) : Various

Insect(s) : Silverleaf Whitefly

Guidelines:

1. Monitor pest numbers and apply control measures before adult populations reach high levels.
2. Select registered insecticide control measures according to the primary growth stage of the pest, the infestation level and the age and type of crop.
3. In cotton, spray decisions should be based on the Silverleaf Whitefly threshold matrix. Refer to the current Cotton Pest Management Guide for further details
4. Where possible, utilise selective insecticides during the early stages of crop development to minimise the impact on beneficial insects.
5. Rotate between registered insecticides that have different modes of action (eg. Group 1, Group 3, Group 4, Group 7, Group 12 and Group 23).
6. Do not apply more than two consecutive applications of insecticides that have the same Mode of Action within and between seasons.
7. The Modes of Action (groups) and registered insecticides for control of Silverleaf Whitefly are listed below.

Group*	Chemical sub-group	Example chemicals
1B	Organophosphate	acephate
3A	Synthetic pyrethroid	bifenthrin
4A	Neonicotinoid	acetamiprid, imidacloprid, thiamethoxam
7C	Pyriproxyfen	pyriproxyfen
12A	Diafenthiuron	diafenthiuron
23	Spirotetramat	spirotetramat
--	Petroleum oil	petroleum oil

***Refer:** **CropLife Australia Insecticide Resistance Management Review Group Mode of Action Classification for Insecticides**

8. Seek advice from the manufacturers and/or government advisory services to determine local resistance levels for particular Group 1, Group 3, Group 4 and Group 7 insecticides.
9. Do not exceed the maximum number of applications permitted on the insecticide label.
10. When using insecticides to control other pests, consider the chemical group in relation to contributing to resistance development of Silverleaf Whitefly.

NOTE:

- Not all chemical groups listed have registered products available in all crops affected by Silverleaf Whitefly. Only use products registered for use in crop to be treated.

Cultural Practices

1. In vegetable crops, ensure seedlings are free of pests prior to transplanting. Inspect transplants carefully upon arrival for whitefly eggs, nymphs and adults.
2. Control alternate weed hosts of Silverleaf Whitefly the 2-3 weeks before planting to reduce early population levels.
3. Clean-up crop residues
   a. Where moderate population levels remain after harvest, apply a registered insecticide or oil treatment effective against adults.
   b. Plough in crops within 2-3 days of application to kill all remaining nymphs on crop foliage to reduce pest migration into new plantings.

Crop(s) : Pome Fruit

Mite(s) : Two-spotted Mite, European Red Mite

Guidelines:

1. Make no more than one application from each registered miticide group per season. Rotate registered miticides that have different mode of action (i.e. Group 6A, Group 13A, Group 14A, Group 21A and Group 2D).
2. For miticides that have the same mode of action (eg. Group 21A) do not use consecutive applications within and between seasons.

Group*	Chemical sub-group	Example chemical
6	Avermectins	abamectin
13	Chlorfenapyr	chlorfenapyr
12C	Propargite	propargite
21A	METI acaricides	fenpyroximate, tebufenpyrad
UN	Bifenazate	bifenazate
10B	Etoxazole	etoxazole

* *Refer CropLife Australia Insecticide Resistance Management Review Group Mode of Action Classification for Insecticides*

Notes:

1. Miticides should be used as part of an Integrated Mite Control (IMC) program.

2. Mite levels should be monitored and thresholds utilised before deciding to make miticide applications.

3. Where practicable, predatory mites should be incorporated into an IMC program.

4. When using insecticides/miticides to control other pests of pome fruit such as codling moth, lightbrown apple moth and woolly aphid, consider the chemical group and the potential impact it may have on resistance development of mite pests.

Crop(s) : Strawberries/ornamentals

Mite : Two Spotted Mite

Guidelines:

1. Monitor mite activity and treat infestations before thresholds are reached, ie. spray earlier rather than later. Seek advice on local threshold levels.
2. Do not apply sequential applications of products from any one chemical group.
3. Preferably products with the same Mode of Action should not be used more than twice in a growing season
4. Incorporate the use of predatory mites for the control of this pest wherever possible.

Insect : Western Flower Thrips

For information refer Industry and Investment NSW website

http://www.dpi.nsw.gov.au/agriculture/horticulture/pests-diseases-hort/multiple/thrips/wft-resistance