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

Lakshmipathi Srigiriraju, PhD
representing IRAC International
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.
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.
IRAC Mode of Action poster, Edition 4, December 2014
Company agreement on mode of action labelling and alignment of IRM label language.

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 insecticides, 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 seeding 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

1. Acetylcholine esterase inhibitors
2. GABA-gated chloride channel antagonists
3. Sodium channel modulators
4. Nicotinic Acetylcholine receptor agonists
5. Nicotinic Acetylcholine receptor allosteric activators
6. Chloride channel activators

The Insecticide Resistance Action Committee (IRAC) was formed in 1984 and is now part of the Stewardship Steering Committee of CropLife International. IRAC provides a coordinated crop protection industry response to prevent or delay the development of resistance in insect and mite pests.
IRAC website: Communication and education

www.irac-online.org
IRAC website: Mode of Action classification tools

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

IRAC website tool

IRAC phone app

IRAC booklet
IRAC website: Pest pages

Tobacco Whitefly

**Description**

A small flat, white insect with a length of approximately 5-7 mm, the wings are white, and the antennae are black. The larvae feed on the leaves and stems of tobacco plants, causing damage and reducing yield.

**Damage:**

- Feeding on leaves and stems, causing disfigured leaves and stunted growth.
- Infestation can lead to reduced yield and quality of the tobacco crop.

**Control Measures:**

- Mechanical removal: Hand-picking and cutting off infested leaves.
- Biological control: Natural predators like ladybugs and lacewings.
- Chemical control: Use of insecticides such as neem oil or pyrethrins.

**Preventive Measures:**

- Intercropping: Growing tobacco with plants that repel pests.
- Crop rotation: Switching crops to disrupt pest life cycles.

**Resistance Management:**

- Monitoring pest populations to reduce the risk of resistance development.
- Rotating chemical treatments to avoid selection pressure on pests.

**Sources:**

- IRAC Website: Pest Pages
- Agricultural Extension Services
- Seedling Suppliers

**Notes:**

- Early detection is crucial for effective control.
- Regular monitoring helps in timely intervention.

**References:**

- IRAC Pest Management Guide
- USDA Plant Protection
- State Agricultural Extension Agencies
IRAC website: Methods and method videos
IRAC test method for Diamondback moth

INTRODUCTION

This method is specific for use on L. and A. larvae. It is intended for determining the susceptibility of Diamondback moth larvae to insecticides. This test is designed for use in the laboratory to test the susceptibility of Diamondback moth larvae to insecticides. This method is specific for use on L. and A. larvae. It is intended for determining the susceptibility of Diamondback moth larvae to insecticides. This test is designed for use in the laboratory to test the susceptibility of Diamondback moth larvae to insecticides.

MATERIALS

The following materials are necessary for the test:

- Test insects: Diamondback moth larvae
- Insecticides: Carbaryl, Deltamethrin, and Malathion
- Test containers: 50 ml glass vials
- Test solution: 2% (v/v) acetone
- Test temperature: 25°C ± 2°C
- Test duration: 24 hours

PROCEDURE

1. Place the test insects into the test containers, each containing 50 ml of acetone solution.
2. Incubate the test containers at 25°C ± 2°C for 24 hours.
3. Record the number of dead insects at the end of the incubation period.

RESULTS

The test results should be recorded and analyzed to determine the susceptibility of the Diamondback moth larvae to the insecticides tested.

DISCUSSION

The results of this test can be used to determine the efficacy of the insecticides against Diamondback moth larvae. This information can be used to develop effective pest management programs.
eConnection: IRAC newsletter

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 insecticidal 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 Budding Pest Team on Myzus persicae and Helicoverpa zea, 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 questions or resistance topics of interest, please let us know so that we can incorporate them in the eConnection. 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 insects are no exception. The consequences of insects developing resistance to transgenic crops will include loss of revenue to growers due to crop losses, 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 multi-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 agricultural systems. These elements include: 1) refuge guidelines, 2) best management practices, 3) education and communication, 4) monitoring, and 5) monitoring of different agricultural systems. Economic and practical considerations are especially important and should complement the biological basis of any IRM recommendation. IRM programs 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://irac-online.org/documents/IRM-white-paper-gene-plan.pdf

Seed Blends for Resistance Management of Insect-Resistant Transgenic Crops
The benefits and drawbacks of providing "refuge in the bag" are complex and the balance depends on a range of species-specific biology, agriculture, and operational considerations. Several refuge products ensure that growers plant appropriate refuges for their insect-resistant biotech crops. Movement of those between refuge and traited plants can reduce the effective refuge area and increase survival of insects that are heterogeneous 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 provider. The IRAC Position Paper describes the technical and practical issues that must be considered when designing such refuge systems and provides guidance on solution making. In general, a planted refuge is biologically warranted to promote product durability, aerobic movement between traited and refuge plants it is not expected to seriously compromise durability, and grower implementation of a separate refuge is known or expected to be insufficient; seed blends can be a valuable option for refuge deployment. The full paper can be found at: http://irac-online.org/documents/seed-blends-refuge.pdf
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

- Feeding
- Respiration
- Digestive
- Reproduction
- Nerve
- Growth/Development/Molting
- Excretory
- Energy/Muscle

Insecticide Resistance Management (IRM) Strategy in Eggplant

To ensure susceptible Fruit Borer population

1st Generation
2nd Generation
3rd Generation
4th Generation
5th Generation

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

- Germ Plasm
- Seedling
- Leaf Development
- Flowering
- Stem Borer
- Brown Plant Hopper
- Green Leaf Hopper

1st Generation
35 Days
35 Days
35 Days

2nd Generation
32 Days
32 Days
32 Days

3rd Generation
30 Days

Insecticide Application (Need-Based)

Option 1
MoA 1
MoA 2
MoA 3

Option 2
MoA 1
MoA 2
MoA 1

2. Follow Good Agricultural Practice (GAP) Principles

<table>
<thead>
<tr>
<th>USE RECOMMENDED DOSE</th>
<th>Label Dosage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Under Dose</td>
<td>Optimal Control</td>
</tr>
<tr>
<td>Resistant RR</td>
<td>Small number of RR survive</td>
</tr>
<tr>
<td>Moderate RS</td>
<td></td>
</tr>
<tr>
<td>Susceptible S</td>
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</tbody>
</table>

Increasing Dosage

- Under Dose
- Label DOSE!
The Diamondback Moth, *Plutella xylostella*: Resistance Management is Key for Sustainable Control

**Introduction and Biological Background**

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

**Life cycle:**
- Egg: 6-10 days
- Larvae: 10 days - 4 weeks
- Pupa: 7-15 days
- Adult: n/a

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

**Case Study:**

Cases of *P. xylostella* resistance to insecticides were reported in the 1980s. Today this species shows resistance to most insecticide classes, including recently introduced compounds with new modes of action (1).

**Plutella xylostella Damage in Cabbage**

Treated with insecticide, Not treated with insecticide

**Resistance Mechanisms**

Several biochemical mechanisms are described as conferring resistance to insects in diamondback moth populations. Many of these mechanisms listed below aid in insecticide resistance factors of 1000-fold or greater.

1. Enhanced metabolic detoxification mechanisms (3, 4)
2. Insecticidal acetylcholinesterase
3. Reduced Cry1 binding to target site in midgut membrane and reduced conversion of Cry1 to toxic (5)
4. Reduced penetration (0.7)
5. 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 plutella
- Insecticide applications with mode of action rotation and window approach
- Crop hygiene

The resistance monitoring method for *Plutella xylostella* (IRAC Method No. 218) 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

**References**

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.

1. Enhanced metabolic detoxification mechanisms (3,4)
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The Diamondback Moth, *Plutella xylostella*: Resistance Management is Key for Sustainable Control

**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:

- Larvae: 6-10 days
- Pupa: 7-15 days
- Adult: 10 days - 4 weeks

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).

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**References**


**Chemical Sub-group or Example of Active**

- AChE inhibitors
- Carbamates, Organophosphates
- Neonicotinoids
- Pyrethroids
- Oximes, Carbamates
- Pyrethroids
- Carbamates
- Organophosphates
- Pyrethroids
- Chloronicotinoids
- Insect growth regulators
- 2,4-D
- Non-systemic herbicides
- Trifluralin
- Methyl bromide
- Diquat
- None

This poster is for educational purposes only. Details are accurate to the best of our knowledge but IRAC and its member companies cannot accept responsibility for how this information is used or interpreted. Advice should always be sought from local experts or advisors and health and safety regulations followed. IRAC DBM Resistance Management poster, Version 3.1, March 2013
Resistance Management (example)

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

[Diagram showing the life cycle of Diamond Back Moth and the application of insecticides at different stages of crop growth.]
The Diamondback Moth, *Plutella xylostella*: Resistance Management is Key for Sustainable Control

**Introduction and Biological Background**

Diamondback moth (*Plutella xylostella L.*) is a highly migratory and cosmopolitan species, and 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:**
  - 10 days - 4 weeks
  - 7-15 days
  - 6-10 days

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

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Cases of *P. xylostella* resistance to insecticides were reported in the 1960s. Today this species shows resistance to most insecticide classes, including recently introduced compounds with new modes of action (3).

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**Life cycle:**
- **Laçée:** 6-10 days
- **Pupa:** 7-15 days
- **10 days-4 weeks**
- **Adult:** 1-3 weeks

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<th>Primary Site of Action</th>
<th>Chemical Sub-group or Exemplifying Active</th>
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<tr>
<td>1</td>
<td>Acetylcholinesterase inhibitors</td>
<td>1A: Carbamates</td>
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<tr>
<td></td>
<td></td>
<td>1B: Organophosphates</td>
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<td>2</td>
<td>GABA-gated Cl channel antagonists</td>
<td>2B: Phenylpyrazoles (Fiproles)</td>
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<td>3</td>
<td>Sodium channel modulators</td>
<td>3A: Pyrethroids, Pyrethrins</td>
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<td>4</td>
<td>Nicotinic acetylcholine receptor agonists</td>
<td>4A: Neonicotinoids</td>
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<td>5</td>
<td>Nicotinic acetylcholine receptor allosteric activators</td>
<td>Spinosyns</td>
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<td>Chloride channel activators</td>
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<td>11</td>
<td>Microbial disruptors of insect midgut membranes and derived toxins</td>
<td><em>Bacillus thuringiensis var. kurstaki</em></td>
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<td>Uncouplers of oxidative phosphorylation via disruption of the proton gradient</td>
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<td>Ryanodine receptor modulators</td>
<td>Diamides</td>
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<td>UN</td>
<td>Compounds of unknown/uncertain MoA</td>
<td>Azadirachtin, Pyridalyl</td>
</tr>
</tbody>
</table>
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.irac-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.irac-online.org