



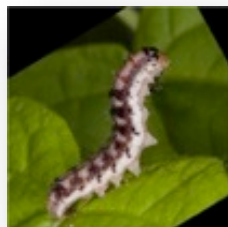
**Insecticide Resistance Action Committee**

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**IRAC, the Insecticide Resistance Action Committee:  
a valuable resource for resistance management.**

**Lakshmipathi Srigiriraju, PhD**  
*representing IRAC International*

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# 30 years of IRAC

## First IRAC Meeting – Brussels, Belgium

13 March 1984

Attendees: 6

### 6 company members:

Voss / Ciba Geigy (Chair)

Lindley / Cyanamide

Cronin / FMC

Davies / ICI

Knauf / Hoechst

Zoebelein / Bayer

## September 1992 Meeting – London, UK

6 company members; 13 attendees



## March 2014 Meeting – RTP North Carolina, USA

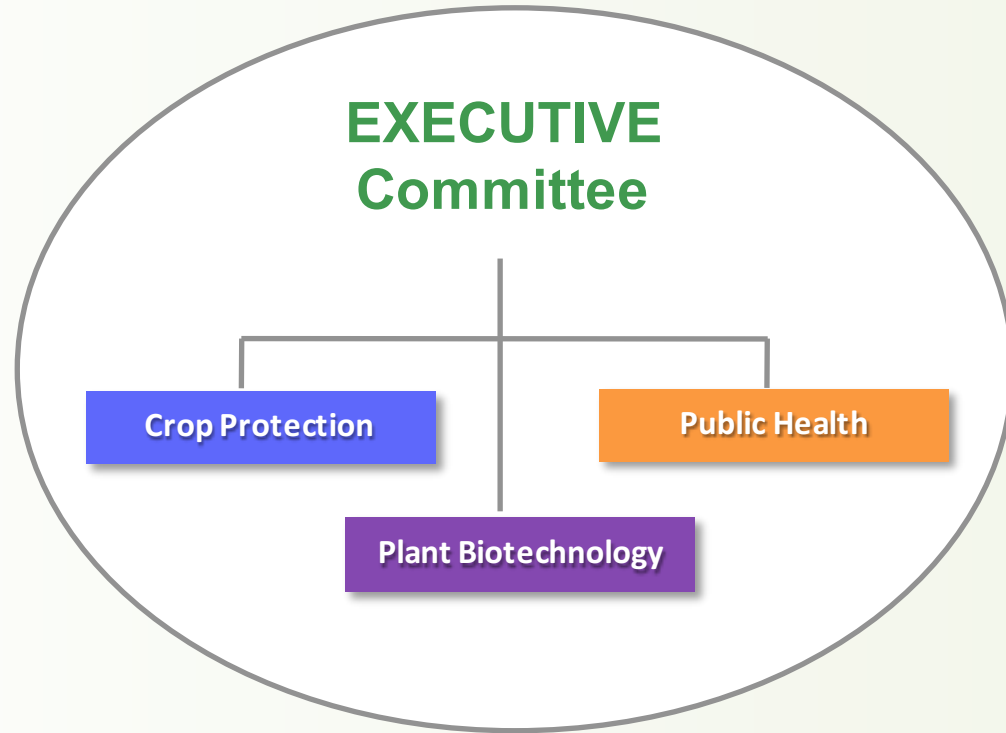
13 company members; 50 attendees





# IRAC Mission

- Facilitate communication and education on resistance to insecticides and insect-resistant traits.
- Promote and facilitate development and implementation of resistance management strategies to maintain efficacy and support sustainable agriculture and improved public health.



- Steering Group
- Outreach
- R. Database (MSU)
- Methods
- Mode of Action
- Public Health
- Biotechnology
- Coleoptera
- Sucking Pest
- Lepidoptera

## IRAC Country Groups





# IRAC Mode of Action Classification System

- The IRAC Mode Of Action (MoA) Classification is the definitive global authority on the target site of insecticides.
- It is the basis of MoA labeling of insecticides worldwide and is an essential tool for the development of insecticide resistance management (IRM) strategies.

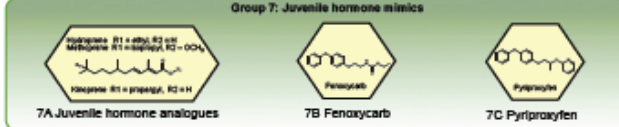
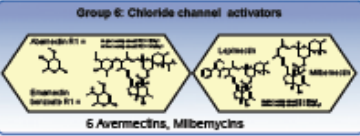
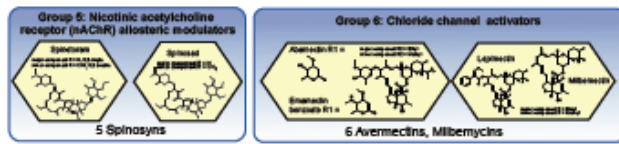
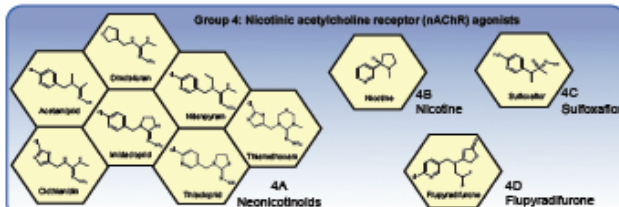
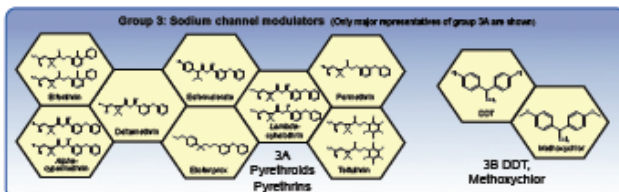
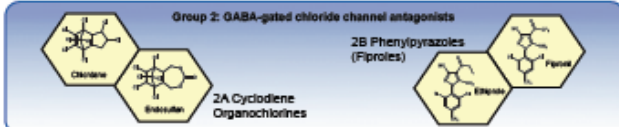
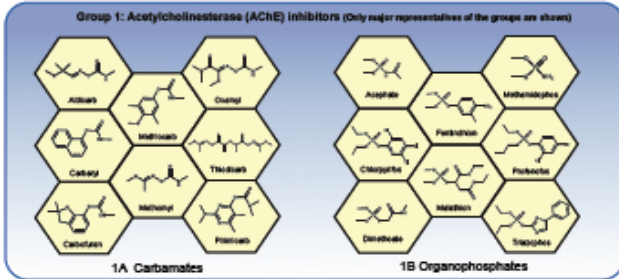
# Mode of Action Classification

# IRAC

Insecticide Resistance Action Committee

## The Key to Resistance Management

- Successive generations of a pest should not be treated with compounds from the same MoA Group.
- Not all of the current groupings are based on knowledge of a shared target protein. For further information, please refer to the IRAC Mode of Action Classification document.
- The color schema used here associates modes of action into broad categories based on the physiological functions affected, as an aid to understanding symptomology, speed of action and other properties of the insecticides, and not for any resistance management purpose. Rotations for resistance management should be based only on the numbered mode of action groups.

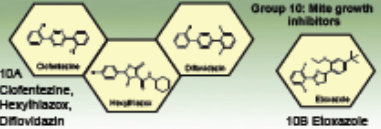
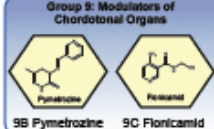


Targeted Physiology

- Nerve & Muscle
- Growth & Development
- Respiration
- Midgut
- Unknown or Non-specific

Guidance on the use of Sub-Groups:

- Represent distinct structural classes believed to have the same mode of action.
- Populate differentiation between compounds that may bind at the same target site but are structurally different enough that risk of metabolic cross-resistance is lower than for close chemical analogs.
- Cross-resistance potential between sub-groups is higher than between groups, so rotation between sub-groups should be considered only when there are no alternatives, and only if cross-resistance does not exist, following consultation with local expert advice. These exceptions are not sustainable, and alternative options should be sought.
- 3B: DDT is no longer used in agriculture and therefore this is only applicable for the control of human disease vectors such as mosquitoes, because of a lack of alternatives.



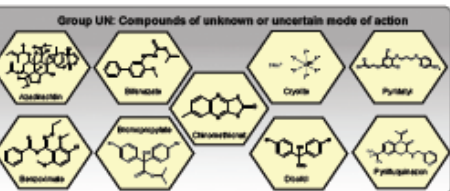
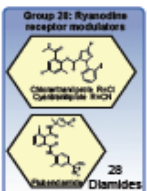
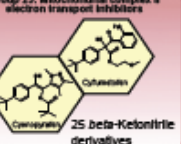
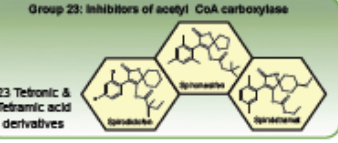
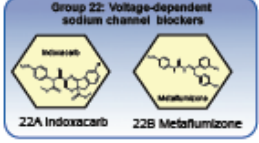
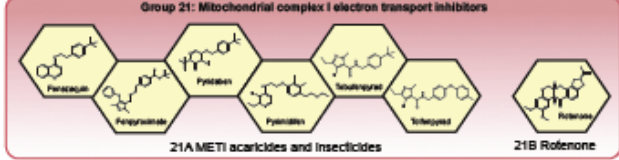
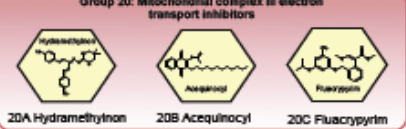
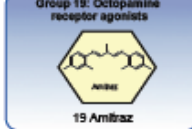
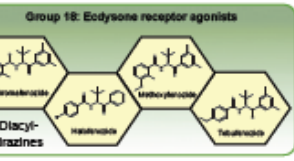
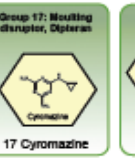
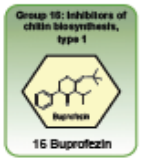
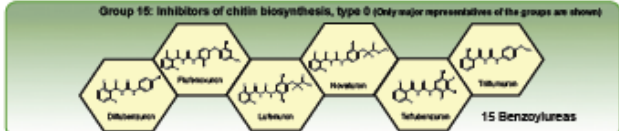
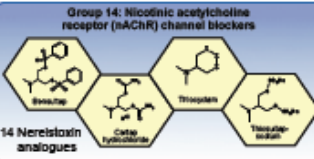
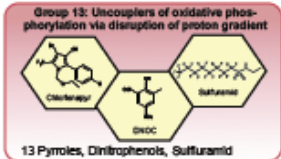
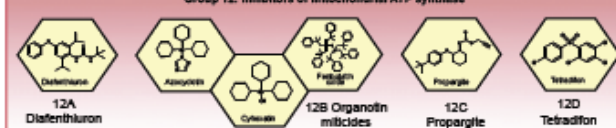
Group 11: Microbial disruptors of insect midgut

Different MoA products that target different insect orders may be used together without concern for their resistance management.

Resistant to certain specific insecticides may provide resistance management benefits for some pests. Consult product specific recommendations.

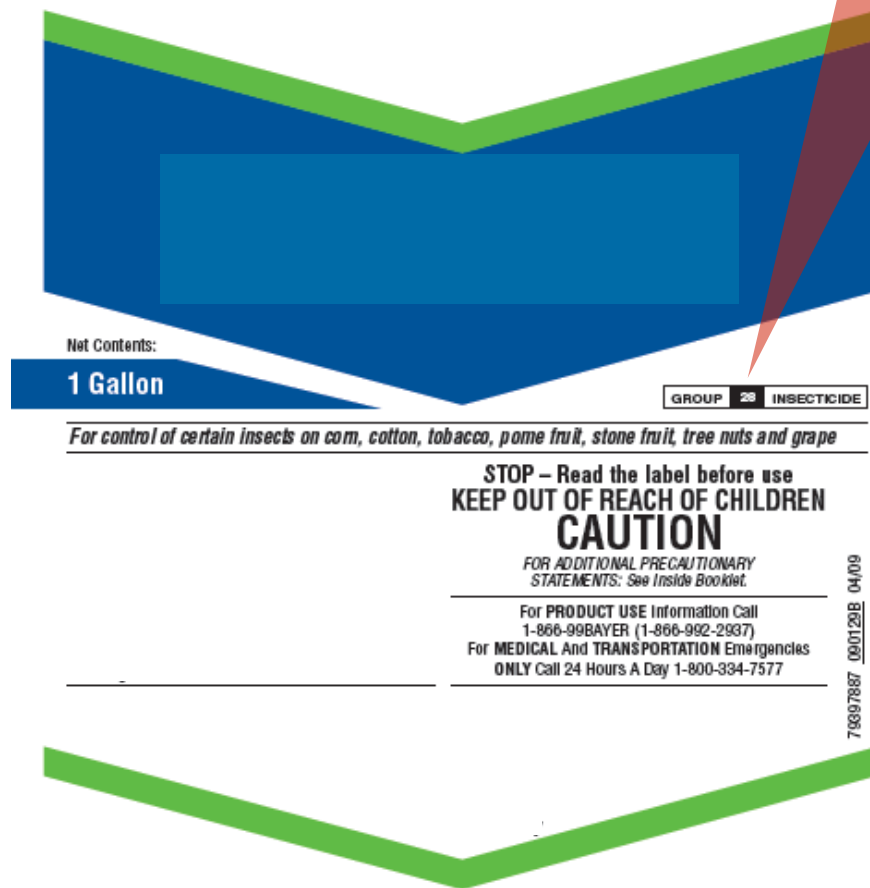
\* Where there are differences among the specific members within the midgut of target insects, targeted crops carrying certain combinations of these proteins provide resistance management benefits.

11A *Bacillus thuringiensis*      11B *Bacillus sphaericus*



# Company agreement on mode of action labelling and alignment of IRM label language.

**GROUP 28 INSECTICIDE**



## Example 2: Short Version

### Insecticide Resistance Management (IRM)

#### General Recommendations:

\_\_\_\_ (product name) contains \_\_\_\_ (active ingredient name), a Group 28 Insecticide.

Unless directed otherwise in the specific crop/insect sections of the label, the following practices are recommended to prevent or delay the development of insecticide resistance to \_\_\_\_ (product name) and to Group 28 insecticides:

- Apply \_\_\_\_ (product name) or other Group 28 insecticides using a "window" approach to avoid exposure of consecutive insect pest generations to the same mode of action. Multiple successive applications of \_\_\_\_ (product name) are acceptable if they are used to treat a single insect generation.
- Following a "window" of \_\_\_\_ (product name) or other Group 28 insecticide, rotate to a "window" of applications of effective insecticides with a different mode of action.
- The total exposure period of all "Group 28-active windows" applied throughout the crop cycle (from seedling to harvest) should not exceed 50% of the crop cycle.
- Incorporate IPM techniques into the overall [pest management program].
- Monitor insect populations for loss of field efficacy.

For additional information on insect resistance, modes of action and monitoring visit the Insecticide Resistance Action Committee (IRAC) on the web at <http://www.irac-online.org>.

## Example 3: Shortest Version – Minimal Text Required on Label

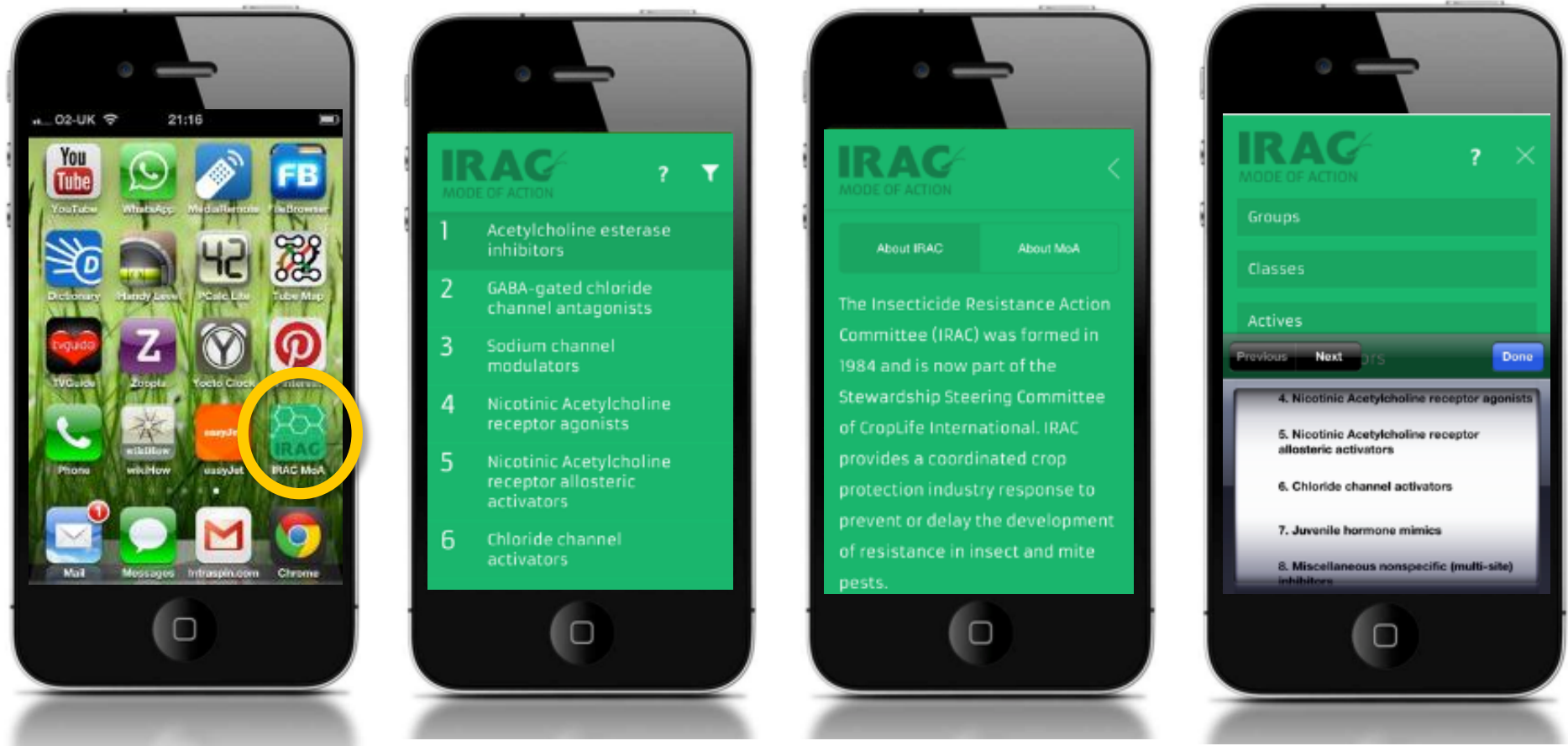
### Insecticide Resistance Management (IRM)

#### General Recommendations:

In order to avoid fast resistance development, avoid treating consecutive generations of the target pest with the same product or products with the same mode of action. Apply \_\_\_\_ (product name) using a "window" approach, alternating blocks of treatments with \_\_\_\_ (product name) followed by blocks of treatments with other effective products with different modes of action. The total exposure period of all "Group 28 active windows" applied throughout the crop cycle cannot exceed 50% of the crop cycle.

For additional information on insect resistance, modes of action and monitoring visit the Insecticide Resistance Action Committee (IRAC) on the web at <http://www.irac-online.org>.

# Mode of Action classification: Phone/Tablet App





# IRAC website: Communication and education

[www.irac-online.org](http://www.irac-online.org)

**IRAC**

Resistance Management for Sustainable Agriculture and Improved Public Health

SEARCH SEARCH

HOME NEWS ABOUT TEAMS PESTS CROPS MODES OF ACTION TEST METHODS INDEX

LASTEST: UPDATED IRAC MOA CLASSIFICATION BOOKLET AND POSTER NOW AVAILABLE. READ MORE

A COLLABORATIVE EFFORT BY 150+ MEMBERS OF THE CROP PROTECTION INDUSTRY

IRAC is prolonging the effectiveness of insecticides, acaricides and traits by implementing insecticide resistance management strategies, countering the development of resistance in the three core sectors of traditional Crop Protection, Plant Biotechnology and Public Health.

Crop Protection

Biotechnology

Public Health

# IRAC website: Mode of Action classification tools

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MODE OF ACTION TEAM BBQ/BELE NEWS DOCUMENTS GUIDELINES POSTERS PRESENTATIONS PUBLICATIONS

## MODE OF ACTION TEAM

The MoA Team, which is largely composed of technical experts, is charged with maintaining the scheme and its status, carrying out updates as required as well as developing educational resources such as posters to promote the correct use of the scheme. The team considers data to support new submissions for entries to the scheme and acts as an arbiter on questions of MoA.

### TEAM OBJECTIVES

- Continue to review and update the MoA scheme as required.
- Develop new versions of the MoA Structure Poster as needed
- Target site mutation table
- Develop new MoA posters and update existing posters as required
- Develop MoA training slides
- MoA page – IRAC Website
- Provide additional information on topics important to MoA and IRM
- Update of MoA Charter
- Address issue of DfV classification
- Implement MoA Classification update notification list

### Tools

**SEARCH THE MOA CLASSIFICATION ONLINE**  
The MoA Classification is available as an interactive searchable eTool allowing you to browse and filter chemical groups, classes and actives.  
[Search now](#)

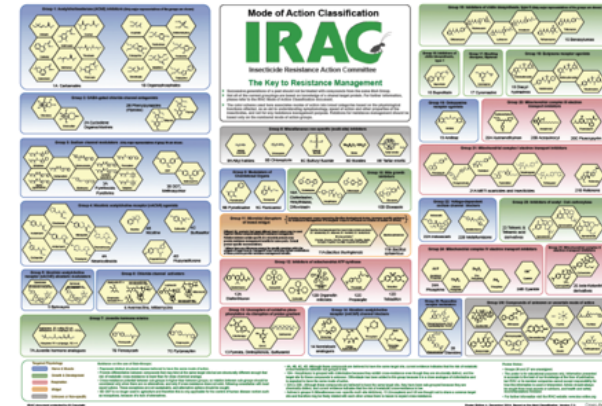
**DOWNLOAD THE MOA APP**  
Download the IRAC MoA application from the Apple iTunes or Google Play App Stores for quick access to reference information on the move.  
[From Apple's App Store](#)  
[From Google Play Store](#)

**DOWNLOAD THE MOA STRUCTURES POSTER**  
The MoA poster with the chemical structures is available for download from the website in various language options. Select the language required from the drop-down menu below.  
[English](#)  
[Spanish](#)  
[Portuguese](#)  
[French](#)  
[Japanese](#)  
[Chinese](#)

**DOWNLOAD THE MOA CLASSIFICATION SCHEME**  
The complete MoA Classification document is available to view or download. This 23-page document provides full details of the scheme with lots of notes and background information.  
[Download PDF](#)

**Team Leader** Vince Salgado

<a href="#">Andrew Crossthwaite</a>	<a href="#">Din Cordova</a>
<a href="#">Danny Karmon</a>	<a href="#">Jerry Watson</a>
<a href="#">Peter Luemmen</a>	<a href="#">Ralf Nauen</a>
<a href="#">Shigero Seito</a>	<a href="#">Tom...</a>



- IRAC MoA poster:
- English
  - Spanish
  - Portuguese
  - French
  - Japanese
  - Chinese

IRAC MoA booklet



IRAC MoA website tool



IRAC MoA phone app

# IRAC website: Pest pages



















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## PEST INFORMATION

Browse our database of pests for information on biology, distribution, resistance status and available resource on IRAC and third-party websites.

SEARCH FILTER BY PEST COMMON NAME...

 Aedes mosquito <i>Aedes spp</i>	 Anopheline Mosquitoes <i>Anopheles spp</i>	 Melon & Cotton Aphid <i>Aphis gossypii</i>	 Tobacco Whitefly <i>Bemisia tabaci</i>	 Cockroaches <i>Cockroach Species</i>	 Codling Moth <i>Cydia pomonella</i>
 Asian Citrus Psyllid <i>Dialeurium citri</i>	 Stink Bug <i>Euschistus Heros</i>	 Western flower thrips <i>Frankliniella occidentalis</i>	 Colorado potato beetle <i>Leptinotarsa decemlineata</i>	 European grapevine moth <i>Lobesia botrana</i>	 Pollen Beetle <i>Meligethes aeneus</i>
 Housefly <i>Musca domestica</i>	 Green peach aphid <i>Myzus persicae</i>	 Brown planthopper <i>Nilaparvata lugens</i>	 European Red Mite <i>Panonychus ulmi</i>	 Diamondback Moth <i>Plutella xylostella</i>	 Sandfly <i>Sandfly species</i>

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LEWISIA TABACI ESPELE NEWS DOCUMENTS GUIDELINES POSTERS PRESENTATIONS PUBLICATIONS

## TOBACCO WHITEFLY

*Bemisia tabaci*

*B. tabaci* found on over 900 host plants on all continents except Antarctica. It reportedly transmits over a hundred virus species. The whitefly thrives in tropical, subtropical, and less predominately in temperate habitats. It is also a major pest of glasshouses. The adults are about 1 mm long; their body is sulphuryellow in color, the wings are white, and the animal is entirely coated with a white, wax-like powder. The first instar nymph is about 0.3 mm in length and it moves about in search of a place to insert its mouthparts into the phloem.

Infestation is easily recognized by examining the undersides of leaves, where all stages of the insect can usually be found. At first, the damage consists of chlorotic spots. The leaves will start to show a yellow mosaic, with the green areas becoming ever smaller. Twisting of stems and curling of leaves may occur, and the plants may become stunted. Heavily-infested leaves often wilt and fall off. In addition to direct feeding, all stages damage the plants through abundant production of honeydew, which encourages the growth of sooty molds, and, most importantly, by the transmission of viruses.

The two most damaging biotypes of *B. tabaci* are the 'B' and 'Q' biotypes. The B-type has a worldwide distribution. The Q-type was largely restricted to the Mediterranean area but has recently been detected in the U.S.A and some regions of China. Biotype status can be diagnosed from esterase banding patterns using polyacrylamide gel electrophoresis (PAGE). *B. tabaci* has been shown to possess a high potential for resistance development.

**EXTERNAL LINKS**

- Bayer CropScience Crop Compendium
- Biotype Dynamics and Resistance to Insecticides in Israel During the Years 2008-2010
- Age-specific expression of a P450 monooxygenase (CYP6CM1) correlates with neonicotinoid resistance in *Bemisia tabaci*.
- Age-specific expression of resistance to a neonicotinoid insecticide in the whitefly *Bemisia tabaci*

**KNOWN RESISTANCE**

- > Organophosphates (1B)
- > Cyclodiene organochlorines (2A)
- > Pyrethroid-Pyrethrins (3A)
- > Neonicotinoids (4A)
- > Pyriproxyfen (7C)
- > Pymetrozine (8B)
- > Buprofezin (1B)

**SUSCEPTIBILITY TEST METHODS**

- > IRAC Susceptibility Test Method 016  
*Trialeurodes Vaporariorum & Bemisia Tabaci (Nymph/Egg)*
- > IRAC Susceptibility Test Method 015  
*Trialeurodes Vaporariorum & Bemisia Tabaci*
- > IRAC Susceptibility Test Method 008  
*Bemisia Tabaci (Adults)*

**PEST DISTRIBUTION**



**KNOWN RESISTANCE**

**SUSCEPTIBILITY TEST METHODS**

**BASF** The Chemical Company

**Bayer CropScience**

**CHEMINOVA**

**DOW** Dow AgroSciences

# IRAC website: Methods and method videos

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## TEST METHODS

Test methods enable resistance monitoring and baseline determination. Shown below are the IRAC Approved Test Methods (green) and underneath are additional methods (grey) taken from external references. Methods are specific to the life stages and insecticide groups for which they have been validated. For more information please visit the [Method team](#) page.

FILTER BY PEST NAME (COMMON OR LATIN NAME) OR DEVELOPMENT STAGE, OR TEST OBJECTIVE OR TYPE...

001 <b>Green peach aphid</b> <i>Myzus persicae</i> All Stages of Development DIP	002 <b>Psyllids</b> <i>Psylla</i> spp. All Stages of Development DIP	003 <b>European Red Mite</b> <i>Tetranychus ulmi</i> <b>Two-spotted Spider Mite</b> <i>Tetranychus urticae</i> Eggs DIP	004 <b>Citrus red spider mite</b> <i>Panonychus citri</i> <b>European Red Mite</b> <i>Panonychus ulmi</i> --- Adults DIP
005 <b>Rice green leafhopper</b> <i>Nephotettix cincticeps</i> <b>Brown planthopper</b> <i>Nilaparvata lugens</i> Adults DIP	006 <b>Red flour beetle</b> <i>Tribolium castaneum</i> All Stages of Development FILTER	007 <b>Corn earworm</b> <i>Helicoverpa armigera</i> <b>Tobacco budworm</b> <i>Heliothis virescens</i> Adults, Larvae DIP	008 <b>Tobacco Whitefly</b> <i>Bemisia tabaci</i> Adults DIP
009 <b>Pear Leaf Blister Moth</b> <i>Leucopeters scitella</i> <b>Apple leaf miner moth</b> <i>Lithocolletis blancardella</i> Larvae, Eggs DIP	010 <b>Western flower thrips</b> <i>Frankliniella occidentalis</i> Adults DIP	011 <b>Pollen Beetle</b> <i>Meligethes aeneus</i> Adults VIAL	012 <b>European Red Mite</b> <i>Panonychus ulmi</i> Adults PETRI-DISH
013 <b>European Red Mite</b> <i>Panonychus ulmi</i> Adults	014 <b>Western flower thrips</b> <i>Frankliniella occidentalis</i> Larvae DIP	015 <b>Tobacco Whitefly</b> <i>Bemisia tabaci</i> <b>Glasshouse whitefly</b> <i>Trialeurodes vaporariorum</i> DIP	016 <b>Tobacco Whitefly</b> <i>Bemisia tabaci</i> <b>Glasshouse whitefly</b> <i>Trialeurodes vaporariorum</i> Nympha, Eggs
017 <b>Codling Moth</b> <i>Cydia pomonella</i> Larvae	018 <b>Diamondback Moth</b> <i>Plutella xylostella</i> Larvae DIP	019 <b>Pea aphid</b> <i>Acyrtosiphon pisum</i> <b>Black bean aphid</b> <i>Aphis fabae</i> --- Adults, Nympha	020 <b>Corn earworm</b> <i>Helicoverpa zea</i> <b>Tobacco budworm</b> <i>Heliothis virescens</i> --- Larvae DIET
021 <b>Pollen Beetle</b> <i>Meligethes aeneus</i> Adults VIAL	022 <b>Tomato leafminer</b> <i>Tuta absoluta</i> DIP	023 <b>Green peach aphid</b> <i>Myzus persicae</i> Nympha FEEDING	024 <b>Melon &amp; Cotton Aphid</b> <i>Aphis gossypii</i> Adults, Nympha FEEDING

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## IRAC SUSCEPTIBILITY TEST METHOD 005

*Nephotettix cincticeps, Nilaparvata lugens*  
Adults

**Approved**

Version 4  
January 2013

**INTRODUCTION**  
Method suitable for Stage 5 nymphs and adults, Stage 3-4 nymphs for insect growth regulator MoA

**Rice Planthoppers - IRAC Susceptibility Test Method 005**

**MATERIALS**

- Transparent plastic or glass tubes, or suitable glass jars for holding treated plants
- Bacteriological agar (e.g. DIFCO no. 1, though other brands will be suitable)
- Containers for preparation of insecticide dilutions
- 30-60ml plastic syringes
- 100-1000ul micro-pipettes for liquids or microbalances for solids
- Extrevon (Invadin) or a similar non-ionic wetting agent
- Paper towels
- Maximum/minimum thermometer
- Containers and suction device (mouth aspirator) for collecting insects
- Untreated rice seedlings (BPH susceptible cultivar) 10-12 days old in pots

**METHODS**

1. Prepare insecticide solution. Pour into the tubes. The pots should be at room temperature.
2. Make sure the plants are well watered before use.
3. Invert the tubes to dip the plants into the insecticide solution.

**Figure 1:** Plant pots with agar poured over the soil surface

**Figure 2:** Plants are dipped fully in the insecticide solution. The insecticide should be at least 2cm above the soil surface.

**gently tap hoppers into tube with treated plant**

3:15 / 6:00

# IRAC test method for Diamondback moth

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## IRAC SUSCEPTIBILITY TEST METHOD 018

*Plutella xylostella*  
Larvae

**Approved**

Version 3.4  
March 2010

**INTRODUCTION**  
This method is suitable for use on L2 and L3 larvae

**MATERIALS**  
Insect-proof containers, scissors, forceps, fine pointed brush, beakers for test liquids, syringes/pipettes for liquids or weighing balance for solids, syringes/pipettes for making dilutions, binocular microscope or hand lens (optional), untreated leaves of a host plant, paper towels, maximum/minimum thermometer, filter papers, seeking pin or fine forceps.

**METHODS**

- Collect a representative sample of insects from a field. These may be larvae suitable for immediate testing, or eggs/L1 larvae for rearing to the appropriate stage or material from which an F1 population for testing can be reared. The insects should not be subjected to temperature, humidity or starvation stress after collection.
- Collect sufficient non-infested, untreated host plant leaves. Whole leaves are preferred or, for some crops, the distal portions. Do not allow leaves to wilt by keeping them in a humid environment (plastic bag). *Brassica oleracea* (cabbages, cauliflowers & collards) are the recommended choice of host plant; however *Brassica rapa* (chinese cabbage, turnip) is also suitable. Choice of host plant should be recorded for future reference.
- Prepare accurate dilutions of the test compound from the identified commercial product. For initial studies, six widely spaced rates are recommended. The use of additional wetter is only recommended for highly waxed leaf material, in which case this wetter solution is used for the "untreated" (control) solution in place of water alone. As the addition of a wetting agent can significantly effect the performance of an insecticide product in a bioassay, it is essential that details of the wetting agent are recorded with any summary data and that only data generated with the same agent and concentration are compared for susceptibility measurements.
- Dip leaves individually in the test liquid for 10 seconds with gentle agitation and place to surface-dry on paper towelling (abaxial surface facing skywards). Ensure the entire leaf surface is emerged equally and do not allow the leaves to wilt. Dip the same number of leaves per treatment (a minimum of four replicate leaves per concentration is recommended), and treat sufficient leaf material to avoid starvation stress in the "untreated" first and work up through the test dilutions (lowest to highest).
- Place the treated surface-dry leaves in the labeled test containers, which must be suitable for holding enough leaf material in good condition for up to 96 hours.  
  
Optional: A filter paper can be placed inside the base of the container to absorb any excess condensation.
- Add equal numbers of L2 larvae to each container, so that a minimum total of 40 larvae are used per treatment, divided between at least four replicate containers. Seal the containers with the container lid.
- Store the containers in an area where they are not exposed to direct sunlight or extremes of temperature. Record maximum and minimum temperatures. If possible a mean temperature of 25°C, 60% RH and 16:8 light/dark regime is preferred.

**MODES OF ACTION**

- > Avermectins-Milbemycins (8)
- > Benzylureas (16)
- > Carbamates (5A)
- > Compounds of Unknown or Uncertain MoA (UN)
- > Cyclocladiene organochlorines (2A)
- > Dicycylhydrazines (12)
- > Indoxacarb (22A)
- > metaflumizone (22B)
- > Organophosphates (1B)
- > Phenylpyrazoles (Fiprole) (25)
- > Pyrethroids-Pyrethrins (3)
- > Spinoyns (5)

**DOWNLOAD**  
[IRAC Susceptibility Test Method 018](#)

**CONTACT INFORMATION**  
**Alan Porter**  
IRAC International Coordinator  
[aporter.ape@gmail.com](mailto:aporter.ape@gmail.com)

web page



Insecticide Resistance Action Committee  
[www.irc-online.org](http://www.irc-online.org)

IRAC Susceptibility Test Methods Series  
Version: 3.4

Method No: 018

**Details:**

Method:	IRAC No. 018	 <i>Plutella xylostella</i> larvae Courtesy of BASF
Status:	Approved	
Species:	Diamondback Moth ( <i>Plutella xylostella</i> )	
Species Stage	Larvae (L2/L3)	
Product Class:	This method is specifically recommended by the IRAC Diamide Working Group for evaluating the susceptibility status of diamide insecticides (IRAC MoA 28)**  This method is also suitable for the following insecticide classes (IRAC MoA class):  Carbamate (1A)* Organophosphate (1B)* Organochlorine (2A)* Fiprole (2B)* Pyrethroid (3A)* Spinosyn (5)* Avermectin (6)** Benzyl urea (15)*** Dicycylhydrazine (12)**** Indoxacarb (22A)* Metaflumizone (22B)* Pyridalyl (un)*	
Comments:	Mortality assessment period may vary depending on insecticide mode of action  The following guidelines may be used:  *72 hours assessment period **96 hour assessment period ***120 hour assessment period (addition of fresh plant material may be necessary to avoid starvation). Larvae should go through full molt before mortality assessment.	

**Description:**

**Materials:**  
Insect-proof containers, scissors, forceps, fine pointed brush, beakers for test liquids, syringes/pipettes for liquids or weighing balance for solids, syringes/pipettes for making dilutions, binocular microscope or hand lens (optional), untreated leaves of a host plant, paper towels, maximum/minimum thermometer, filter papers, seeking pin or fine forceps.

Page 1

PDF document

# eConnection: IRAC newsletter

IRAC NEWSLETTER ISSUE 35 OCTOBER 2014

**IRAC**  
Insecticide Resistance Action Committee

eConnection

**FEATURED IRAC MEMBER:**  
*Clint Pilcher (DuPont Pioneer) joined the IRAC Plant Biotechnology Team in 2011, and became Team Leader earlier this year. He also represents the Team on the IRAC Steering Group.*



**IN THIS ISSUE:**  
**WHITE PAPERS FROM THE IRAC PLANT BIOTECH TEAM**  
*Summary of three white papers covering IRM for transgenic crops in small-holder systems, Industry perspectives on IRM for transgenic crops and IRM for seed blends.*

**RECENTLY UPDATED IRAC POSTERS**  
*New posters covering insecticide resistance mechanisms for Myzus persicae and IRM for Diuraphis citri.*

**RESISTANCE STATUS OF CEREAL APHIDS**  
*A challenge for cereal growers in Northern Europe from pyrethroid resistance in Sitobion avenae.*

**IRM VALUE USING TRAITS AND TRADITIONAL CHEMISTRY**  
*A statement from IRAC International outlining key considerations.*

**NEWS SNIPPETS & CONFERENCES**  
[www.irac-online.org](http://www.irac-online.org)

**About This Issue**  
 Welcome to another IRAC eConnection Newsletter. As always we try to bring you interesting and informative articles about the work of IRAC and insecticide resistance news from around the world.

In this issue we have summaries of position papers from the Biotechnology Team, details of two updated posters from the Sucking Pest Team on *Myzus persicae* and *Diuraphis citri*, the resistance status of cereal aphids in Northern Europe and a statement from IRAC International on IRM considerations when using both traditional chemistries and traits.

Remember, if you have any news or resistance topics of interest, please let us know so that we can inform others in the IRAC Network. We hope you enjoy the issue.

**IRAC Plant Biotechnology Team White Papers**  
 The IRAC Biotechnology Team recently produced three white papers covering different aspects of insect resistance management for biotech crops which can be downloaded from the IRAC website. Team members summarize the key points from these papers below.

**Insect Resistance Management (IRM) for Transgenic Crops in Small-Holder Agricultural Systems**  
 Insects are capable of developing resistance to any pest management tactic, transgenic insect-protected crops are no exception. The consequences of insects developing resistance to transgenic crops will include: loss of revenue to growers due to yield loss, increased costs associated with more aggressive management measures and alteration to crop practices. It is incumbent on technology providers to take proactive measures to delay its onset and develop insect resistance management programs for transgenic crops.

Developing IRM programs in agricultural systems that are dominated by small holders where the economic and practical considerations vary from industrial agricultural systems deserve special consideration. This guide provides an overview of important elements to a proactive IRM program and includes recommendations for IRM in small-holder agriculture systems. These elements include: 1) refuge guidelines, 2) best management practices, 3) education and communication, 4) monitoring, and 5) on-going research. Critical to small-holder agriculture systems, economic and practical realities are especially important and should complement the scientific basis of any recommended IRM program. Developers must take into account the economic, social and rural agricultural community. In addition, regulators should encourage technology providers to simplify and harmonize IRM programs for similar transgenic products. The full paper can be found at: <http://www.irac-online.org/documents/irm-in-small-holder-systems/?text=pdf>

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IRAC NEWSLETTER ISSUE 35 OCTOBER 2014

**IRAC Plant Biotechnology Team White Papers (Contd.)**

**Industry Perspectives on Insect Resistance Monitoring for Transgenic Insect-Protected Crops**  
 Resistance monitoring is a fundamental component of insect resistance management (IRM) programs, the goal of which is to maintain product value to customers. This paper provides a consensus of IRAC member views regarding monitoring for insect resistance to transgenic crops. Resistance monitoring provides a means of detecting reductions in susceptibility of target insect pests to insecticides or Bt proteins that could reduce the economic value of the product; the primary goal being to detect resistance early enough to effectively deploy resistance mitigation measures and modify the IRM strategy.



Top left picture: Plant assay containers incubating in grower chamber  
 Bottom left picture: Burlese funnels used to extract larvae from root mats  
 Right picture: Larval corn rootworm samples extracted from different treatments  
 Photographs courtesy of Steve Thompson, DuPont Pioneer

Topics in the paper include an overview of properties of a successful resistance monitoring program, what pest species to monitor, where to focus monitoring, laboratory field-based monitoring approaches, appropriate characterization of field collections, and interpretation of bioassay data. The paper closes with a summary of IRAC members' commitment to sustainability and transparency pertaining to resistance monitoring. The full paper can be found at: <http://www.irac-online.org/documents/industry-perspectives-on-irm-monitoring/?text=pdf>

**Seed Blends for Resistance Management of Insect-Protected Transgenic Crops**  
 The benefits and disadvantages of providing "refuge in the bag" are complex and the balance depends on a range of system-specific biological, agricultural, and operational considerations. While blended refuge products assure that growers plant appropriate refuges for their insect-protected biotech crops, movement of larvae between refuge and traited plants can reduce the effective refuge size and increase survival of insects that are heterozygous for resistance alleles. IRAC recognizes that for a blended refuge strategy to be successful for a given pest/crop system, it must be widely adopted among the biotech trait providers. The IRAC Position Paper describes the technical and practical issues that must be considered when evaluating blended refuge and provides guidance on decision making. In general, if a planted refuge is biologically warranted to promote product durability, larval movement between traited and refuge plants is not expected to seriously compromise durability, and grower implementation of a separate refuge is known or expected to be low, seed blends can be a valuable option for refuge deployment. The full paper can be found at: <http://www.irac-online.org/documents/seed-blends-for-irm/?text=pdf>

2

# IRAC Educational resources

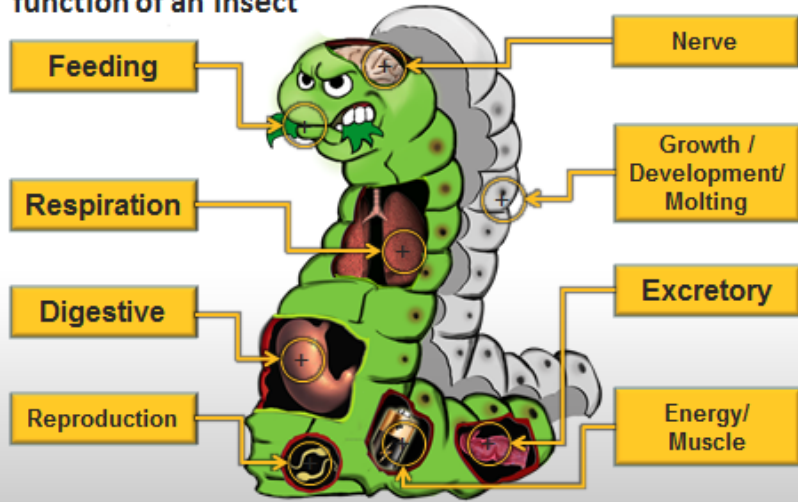
- Posters
- Presentations
- Booklets
- Guidelines
- Publications



*Example:* Farmer-focused graphic in Chinese explaining how resistance develops.

# Insecticide Mode of Action (MoA)

A specific Mode of Action will target a specific part/function of an insect



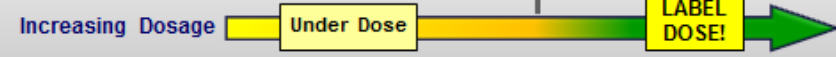
## 2. Follow Good Agricultural Practice (GAP) Principles

**USE RECOMMENDED DOSE**

**Under Dose:**  
Kills most Susceptible but many RS and RR survive

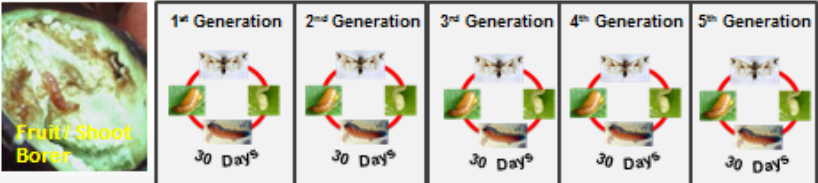
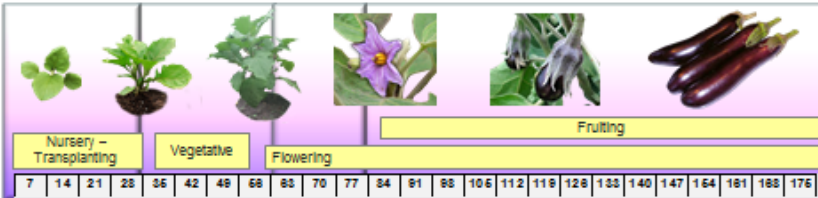
**Label Dosage:**  
Optimal Control  
Small number of RR survive

Resistant RR		
Moderate RS		
Susceptible S		



## Insecticide Resistance Management (IRM) Strategy in Eggplant

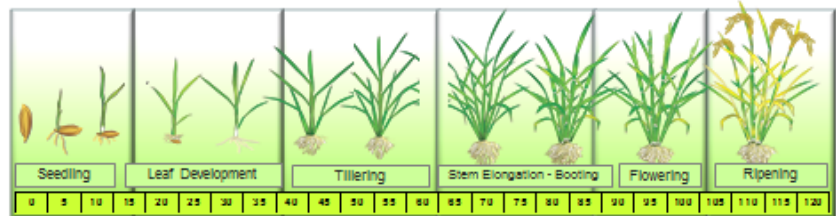
To ensure susceptible Fruit Borer population



**Insecticide Application (Need-Based)**

Option 1	MoA 1	MoA 2	MoA 3	MoA 4	MoA 5
Option 2	MoA 1	MoA 2	MoA 1	MoA 2	MoA 1

## Insecticide Resistance Management (IRM) Strategy in Rice



	1 <sup>st</sup> Generation	2 <sup>nd</sup> Generation	3 <sup>rd</sup> Generation
Stemborer	35 Days	35 Days	35 Days
Brown Plant Hopper	32 Days	32 Days	32 Days
Green Leaf Hopper	30 Days		

**Insecticide Application (Need-Based)**

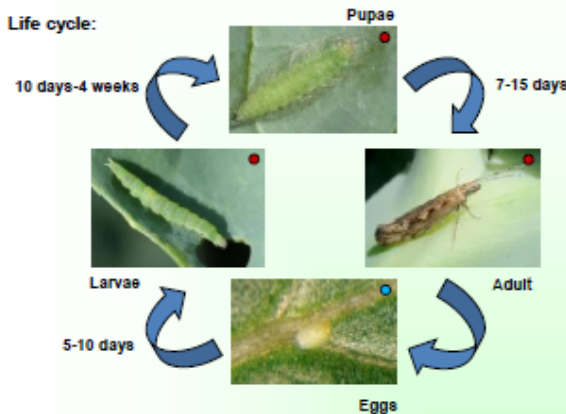
Option 1	MoA 1	MoA 2	MoA 3
Option 2	MoA 1	MoA 2	MoA 1



### Introduction and Biological Background

Diamondback moth (*Plutella xylostella* L.) is a highly migratory and cosmopolitan species, and is one of the most important insect pests of cruciferous crops worldwide. Globally, direct losses and control costs are estimated to be US\$ 1 billion (1).

#### Life cycle:



In temperate regions, *P. xylostella* is unable to overwinter and therefore annual outbreaks are attributed to migration, but in tropical and sub-tropical regions there can be a large number of continuous generations per year (e.g. up to 21 in Taiwan) (2).

*P. xylostella* is considered to be one of the most difficult pests to control. Continuous insecticide applications have been, and in many regions still are, the main tool employed for crop protection.

Cases of *P. xylostella* resistance to insecticides were reported in the 1950's. Today this species shows resistance to most insecticide classes, including recently introduced compounds with new modes of action (3).

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### *Plutella xylostella* Damage in Cabbage



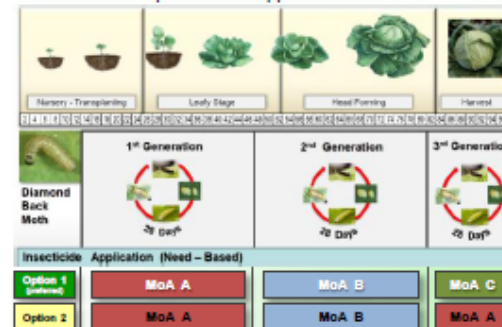
### Resistance Mechanisms

Several biochemical mechanisms are described as conferring resistance to insecticides in diamondback moth populations. Many of these mechanisms listed below act in concert and can provide resistance factors of 1000-fold or greater.

- Enhanced metabolic detoxification mechanisms (3,4)
- Insensitive acetylcholinesterase
- Reduced Cry1C binding to target site in midgut membrane and reduced conversion of Cry1C protoxin to toxin (5)
- Reduced penetration (6,7)
- Target-site resistance (7-10)

### Resistance Management (example)

The figure below shows a resistance management strategy developed for use in Brassica crops in the Philippines.



### General IRM Tactics

A combination of all available tools for *P. xylostella* management should be used to prevent the development of insecticide resistance:

- resistant varieties
- refuge crops
- biological control with natural enemies, e.g. *Cotesia plutellae*
- insecticide applications with mode of action rotation and windows approach
- crop hygiene

The resistance monitoring method for *Plutella xylostella* (IRAC Method No. 018) is available on the IRAC website and should be used to evaluate insecticide susceptibility.



### Chemical Control of *Plutella xylostella*

- Select insecticides based on known local effectiveness and selectivity
- Rotate insecticides by mode of action group, using a window approach
- Use only insecticides registered for diamondback moth control
- Always follow the directions for use on the label of each product

MoA	Primary Site of Action	Chemical Sub-group or Exemplifying Active
1	Acetylcholinesterase inhibitors	1A: Carbamates 1B: Organophosphates
2	GABA-gated Cl channel antagonists	2B: Phenylpyrazoles (Fluproles)
3	Sodium channel modulators	3A: Pyrethroids, Pyrethrins
4	Nicotinic acetylcholine receptor agonists	4A: Neonicotinoids
5	Nicotinic acetylcholine receptor allosteric activators	5: spinosyns
8	Chloride channel activators	Avermectins, Milbemectins
11	Microbial disruptors of insect midgut membranes and derived toxins	<i>Bacillus thuringiensis</i> var. <i>kurstaki</i>
13	Uncouplers of oxidative phosphorylation via disruption of the proton gradient	Pyriproxyfen
16	Inhibitors of chitin biosynthesis, type B	Benzoylureas
18	Ecdysone receptor agonists	Diazinylhydrazines
21	Mitochondrial complex I electron transport inhibitors	21A: Tolifenpyrad
22	Voltage-dependent Na channel blockers	22A: Indoxacarb 22B: Mefenflumizone
28	Ryanodine receptor modulators	Diamides
UN	Compounds of unknown/uncertain MoA	Azadirachtin, Pyridalyl

## Resistance Mechanisms

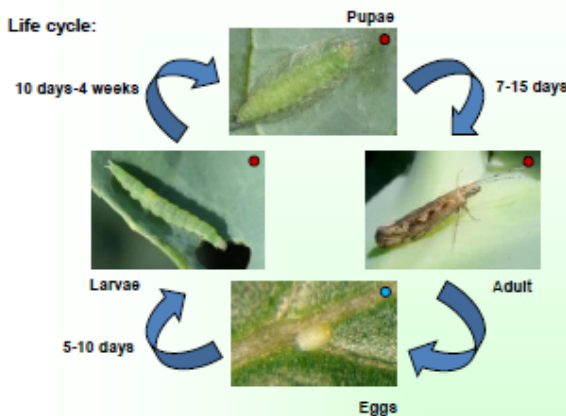
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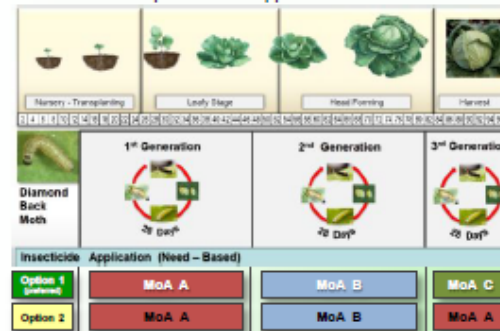
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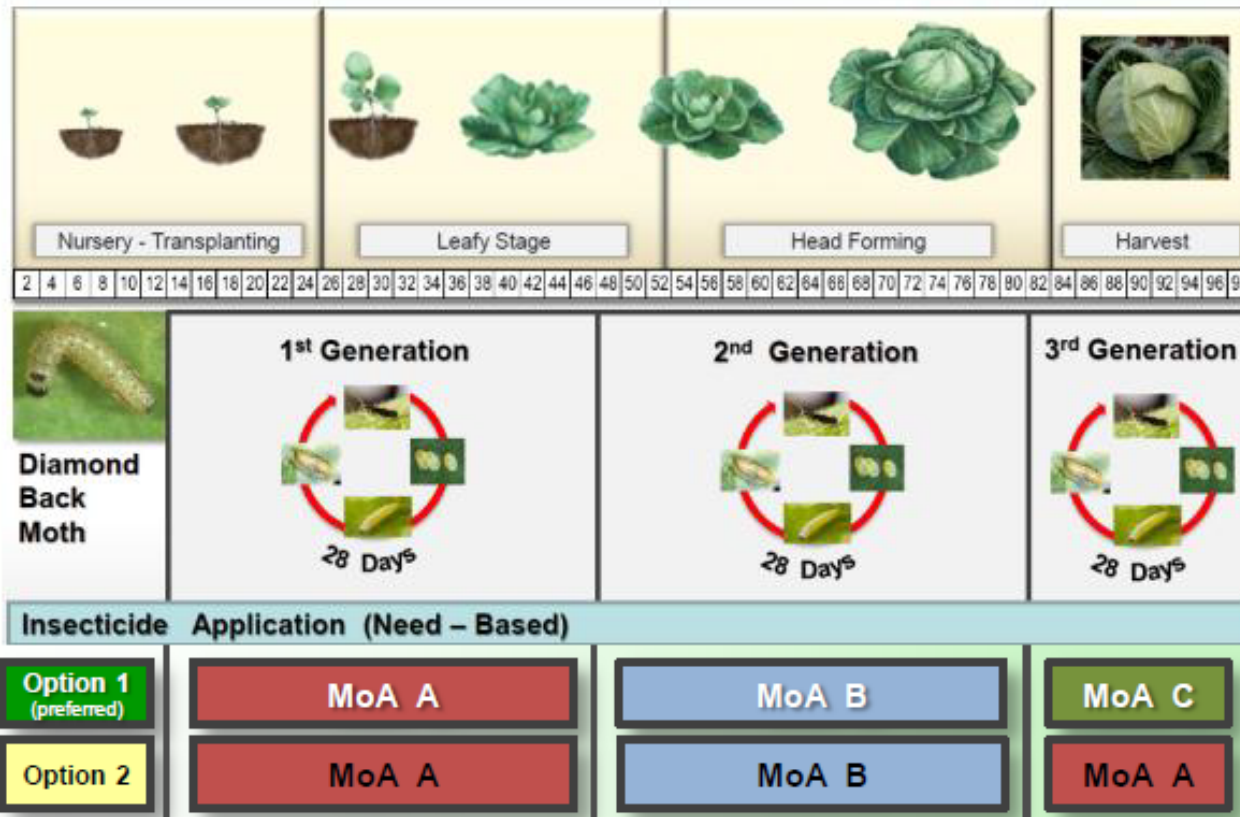
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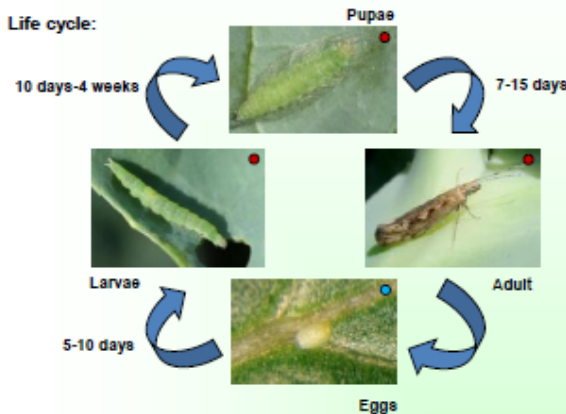
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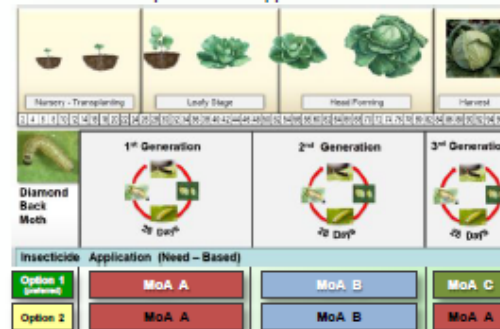
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2	GABA-gated Cl channel antagonists	2B: Phenylpyrazoles (Fluproles)
3	Sodium channel modulators	3A: Pyrethroids, Pyrethrins
4	Nicotinic acetylcholine receptor agonists	4A: Neonicotinoids
5	Nicotinic acetylcholine receptor allosteric activators	5: spinosyns
6	Chloride channel activators	Avermectins, Milbemectins
11	Microbial disruptors of insect midgut membranes and derived toxins	<i>Bacillus thuringiensis</i> var. <i>kurstaki</i>
13	Uncouplers of oxidative phosphorylation via disruption of the proton gradient	Pyriproxyfen
16	Inhibitors of chitin biosynthesis, type B	Benzoylureas
18	Ecdysone receptor agonists	Diazinylhydrazines
21	Mitochondrial complex I electron transport inhibitors	21A: Tolifenpyrad
22	Voltage-dependent Na channel blockers	22A: Indoxacarb 22B: Metafenzone
28	Ryanodine receptor modulators	Diamides
UN	Compounds of unknown/uncertain MoA	Azadirachtin, Pyridalyl

# General IRM Tactics

A combination of all available tools for *P. xylostella* management should be used to prevent the development of insecticide resistance:

- resistant varieties
- refuge crops
- biological control with natural enemies, e.g. *Cotesia plutellae*
- insecticide applications with mode of action rotation and windows approach
- crop hygiene

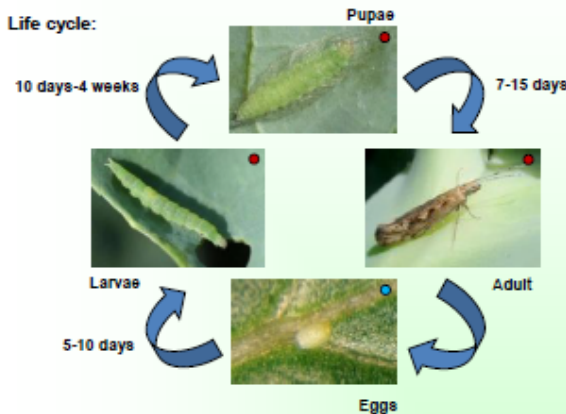
The resistance monitoring method for *Plutella xylostella* (IRAC Method No. 018) is available on the IRAC website and should be used to evaluate insecticide susceptibility.



### Introduction and Biological Background

Diamondback moth (*Plutella xylostella* L.) is a highly migratory and cosmopolitan species, and is one of the most important insect pests of cruciferous crops worldwide. Globally, direct losses and control costs are estimated to be US\$ 1 billion (1).

#### Life cycle:



In temperate regions, *P. xylostella* is unable to overwinter and therefore annual outbreaks are attributed to migration, but in tropical and sub-tropical regions there can be a large number of continuous generations per year (e.g. up to 21 in Taiwan) (2).

*P. xylostella* is considered to be one of the most difficult pests to control. Continuous insecticide applications have been, and in many regions still are, the main tool employed for crop protection.

Cases of *P. xylostella* resistance to insecticides were reported in the 1950's. Today this species shows resistance to most insecticide classes, including recently introduced compounds with new modes of action (3).

#### References

- Gyauwacz, D., A. Rossbach, D. Russell, R. Srinivasan, A.M. Shelton. 2010. *Crop Protection* 22 (1): 69-79
- Chapman, J.W., D.R. Reynolds, A.D. Smith, J.R. Riley, D.E. Pedgley, I.P. Woiwod. 2002. *Ecol. Entomol.* 27: 641-650
- Zhao, J.Z., L.H. Collins, X.Y. Li, R.F.L. Mau, G.D. Thompson et al. 2006. *J. Econ. Entomol.* 39: 176-181
- Hung, C.F., C.H. Kao, C.C. Liu, J.G. Lin, and C.N. Sun. 1990. *J. Econ. Entomol.* 83: 361-365
- Liu, Y.S., B.E. Tabashnik, J. Mason, B. Eschiche, and J. Ferré. 2000. *J. Econ. Entomol.* 33: 1-5
- Noppun, V., Saito, T., Miyata, T., 1986. *Pestic. Biochem. Physiol.* 33: 83-87.
- Li, A., Y. Yang, B. Wu, C. Li, and Y. Wu. 2006. *J. Econ. Entomol.* 39: 914-919
- Baxter, S.W., Chen, M., Dawson, A., Zhao, J.Z., Vogel, H., Shelton, A.M., Heckel, D.G., Jiggins, C.D., 2010. *PLoS Genetics* 6: e1000802
- Sonoda, S., 2010. *Pest. Manag. Sci.* 66: 572-575
- Trocik, B., C.T. Zimmer, J. Elias, C. Schom, C. Bass, T.G.E. Davies, L.M. Field, M.S. Williamson, R. Slater, R. Nauen. 2012. *Insect Biochem Mol Biol* 112: 873-880

### *Plutella xylostella* Damage in Cabbage



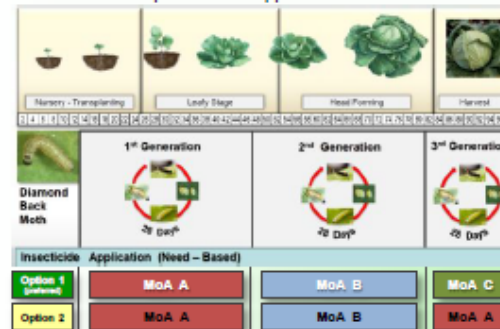
### Resistance Mechanisms

Several biochemical mechanisms are described as conferring resistance to insecticides in diamondback moth populations. Many of these mechanisms listed below act in concert and can provide resistance factors of 1000-fold or greater.

- Enhanced metabolic detoxification mechanisms (3,4)
- Insensitive acetylcholinesterase
- Reduced Cry1C binding to target site in midgut membrane and reduced conversion of Cry1C protoxin to toxin (5)
- Reduced penetration (6,7)
- Target-site resistance (7-10)

### Resistance Management (example)

The figure below shows a resistance management strategy developed for use in Brassica crops in the Philippines.



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### Chemical Control of *Plutella xylostella*

- Select insecticides based on known local effectiveness and selectivity
- Rotate insecticides by mode of action group, using a window approach
- Use only insecticides registered for diamondback moth control
- Always follow the directions for use on the label of each product

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18	Ecdysone receptor agonists	Diacylhydrazines
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# Summary

- IRAC is comprised primarily of representatives from agrochemical, seed, and public health companies affiliated with CropLife, and it provides coordinated industry efforts to prevent or delay resistance in insect and mite pests.
- IRAC International consists of several global teams that work with a number of IRAC Country Groups.
- A key resistance management tool is the IRAC Mode of Action Classification system.
  - IRAC's numbered MoA groups are a simple way to communicate MoA information on product labels, which promotes more effective product rotation.
- You can access IRAC's resources at the IRAC website ([www.irc-online.org](http://www.irc-online.org)).
  - Mode of action classification tools (webpage, posters, booklet, phone/tablet app).
  - Pest pages with details on pest biology and resistance.
  - Test methods (webpage, PDF, and video formats).
  - Michigan State University Arthropod Pesticide Resistance Database.
  - eConnection electronic newsletter.
  - Posters, publications, and presentations covering many aspects of resistance management for insecticides and insect-resistant traits.



**Thank you**

*Questions?*

[www.ircac-online.org](http://www.ircac-online.org)