Insecticide Resistance Action Committee

Using "Mode of Action" to Manage Insecticide Resistance

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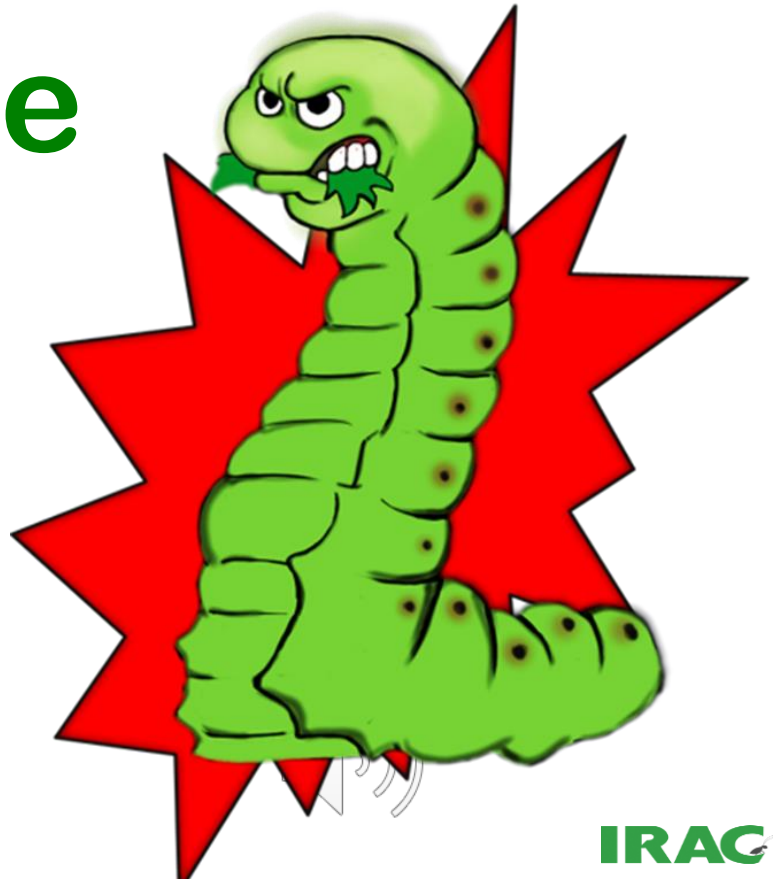

The Insecticide Resistance Action Committee (IRAC) is a coordinated industry response to resistance management

What is Insecticide Resistance?

- Insecticide resistance is the **decreased susceptibility** of a pest population to an insecticide that was previously effective at controlling that pest.
- Insecticide resistance typically evolves through **genetic selection** by excessive exposure of insecticides with the same mode of action (MOA) to the same pest population. Resistant individuals survive and **transfer their genetic traits** to their offspring.
- **Overdependence** on the same insecticide MOA leads to greater potential for resistance in a pest population.

RED FLAG
- **Field failure**
- **Lab verfication**

YELLOW FLAG
- **Observation**
- **Not verified**

or
- **Low "R" level**

GREEN FLAG
- **Green Markets have mainly susceptible populations**

Basic Genetics Training Required

….all about the individual

Genetic Nomenclature	Individual Insect "R" Status	# "R" Genes (alleles)
RR	High	2
RS	Moderate	1
SS	Susceptible	0

Assume co-dominance:
RS x SS = ½ RS + ½ SS

- Typically high % of population is RS
- Mix of individuals in population
- Need to remove "R" genes

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What is an Insecticide's 'Mode of Action'?

The Mode of action defines the process
of how an insecticide works on an insect at the molecular level

GROUP	22	INSECTICDE
GROUP	4	INSECTCIDE

GROUP	11	INSECTICDE

Why know the Mode of Action of Insecticides?

The Key To Managing Resistance (target site)

IRAC Insecticide Mode of Action (MoA)

CLASSIFICATION PER TARGET SITE

Nerve & muscle targets

Group 1 Acetylcholinesterase (AChE) inhibitors
Group 2 GABA-gated chloride channel blockers
Group 3 Sodium channel modulators
Group 4 Nicotinio acetylcholine receptor (nAChR) competitive modulators
Group 5 Nicotinic acetylcholine receptor (nAChR) allosteric modulators
Group 6 Glutamate-gated chloride channel (GluCl) allosteric modulators
Group 9 Chordotonal organ TRPV channel modulators
Group 14 Nicotinic acetylcholine receptor (nAChR) channel blockers
Group 19 Octopamine receptor agonists
Group 22 Voltage dependent sodium channel blockers
Group 28 Ryanodine receptor modulators
Group 29 Chordotonal organ modulators
Group 30 GABA-gated chloride channel allosteric modulators/Broflanamide

Nerve & muscle targets

Group 11 Microbial disruptors of insect midgut membranes
Group 31 Granuloviruses, Nucleopolyhedroviruses

Nerve & muscle targets

Group 8 Miscellaneous non-specific (multi-site) inhibitors

Respiration targets

Group 12 Inhibitors of mitochondrial ATP synthesis
Group 13 Uncouplers of oxidative phosphorylation via disruption of the proton gradient
Group 20 Mitochondrial complex III electron transport inhibitors
Group 21 Mitochondrial complex I electron transport inhibitors
Group 24 Mitochondrial complex IV electron transport inhibitors
Group 25 Mitochondrial complex II electron transport inhibitors

Growth & Development targets

Group 7 Juvenile hormone mimics
Group 10 Mite growth inhibitors,
Group 15 Inhibitors of chitin biosynthesis, Type 0, Benzoylureas
Group 16 Inhibitors of chitin biosynthesis, type 1,
Group 17 Moulting disruptors
Group 18 Ecdysone receptor agonists
Group 23 Inhibitors of acetyl CoA carboxylase

For a full and up to date list of insecticide target site classification please visit the IRAC website at http://www.irac-online.org/modes-of-action

IRAC Insecticide Mode of Action (MoA)

CLASSIFICATION PER TARGET SITE

Nerve & muscle targets

Group 1 Acetylcholinesterase (AChE) inhibitors
Group 2 GABA-gated chloride channel
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Group 14 Nicotinic acetylcholine r
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Nerve & muscle target

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Nerve & muscle targets

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Respiration ts

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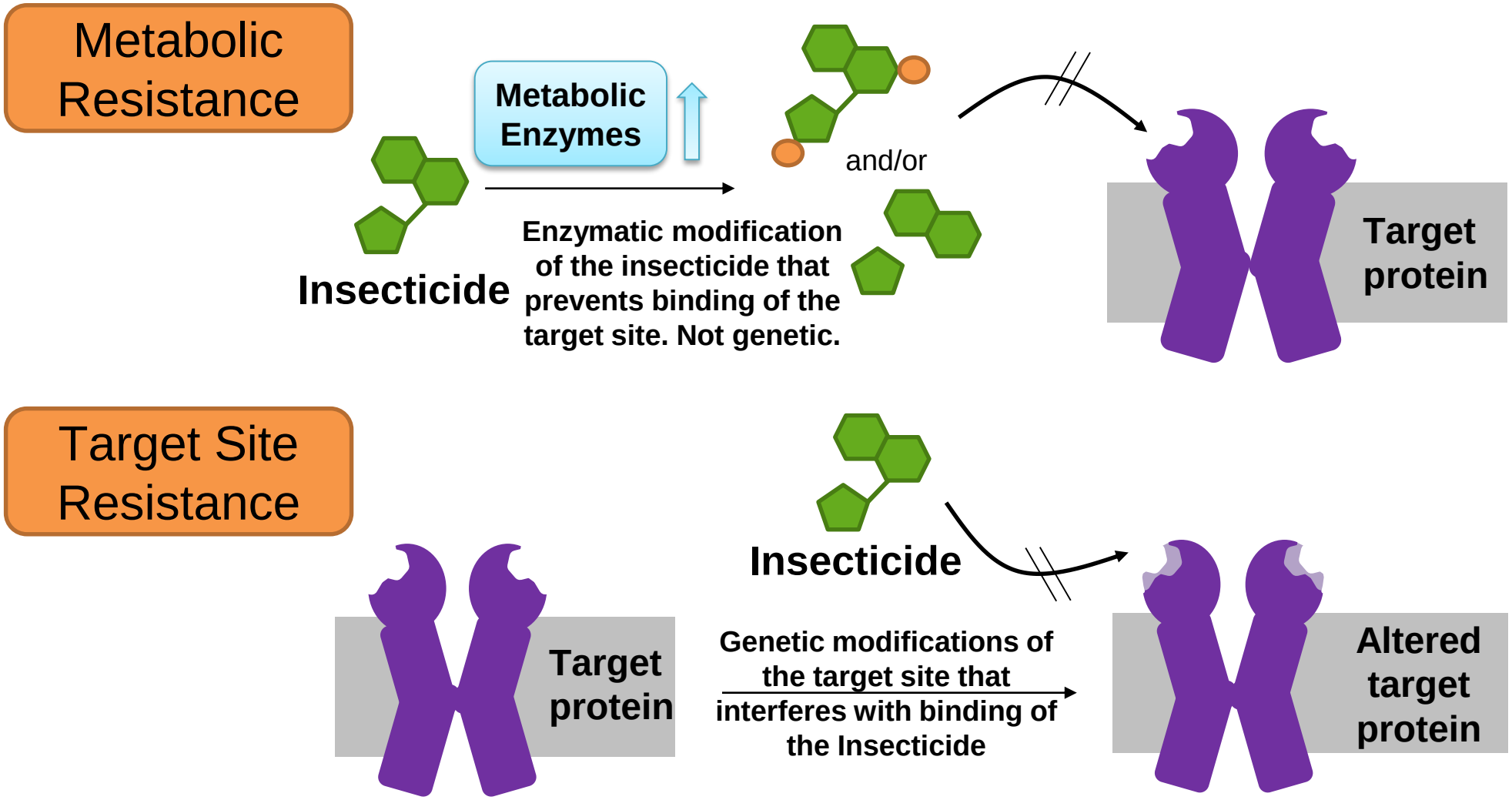
EXAMPES OF TARGET SITES

1. Acetylcholinesterase
2. Chloride channels
3. Sodium channels
15. Chitin synthesis
11. Microbial disruptors
12. Mitochondrial ATP
28. Ryanodine receptors-Calcium channels

For a full and up to date list of insecticide target site classification please visit the IRAC website at http://www.irac-online.org/modes-of-action

Major Mechanisms of Insecticide Resistance



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Target Site Resistance to One Active Means Cross Resistance To All Actives With Same MoA

Metabolic Resistance to One Active Usually Does Not Confer Resistance to the Other Actives

Biochemical Targets Differ in Their Propensity to Develop Resistance

4 Nicotinic acetylcholine receptor (nAChR) competitive modulators	4A Neonicotinoids	Acetamiprid, Clothianidin, Dinotefuran, Imidacloprid, Nitenpyram, Thiacloprid, Thiamethoxam
	4B Nicotine	Nicotine
	4C Sulfoximines	Sulfoxaflor
	4D Butenolides	Flupyradifurone
	4E Mesoionics	Triflumezopyrim
28 Ryanodine receptor modulators	Diamides	Chlorantraniliprole, Cyantraniliprole, Cyclaniliprole, Flubendiamide, Tetraniliprole

Metabolic Resistance is More Common

Target Site Resistance is More Common

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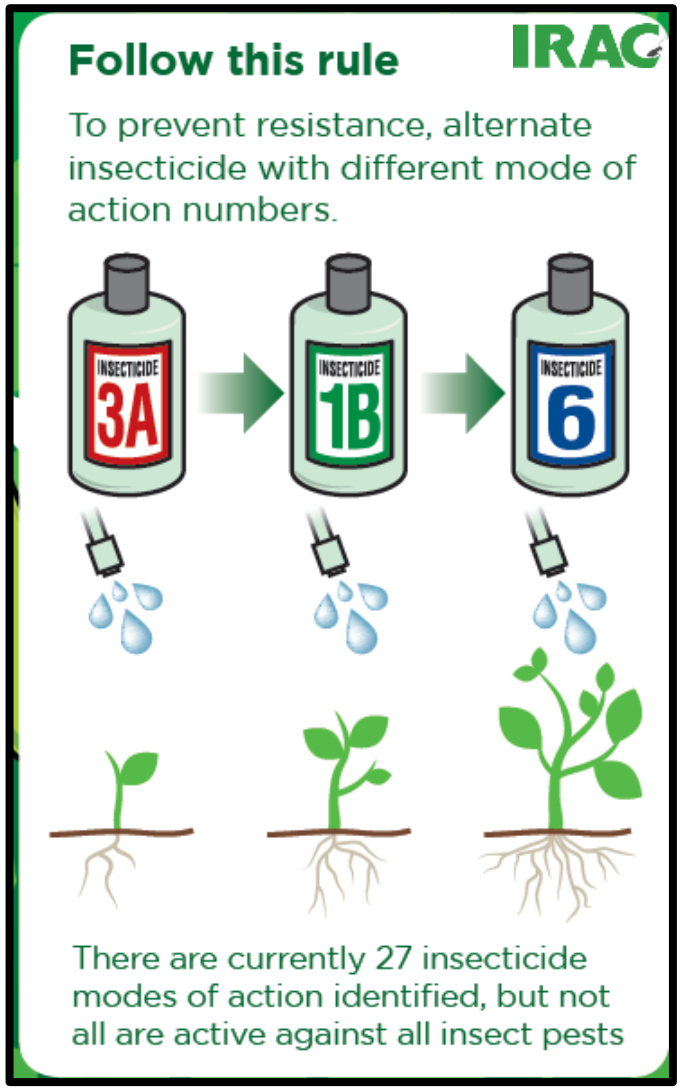
Rotate insecticides with different modes of action to reduce selection pressure for resistance

- **Two successive insect generations shouldn't be treated with the same MoA insecticides.**
- **Repeated exposure of pest populations to insecticides with the same Mode of Action will select for resistant insects.**



Tank Mixing vs MoA Rotation:

General Guidance for Pesticide Resistance Management

	Fungicides	Herbicides	Insecticides
Much Preferred	Mixes	Mixes	Rotation
Acceptable	Rotation	Rotation	Mixes

Mixes = tank mix or premixed active ingredients

Tank Mixing vs MoA Rotation:
General Guidance for Pesticide Resistance Management

	Fungicides	Herbicides	Insecticides
Much Preferred	Mixes	Mixes	Rotation
Acceptable	Rotation	Rotation	Mixes

Mixes = tank mix

Both Rotation and Mixing RM Strategies Require Knowledge of Product Modes of Action

Insecticidal Mode of Action

Growers/Customers need to understand:

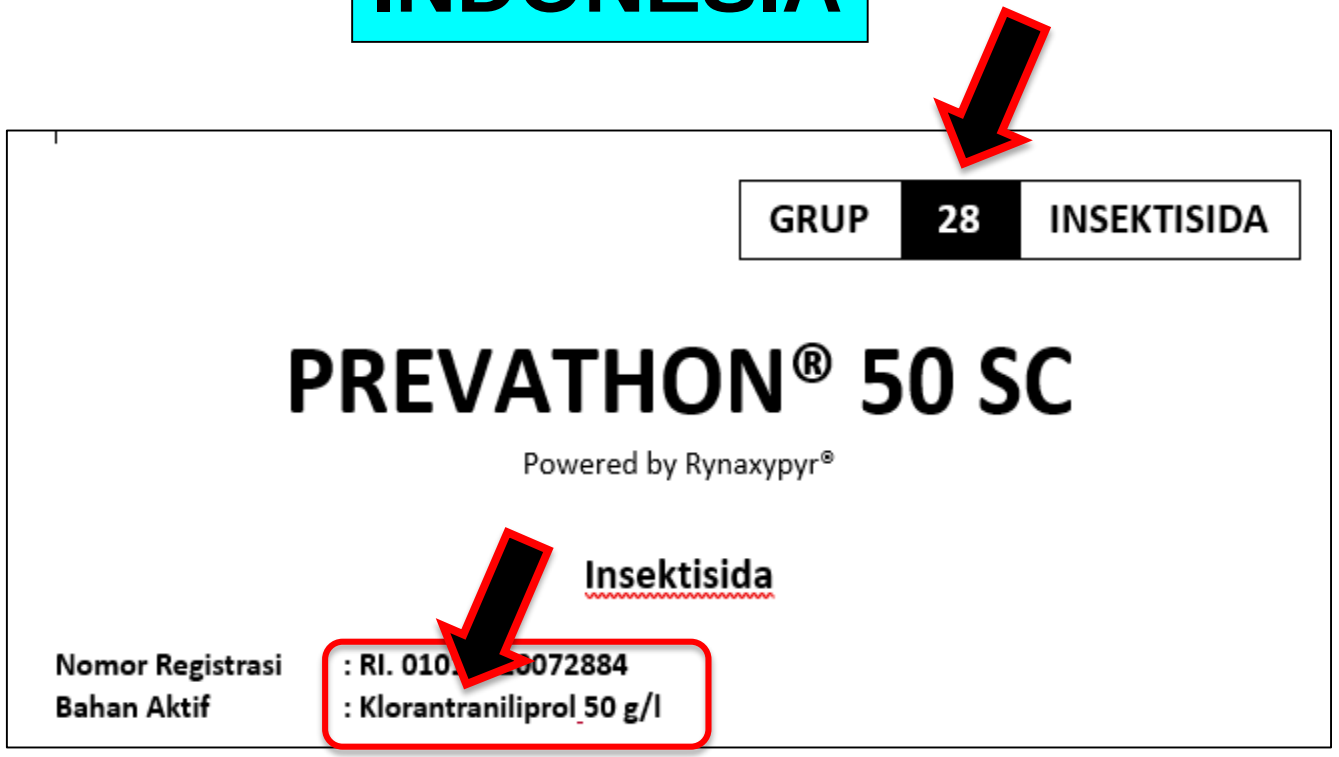
- What is the MoA # for each product
- Where to find it
- What to do with it.

- **What is the MoA # for each product**

Labels That Display IRAC Mode of Action Number for Quick Identification

PHILIPPINES

INDONESIA

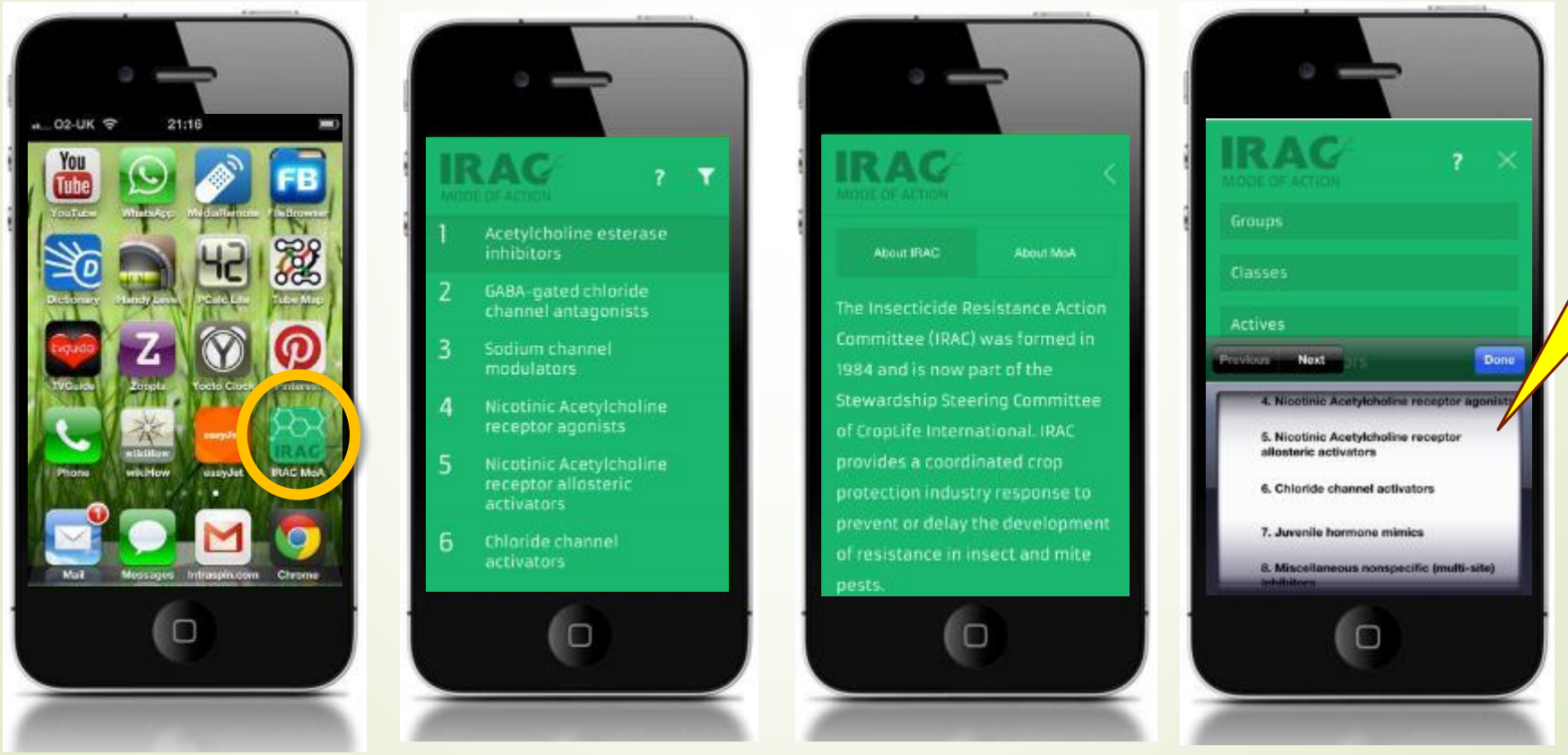


- **Where to find it**

A Tool to Help You Identify Different Product Chemistries and Mode of Action #'s

Mode of Action Classification: Phone/Tablet App (Its Free!!)

Search for: IRAC moa



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What to do with it.

IRM RECOMMENDED LANGUAGE IN LABEL TEXT

Contains at least three 'REQUIRED' components:

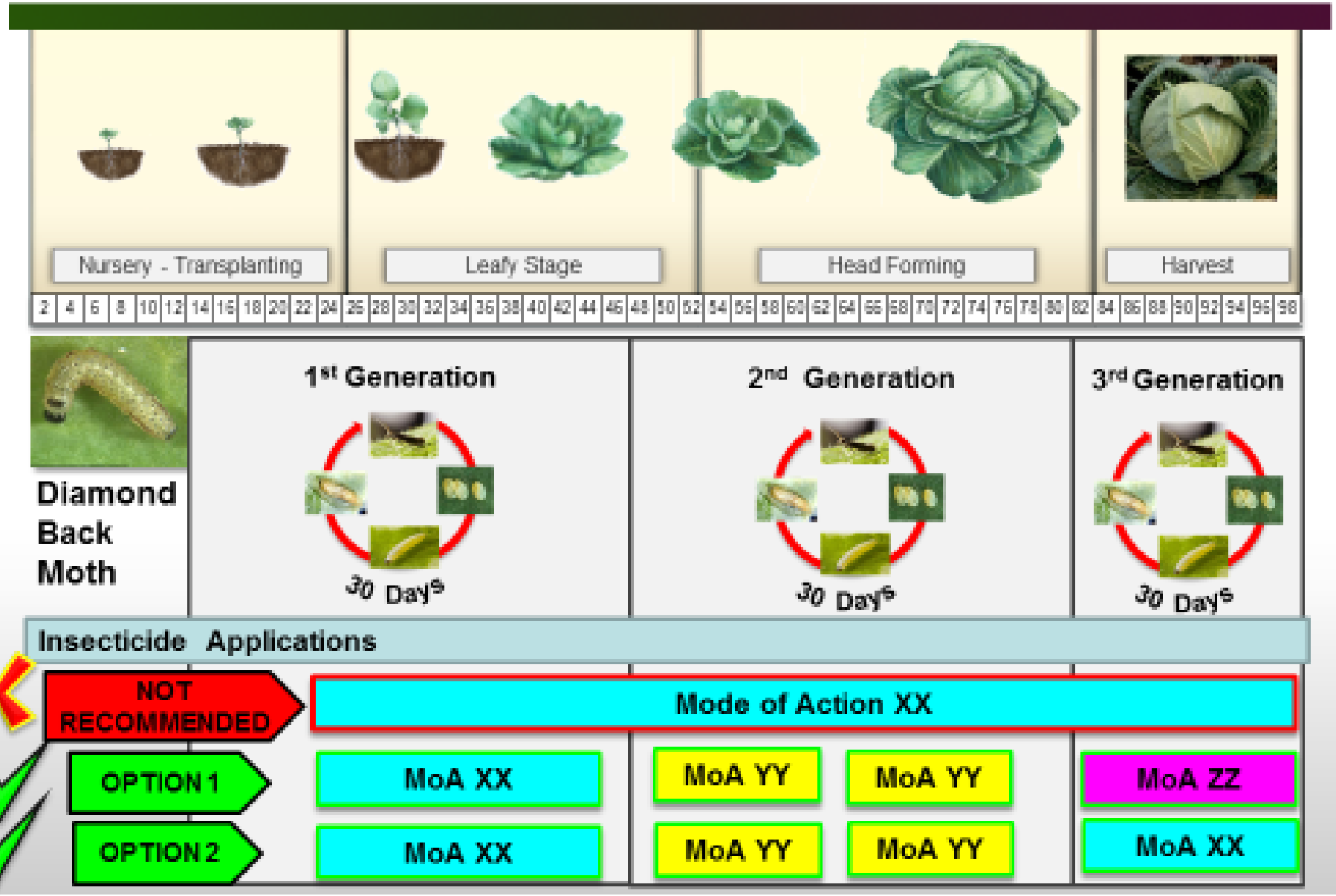
1. State the IRAC MoA Group Number (in addition to the icon shown elsewhere)
2. Provide guidance to avoid treating consecutive generations with the same MoA.
3. Rotate products with different Modes of Action using MoA treatment windows.

1. *[Product]* is a Group *N* insecticide
2. Do not exclusively use *[Product]* or other Group *N* insecticides to control the same pest throughout the season. Avoid exposing consecutive generations of a pest to the same mode of action by using the "application window" approach which rotates products with different MoA chemistries.
3. An "application window" is the period of residual activity that a single application or sequential applications of a MoA provide. It can also be defined as the duration of an insect generation or if unknown, then use an approximate 30 day period. Rotate windows of treatments of *[Product]* and other Group *N* products followed by blocks of treatments with other effective products from different modes of action before returning to Group *N* products.

- Implement Integrated Pest Management (IPM) practices to control pest populations and reduce the development of insect resistance.
- Use recommended label rates, timings, and spray intervals with maintained application equipment to reduce insect resistance risk.
- For additional information on insect resistance, visit the Insecticide Resistance Action Committee (IRAC) website at http://www.irac-online.org

- **What to do with it.**

IRM rotation strategy developed for brassica crops in Philippines



MODE OF ACTION ROTATION BY WINDOWS

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Insecticidal Mode of Action

Growers/Customers need to understand:

Same MoA: **Product Characteristics are sometimes Similar**

IMPACTS RM

- **Product attributes:**
  - contact (KD), ingestion, adulticide, ovicidal, pest spectrum, beneficial safety, systemic

Max population control in a generation. Remove multiple pest stages.

Conserve beneficials

- **Spray timing and number of apps:**
  - treatment thresholds differ by product
  - adult flight, egg laying, first larvae, sight of damage, (rescue?)

Poor timing – Poor control! Leaves RS insects

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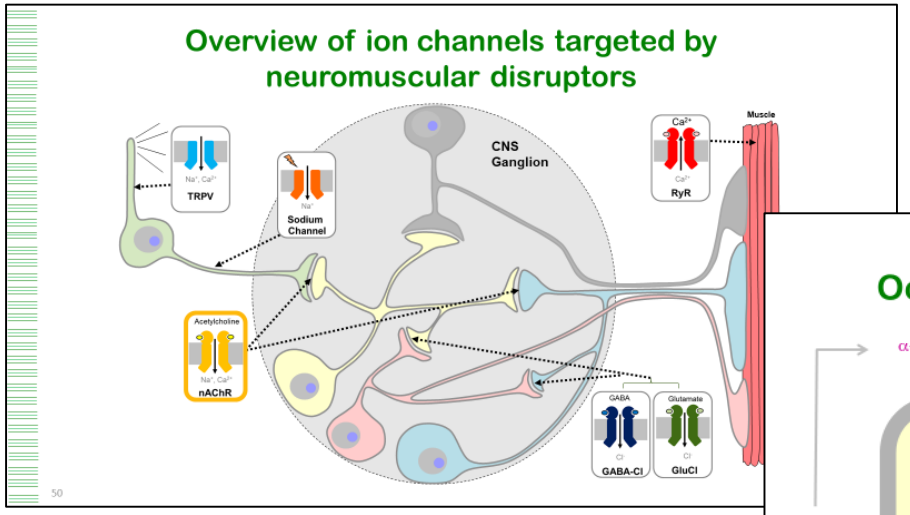
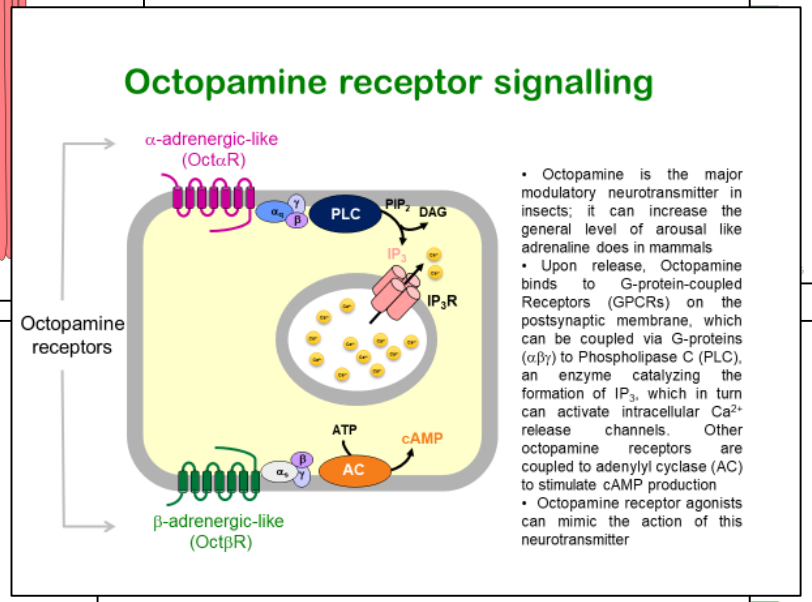
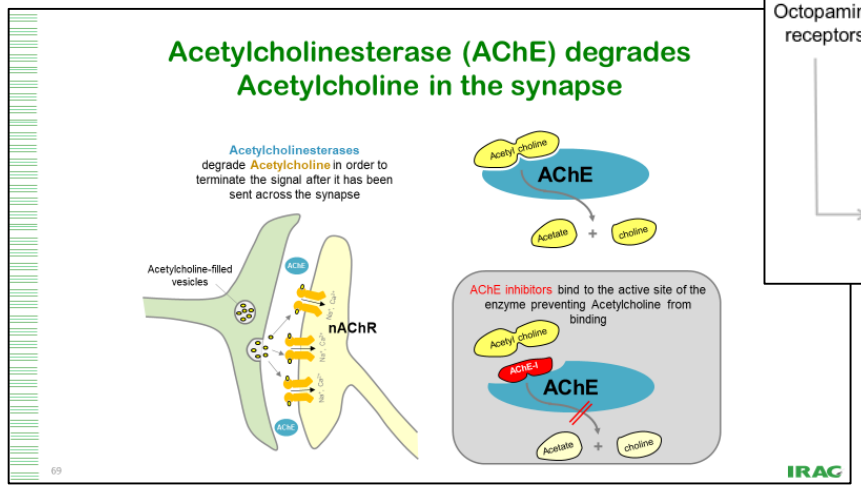
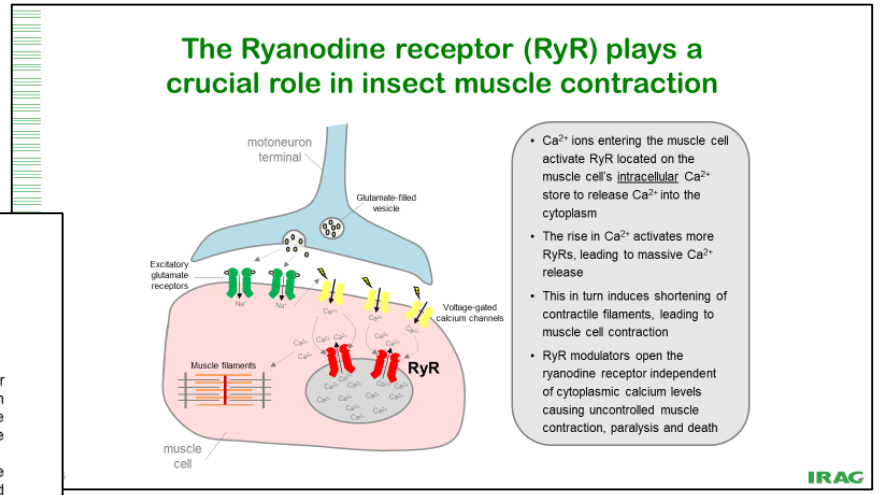
MoA: Understanding How Insecticides Bind to Target Sites at the Molecular Level…..is Complicated

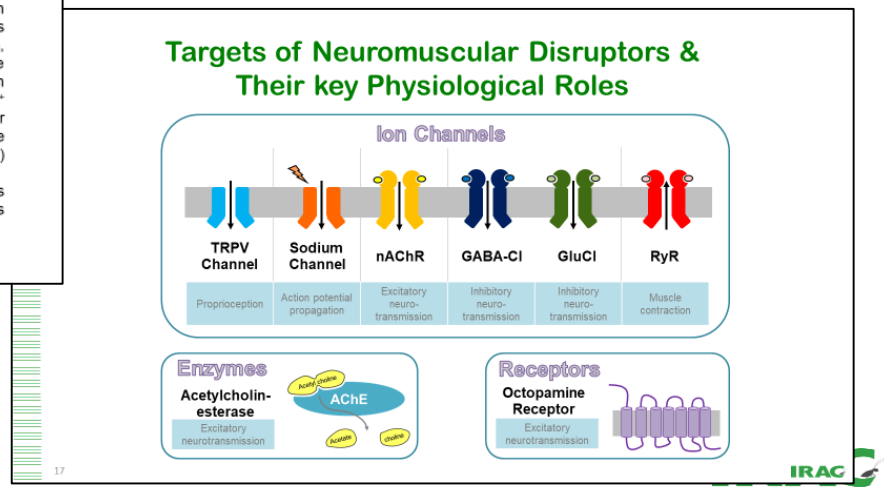
Detailed IRAC tutorial available at
http://www.irac-online.org/modes-of-action







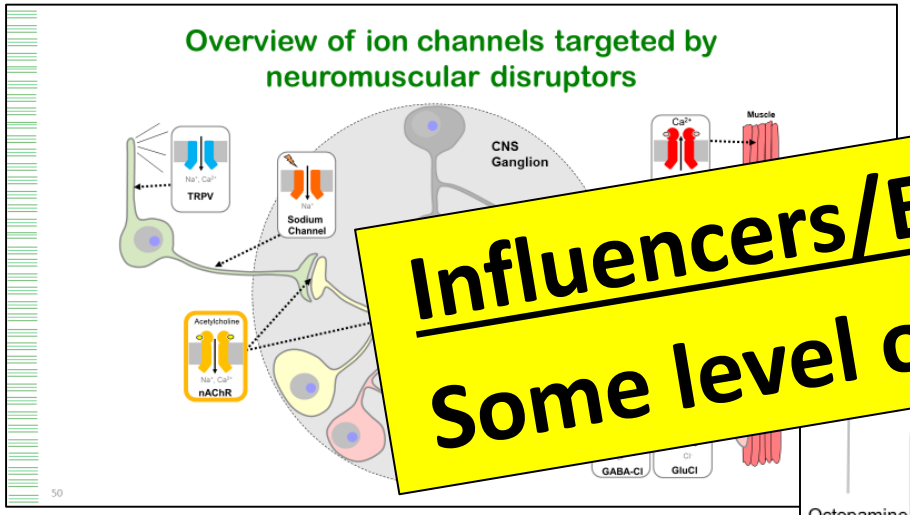


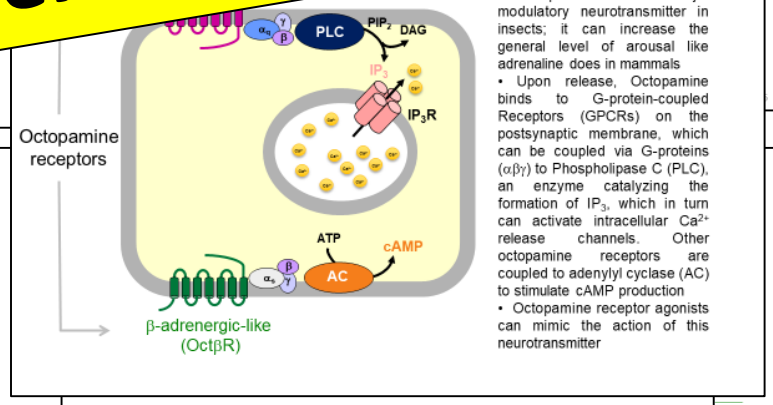


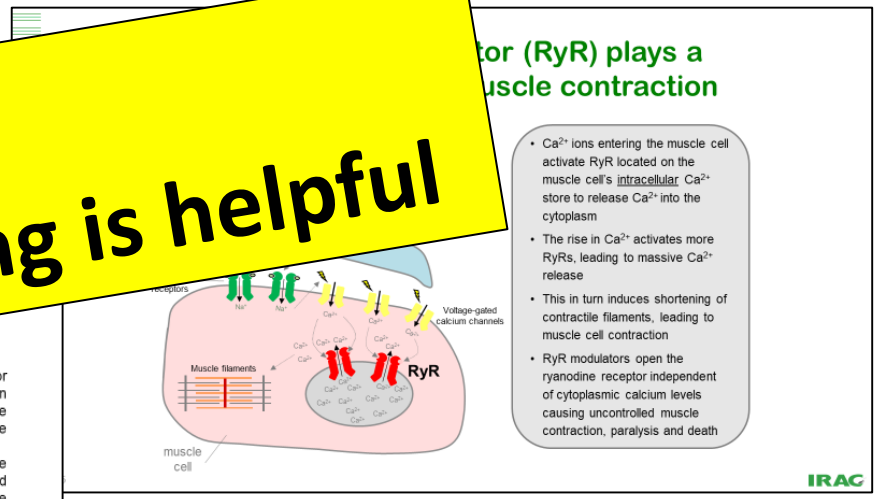
MoA: Understanding How Insecticides Bind to Target Sites at the Molecular Level…..is Complicated

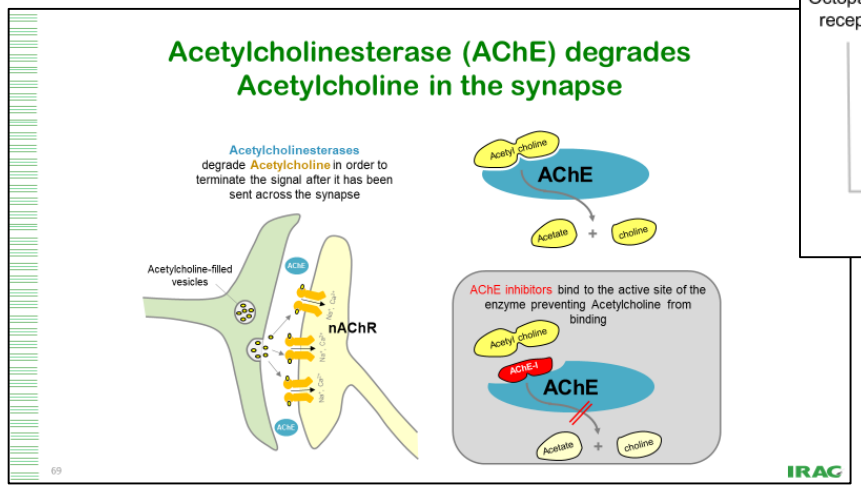
Detailed IRAC tutorial available at
http://www.irac-online.org/modes-of-action

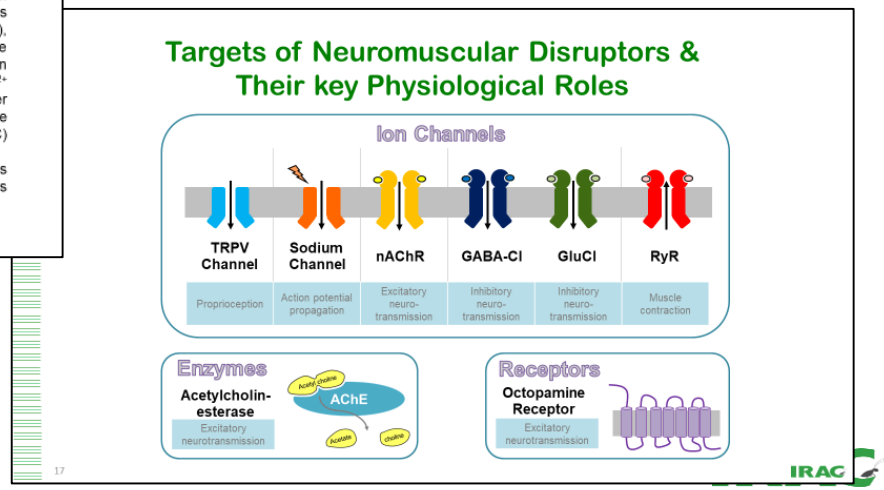
Influencers/Experts:
Some level of understanding is helpful







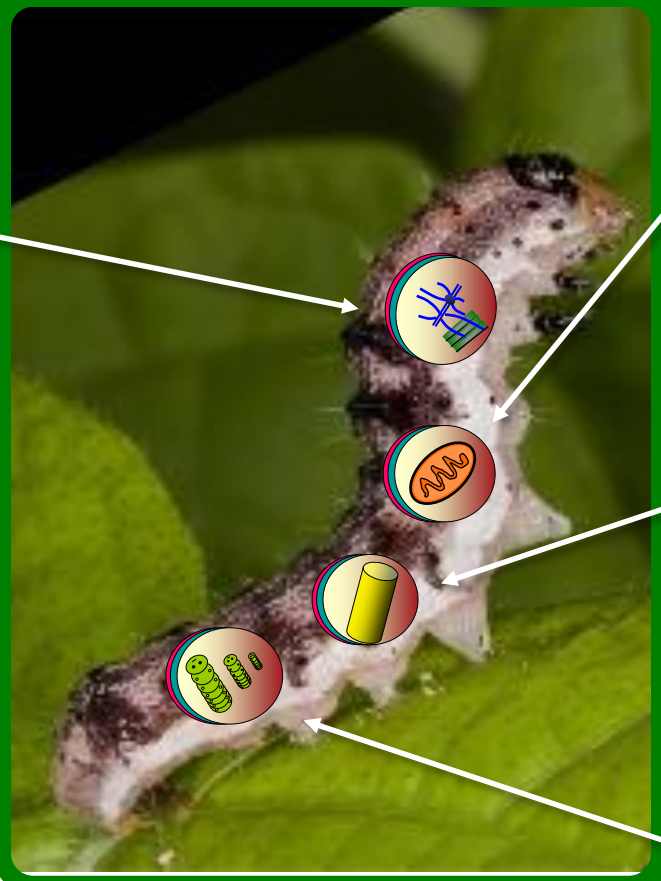




Lepidoptera - Mode of Action Classification by Target Site

Nerve & Muscle Targets

1. Acetylcholinesterase (AChE) inhibitors
   1A: Carbamates
   1B: Organophosphates
2. GABA-gated chloride channel blockers
   2A: Cyclodiene Organochlorines
   2B: Phenylpyrazoles
3. Sodium channel modulators
   3A: Pyrethrins, Pyrethroids
4. Nicotinic acetylcholine receptor (nAChR) competitive modulators
   4A: Neonicotinoids
5. Nicotinic acetylcholine receptor (nAChR) allosteric modulators Site I
   5 Spinosyns
6. Glutamate-gated chloride channel (GluCl) allosteric modulators
   6: Avermectins, Milbemycins
14. Nicotinic acetylcholine receptor (nAChR) channel blockers
    14: Nereistoxin analogues
22. Voltage-dependent sodium channel blockers
    22A: Oxadiazines
    22B: Semicarbazones
28. Ryanodine receptor modulators
    28: Diamides
30. GABA-gated chloride channel allosteric modulators
    30: Meta-diamides, Isoxazolines
32. Nicotinic acetylcholine receptor (nAChR) allosteric modulators Site II
    32: GS-omega/kappa HXTX-HV1a Peptide



Respiration Targets

13. Uncouplers of oxidative phosphorylation via disruption of the proton gradient
    13: Chlorfenapyr
21. Mitochondrial complex I electron transport inhibitors
    21A: METI acaracides and insecticides (Tolfenpyrad)

Midgut Targets

11. Microbial disruptors of insect midgut membranes
    11A: Bacillus thuringiensis,
    11B: Bacillus sphaericus
31. Baculoviruses
    31: Host-specific occluded pathogenic viruses Granuloviruses, Nucleopolyhedroviruses

Growth & Development Targets

7. Juvenile hormone mimics
   7A: Juvenile hormone analogues (Hydroprene)
   7B: Fenoxycarb
15. Inhibitors of chitin biosynthesis affecting CHS1
    15: Benzoylureas
18. Ecdysone receptor agonists
    18: Diacylhydrazines

Unknown or uncertain MoA

Azadirachtin, Pyridalyl, Beauveria bassiana, Burkholderia spp, *Paecilomyces fumosoroseus*

Nerve & Muscle Targets

1. Acetylcholinesterase (AChE) inhibitors
   1A: Carbamates
   1B: Organophosphates
2. GABA-gated chloride channel blockers
   2A: Cyclodiene Organochlorines
   2B: Phenylpyrazoles
3. Sodium channel modulators
   3A: Pyrethrins, Pyrethroids
4. Nicotinic acetylcholine receptor (nAChR) competitive modulators
   4A: Neonicotinoids
   4C: Sulfoximines
   4D: Butenolides
   4E: Mesoionics
9. Chordotonal organ TRPV channel modulators
   9B: Pyridine azomethine derivatives
   9D: Pyropenes
22. Voltage-dependent sodium channel blockers
   22A: Oxadiazines
28. Ryanodine receptor modulators
   28: Diamides (Cyantraniliprole)
29. Chordotonal organ modulators – undefined target site
   29: *Flonicamid*
32. Nicotinic acetylcholine receptor (nAChR) allosteric modulators Site II
   32: GS-omega/kappa HXTX-HV1a Peptide

Aphids, Whiteflies, Planthoppers and Leafhoppers - Mode of Action Classification by Target Site



MoA Group	Aphids	Whiteflies	Planthoppers Leafhoppers
1A	X	X	X
1B	X	X	X
2A	X	X	X
2B			X
3A	X	X	X
4A	X	X	X
4C	X	X	X
4D	X	X	X
4E			X
7A	X	X	
7C		X	
9B	X	X	X
9D	X	X	X
12A	X	X	
15		X	
16		X	X
21A		X	
22A			X
23	X	X	
28	X	X	X
29	X	X	X
32	X	X	

Respiration Targets

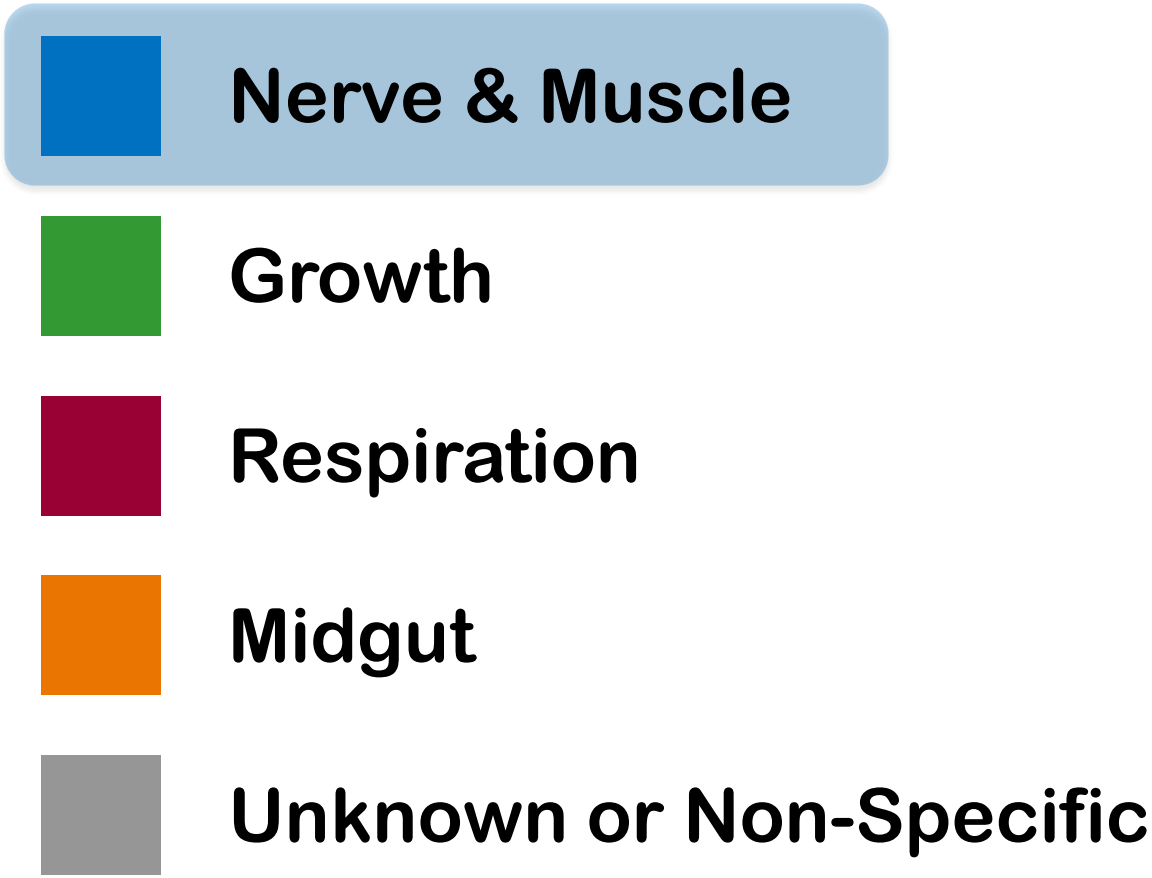
12. Inhibitors of mitochondrial ATP synthesis
   12A: Difenthiuron
21. Mitochondrial complex I electron transport inhibitors
   21A: METI acaracides and insecticides (Pyridaben, Tolfenpyrad)

Growth & Development Targets

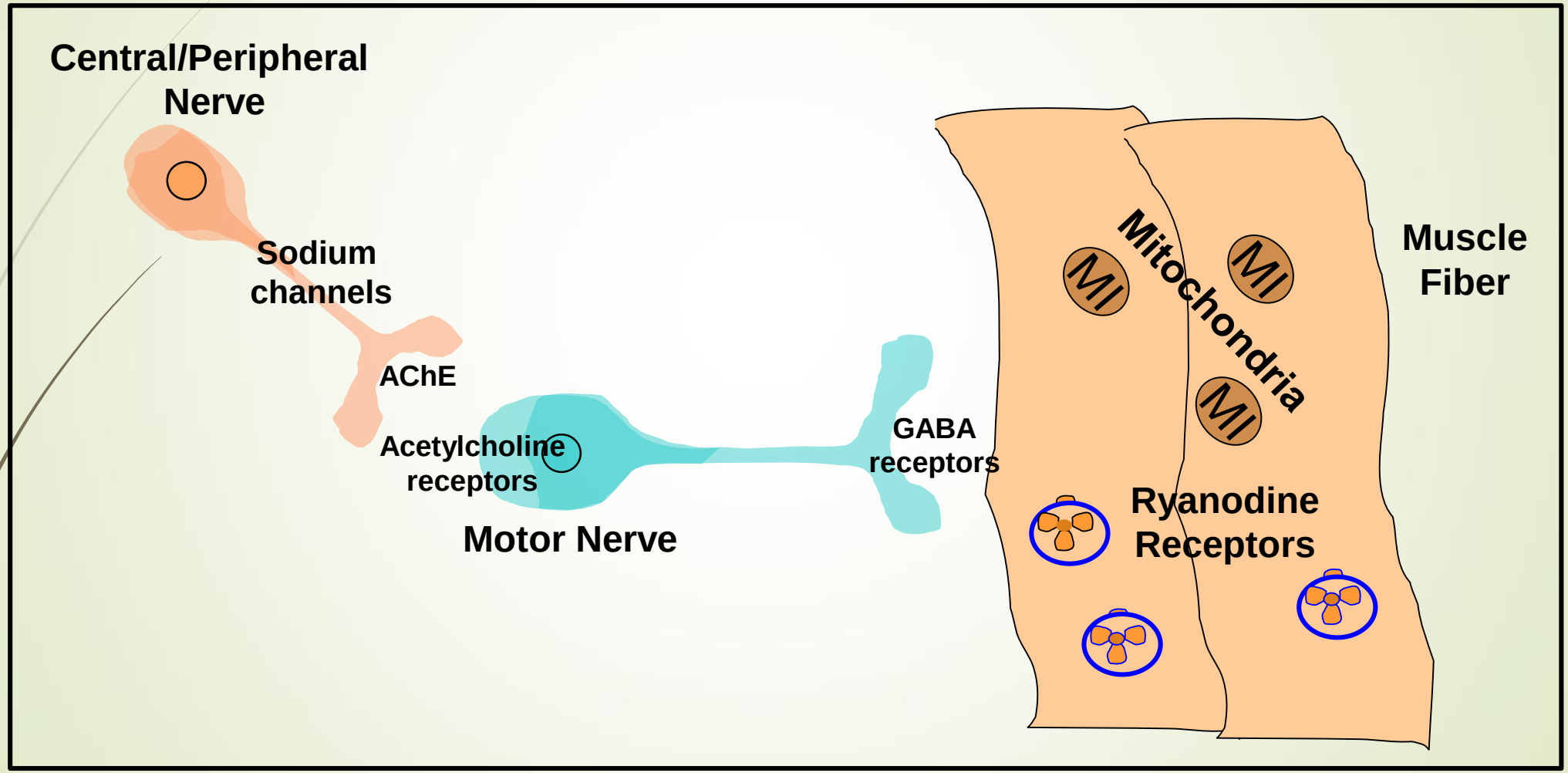
7. Juvenile hormone mimics
   7A: Kinoprene
   7C: Pyriproxyfen
15. Inhibitors of chitin biosynthesis, affecting CHS1
   15: Benzoylureas
16. Inhibitors of chitin biosynthesis, type 1
   16: Buprofezin
23. Inhibitors of acetyl CoA carboxylase
   23: Tetronic & Tetramic acid derivatives

The table lists the main mode of action groups for the control of aphids, whiteflies and hoppers. However, the availability may differ regionally due to registration status.

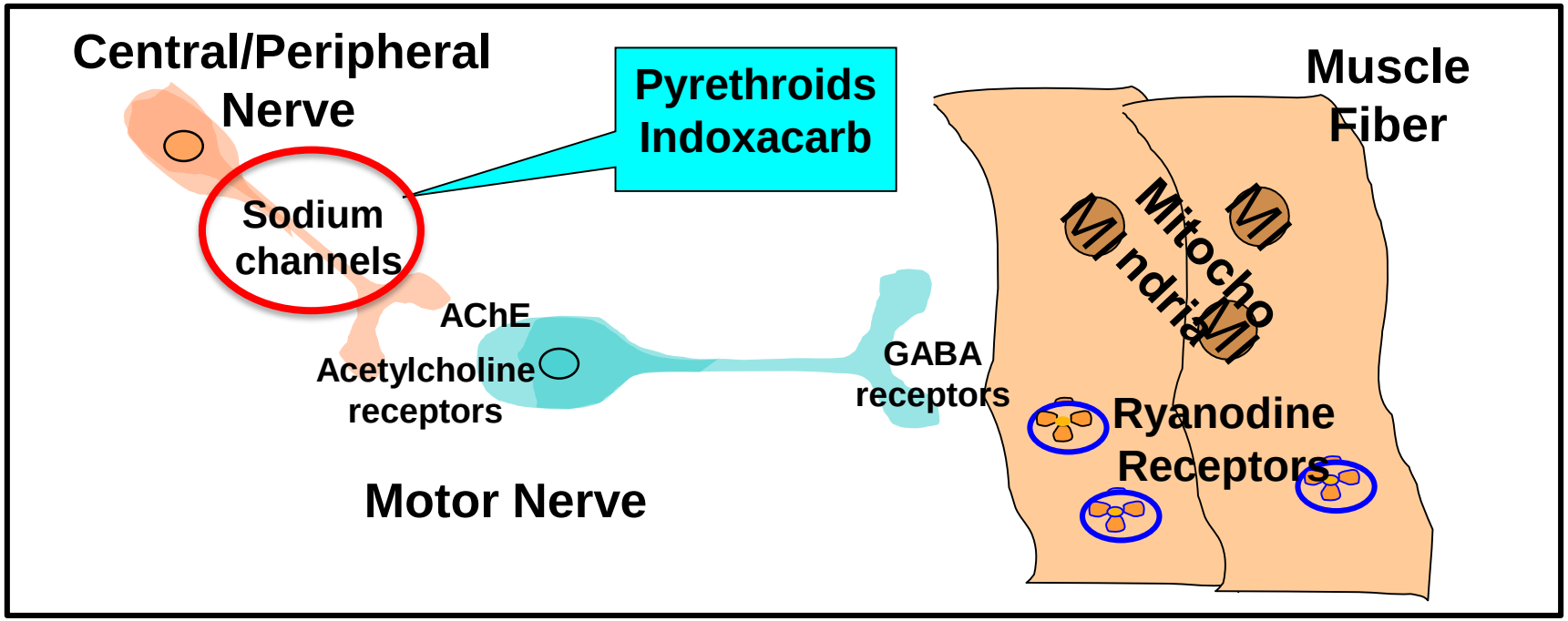
Insecticide Mode of Action Major Classes



Nerve and Muscle Targets for Insecticidal Control



Mode of Action (Nerve and Muscle Target)		Chemical Group	Active ingredients	MoA #
Sodium channel modulators *(OPENS)*	Prolong influx of sodium ions into the nerve cells leading to an over stimulated nervous system; paralysis and rapid knockdown	Pyrethroids	Betacyfluthrin Bifenthrin Cypermethrin Deltamethrin Lambda cyhalothrin Permethrin	3A
Voltage dependent sodium channel *(BLOCKER)*	Block sodium channels resulting to nervous system shutdown and paralysis	Oxadiazines	Indoxacarb Metaflumizone	22 A



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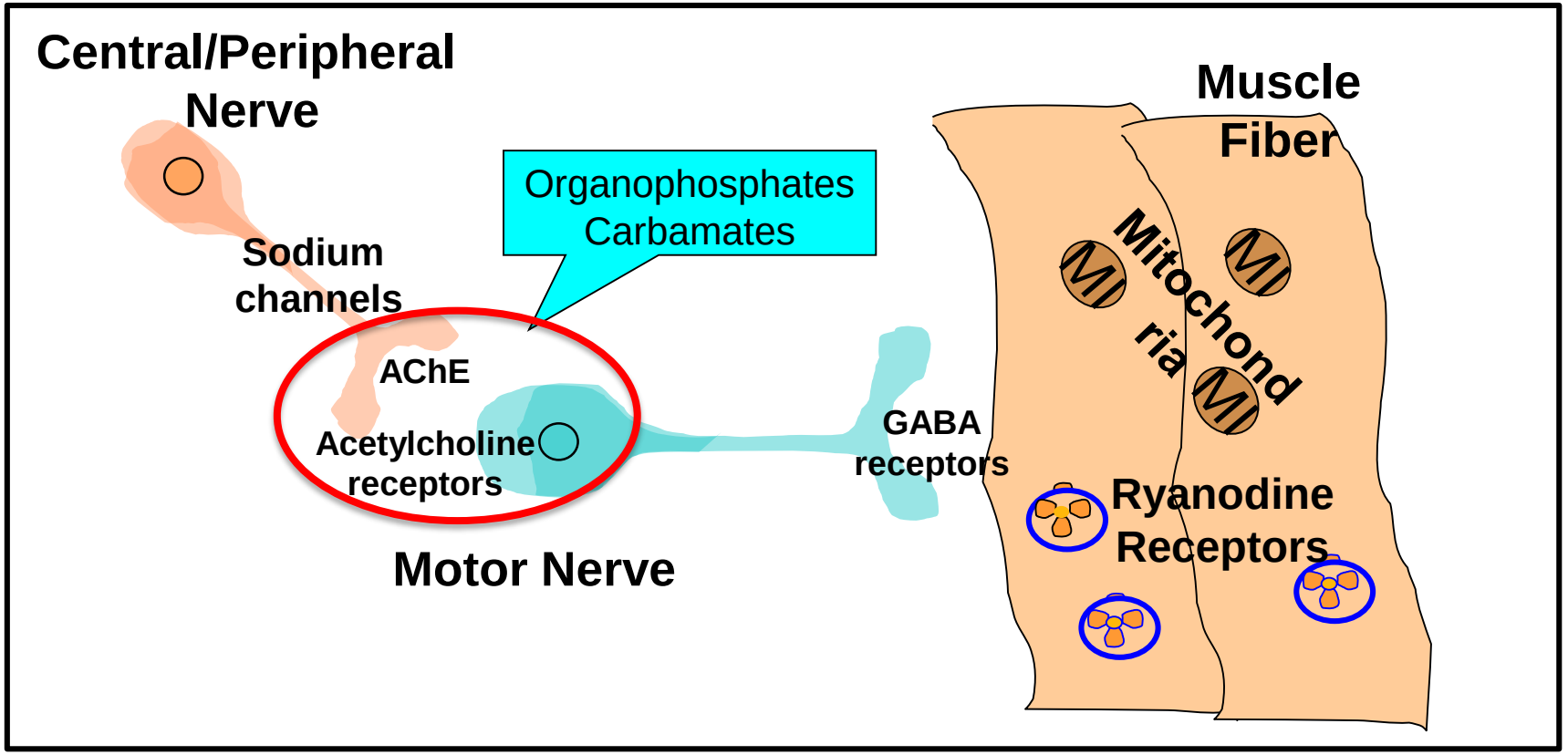
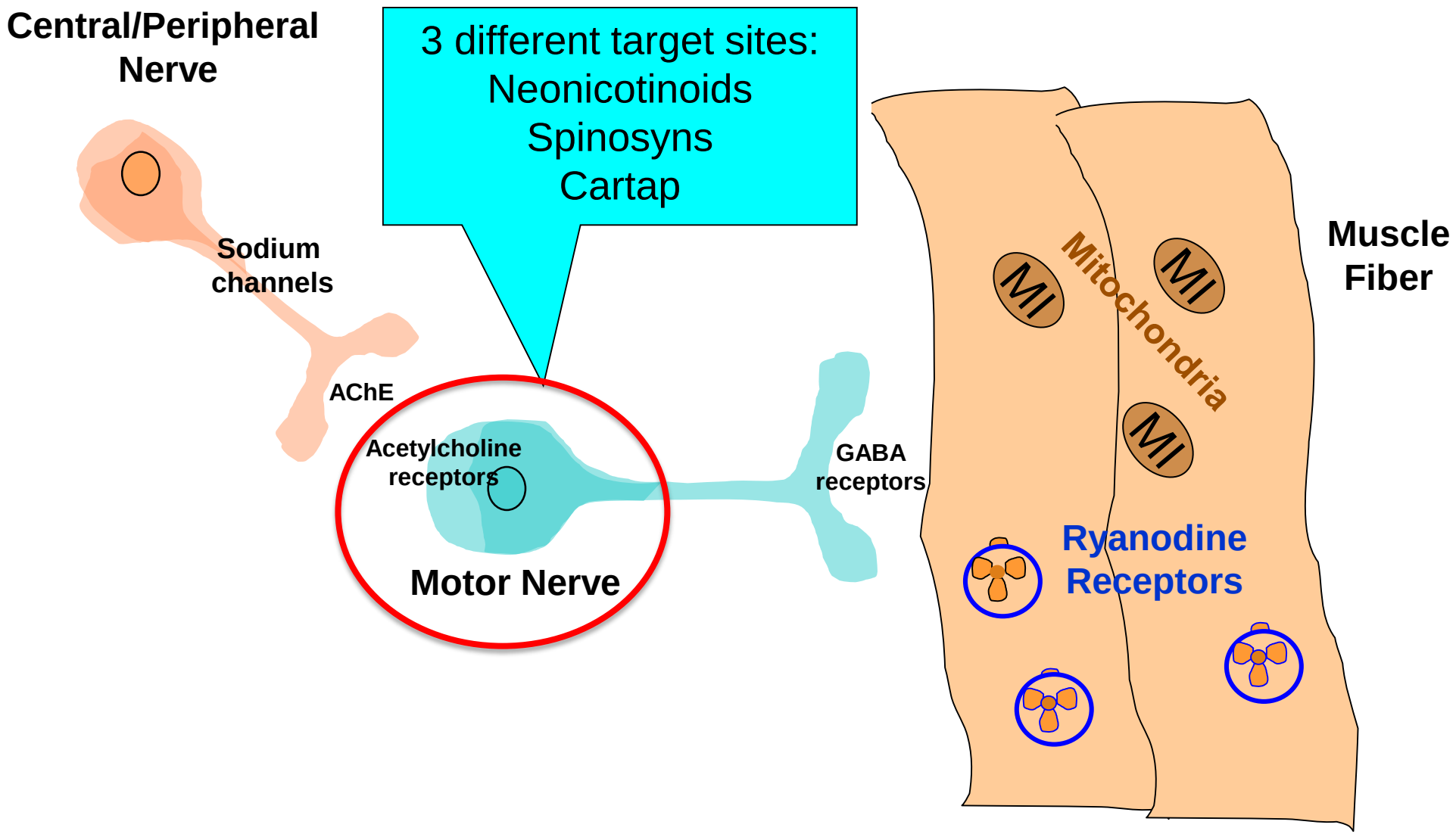
Mode of Action (Nerve and Muscle Target)		Chemical Group	Active ingredients	MoA #
Acetylcholinesterase inhibitors	Cause unregulated neuro transmission in the neuro muscular system resulting in disruption of insect locomotion and eventual paralysis	Organophosphates	Profenophos, Chlorpyrifos Malathion Phenthoate	1A
		Carbamates	Carbofuran Carbaryl Thiodicarb	1B



Mode of Action (Nerve Target) Chemical Groups: Neonicotinoids, Nereistoxin analogues, Spinosyns



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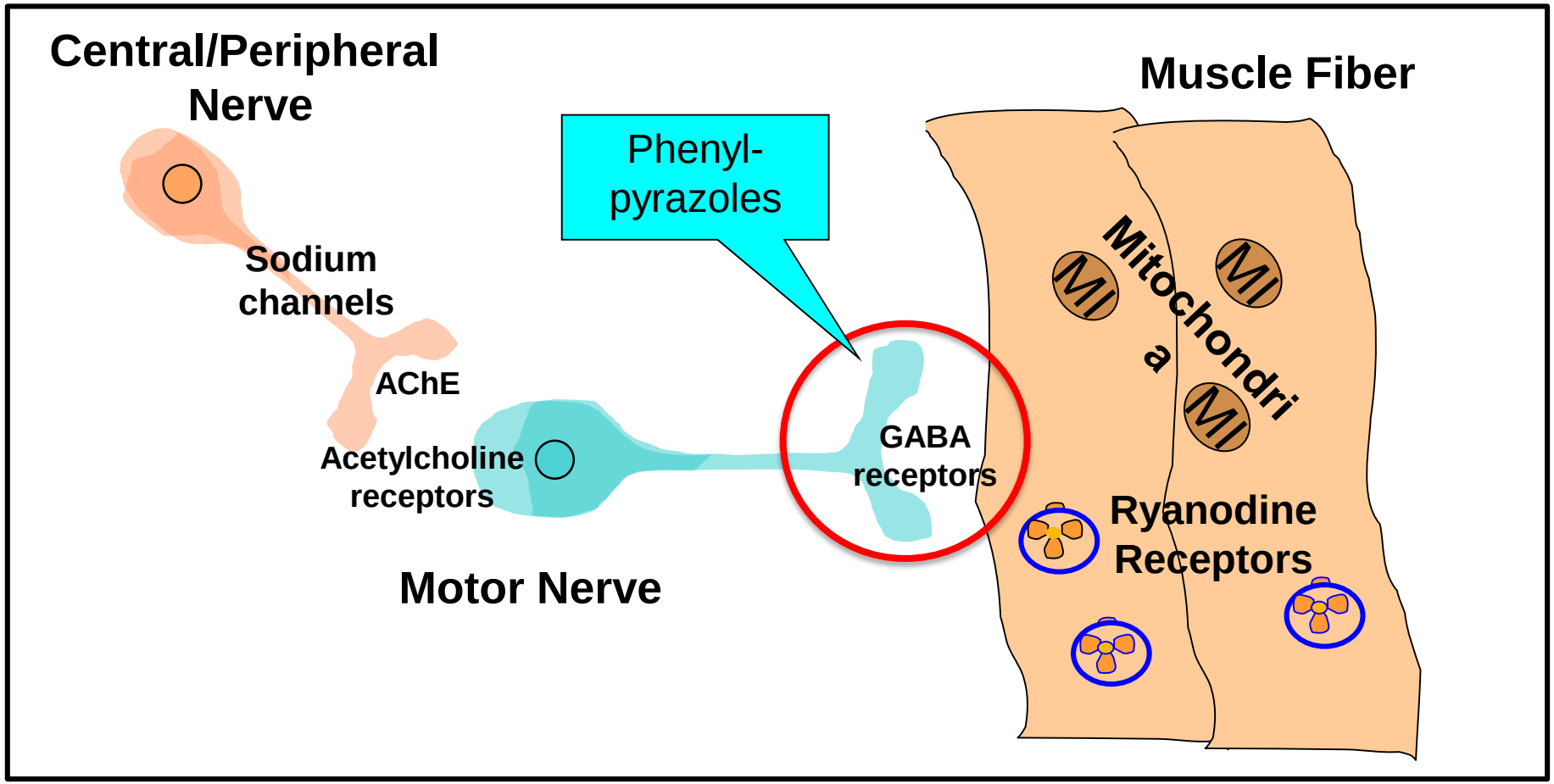
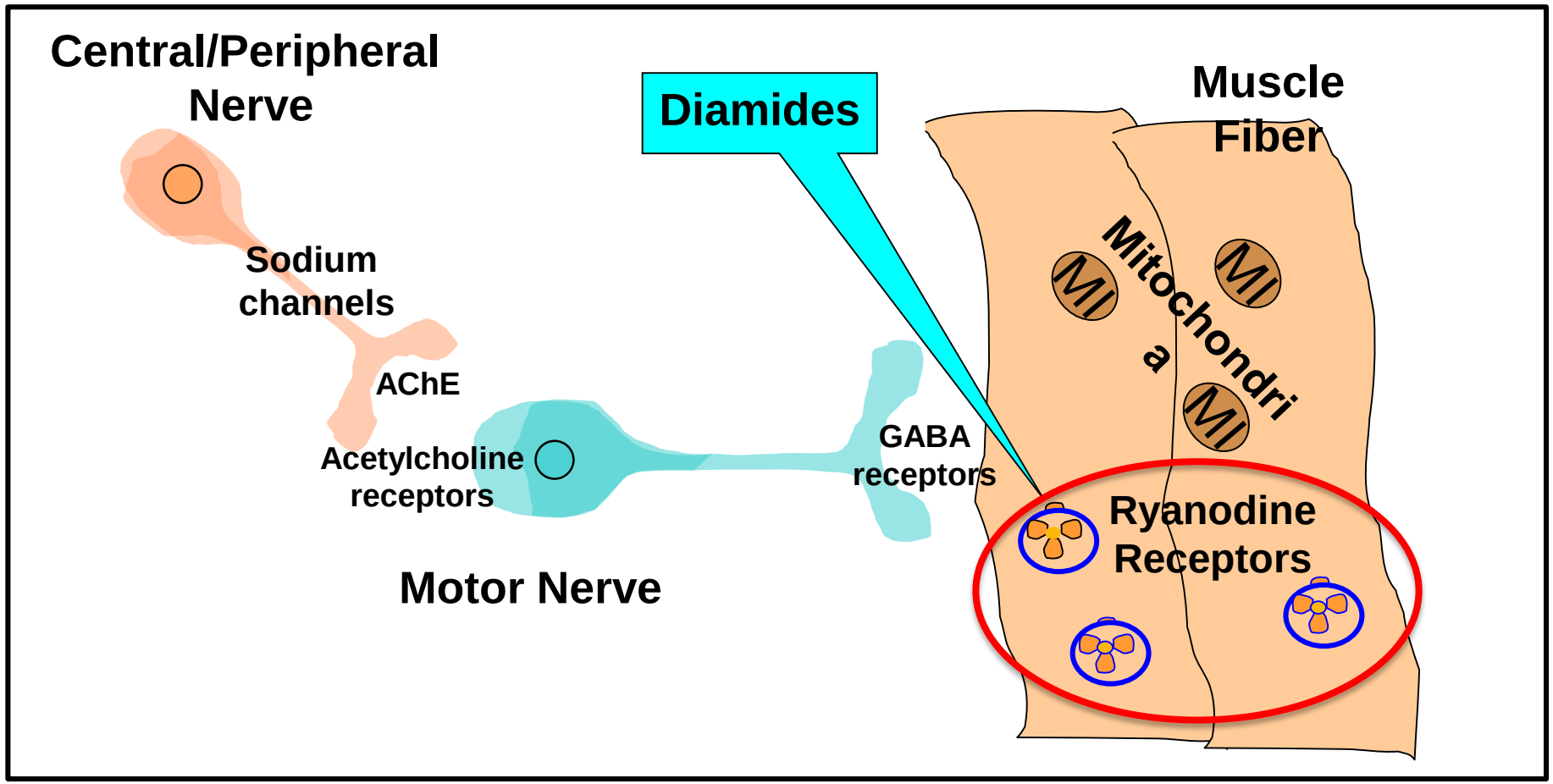
Mode of Action (Nerve and Muscle Target)		Chemical Group	Active ingredients	MoA #
nAChr Nicotinic acetylcholine receptor competitive modulators	Cause sustained influx of calcium ions into the post synaptic neuron leading to overstimulation of nerves and paralyzing the pest insect	Neonicotinoids	Acetamiprid Clothianidin Dinotefuran Imidacloprid Thiametoxam Thiacloprid Nitempyram	4A
nAChr Nicotinic acetylcholine receptor channel blockers	Block the nAChR ion channel, resulting to nervous system block and paralysis	Nereistoxin analogues	Cartap	14
nAChr Nicotinic acetylcholine receptor allosteric modulators	Spinosyns primarily target the binding sites on nicotinic acetylcholine receptors (nAChRs) of the insect nervous system that are distinct from those at which other insecticides have their activity. This leads to disruption of acetylcholine neurotransmission and hyperexitation.	Spinosyns	Spinosad Spinetoram	5

Mode of Action (Nerve and Muscle Target)		Chemical Group	Active ingredients	MoA #
GABA –gated chloride channel blockers	Cause hyper excitation of nerves and muscles	Phenylpyrazoles	Ethiprole Fipronil	2B



Mode of Action (Nerve Target)		Chemical Group	Active ingredients	MoA #
Ryanodine receptor modulators	Ryanodine receptors control the release of stored calcium ions inside muscle tissue. Diamides affect the receptor, open the ion channels, and release calcium ions leading to paralysis and death	Diamides	Chlorantraniliprole Cyantraniliprole Cyclaniliprole Flubendiamide Tetraniliprole	28



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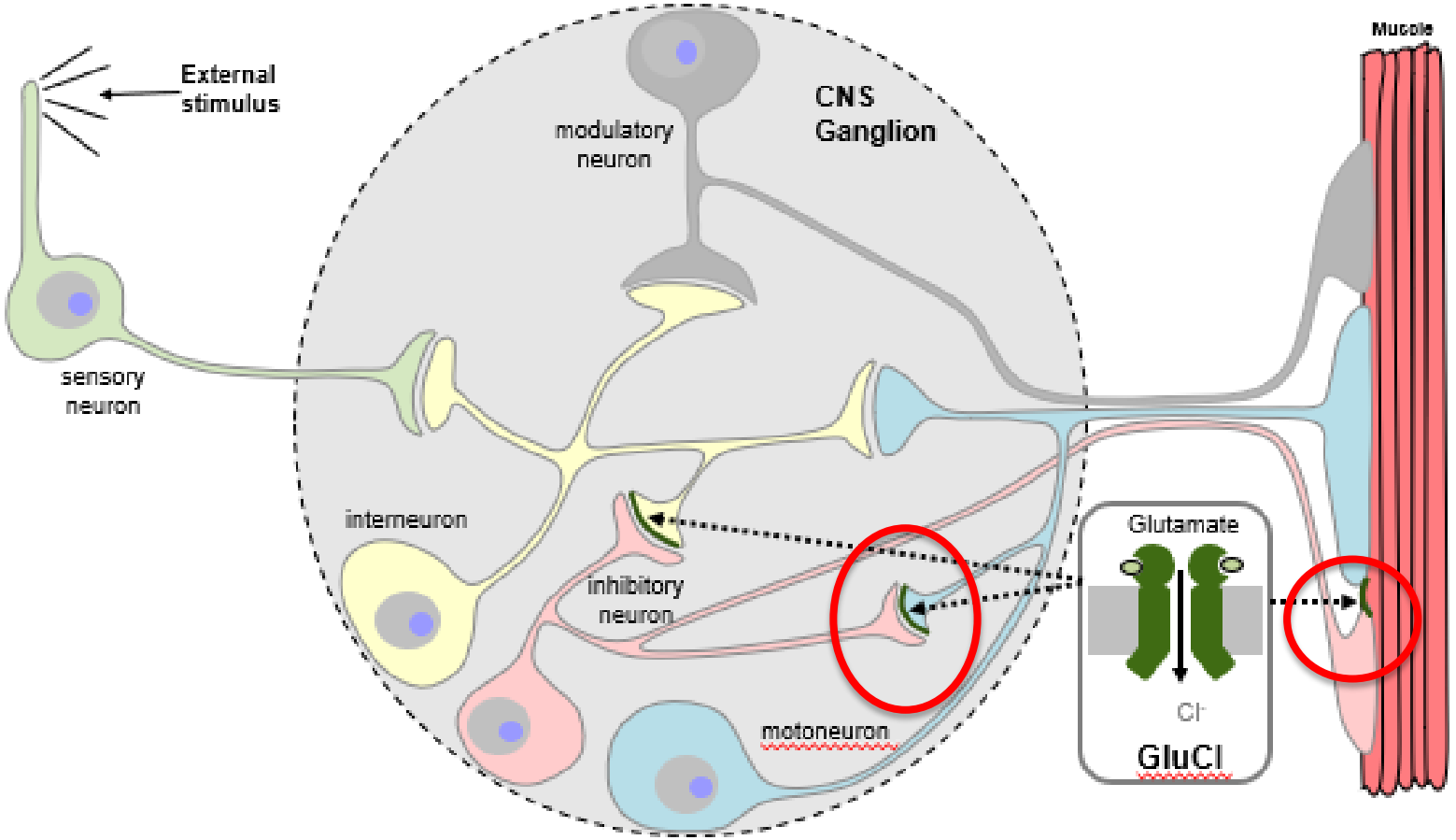
Mode of Action (Nerve Target)		Chemical Group	Active ingredients	MoA #
Glutamate-gated chloride channel allosteric modulators	Stimulates the uncontrolled influx of chloride ions in post synaptic nerve cells de-regulatng the nervous system leading to paralysis and death	Avermectins	Abamectin Emamectin	6

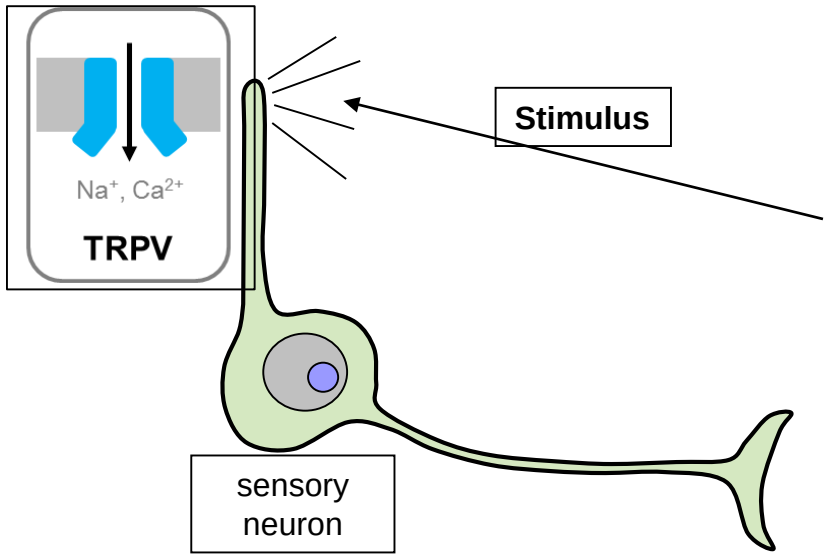


- Inhibitory Glutamate-gated chloride channels (GluCl) are widespread on insect nerve and muscle cells and likely function in inhibitory neurotransmission
- GluCl modulators activate chloride influx, causing flaccid paralysis

Mode of Action (Nerve Target)		Chemical Group	Active ingredients	MoA #
Chordotonal organ TRPV channel modulators	Prevent target insects from feeding and reproducing due to malfunction of hind legs, fail to attach to the plant and mate	Pyridine azomethine derivatives	Pymetrozine Afidopyropen	9

Insect stretch receptor signaling (Chordotonal Organ)

The detection of the relative position and motion of body parts



- Sight
- Taste
- Smell
- Touch
- Hearing (antenna)
- Gravity (antenna)
- Proprioception* (joints)
- Others

Sensed by stretch receptors

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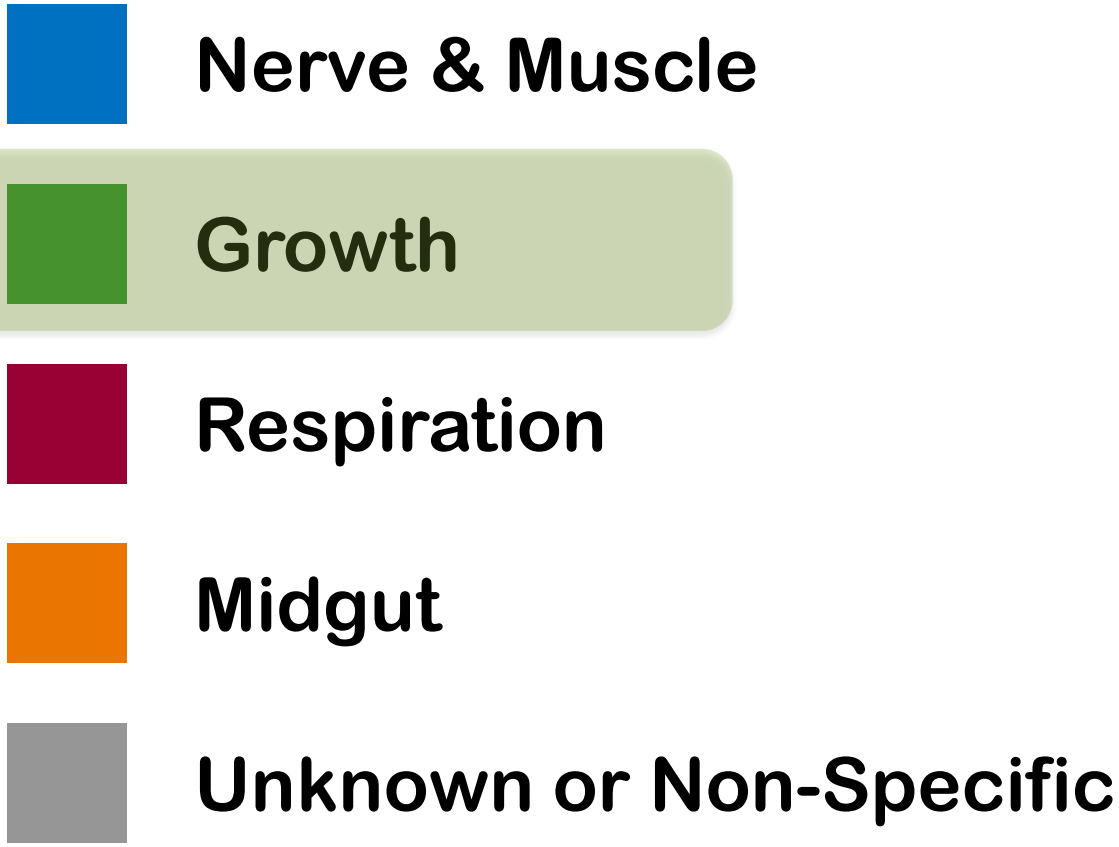
Insecticide Mode of Action
Major classes



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Growth & Development Disruptors

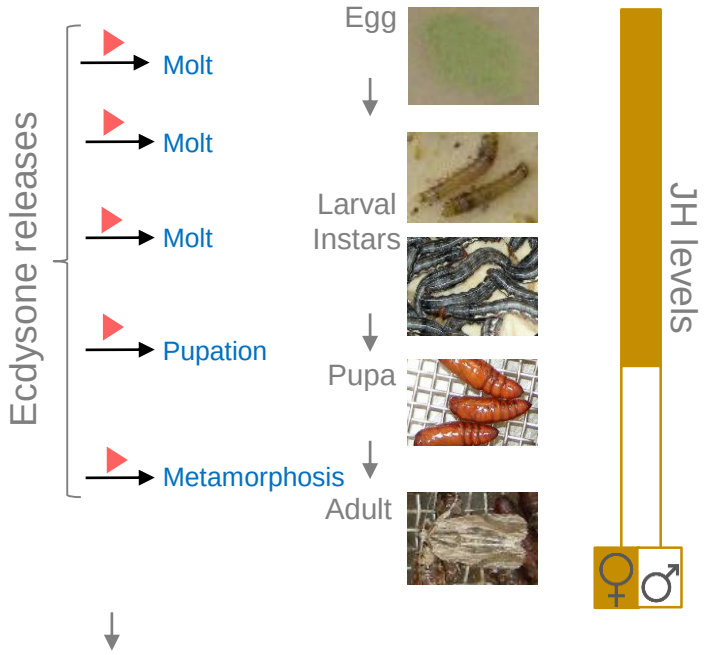
The insect's skeleton is external (**exoskeleton)** and contains **chitin.** Since the exoskeleton cannot expand, it must be replaced with a larger one by the process of molting as the insect grows, requiring **chitin synthesis**.
Molting is under strict hormonal control:

Ecdysone is released to induce molting

EcR agonists persistently activates Ecdysone receptors causing the insect to go into an early incomplete molt, leading to death

Ecdysone

Juvenile Hormone (JH)



JH prevents molting to a more mature stage

JH production stops during metamorphosis

JH mimics suppress the development of adult characteristics keeping the insect in an 'immature' state

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Insect Growth Regulator Effects

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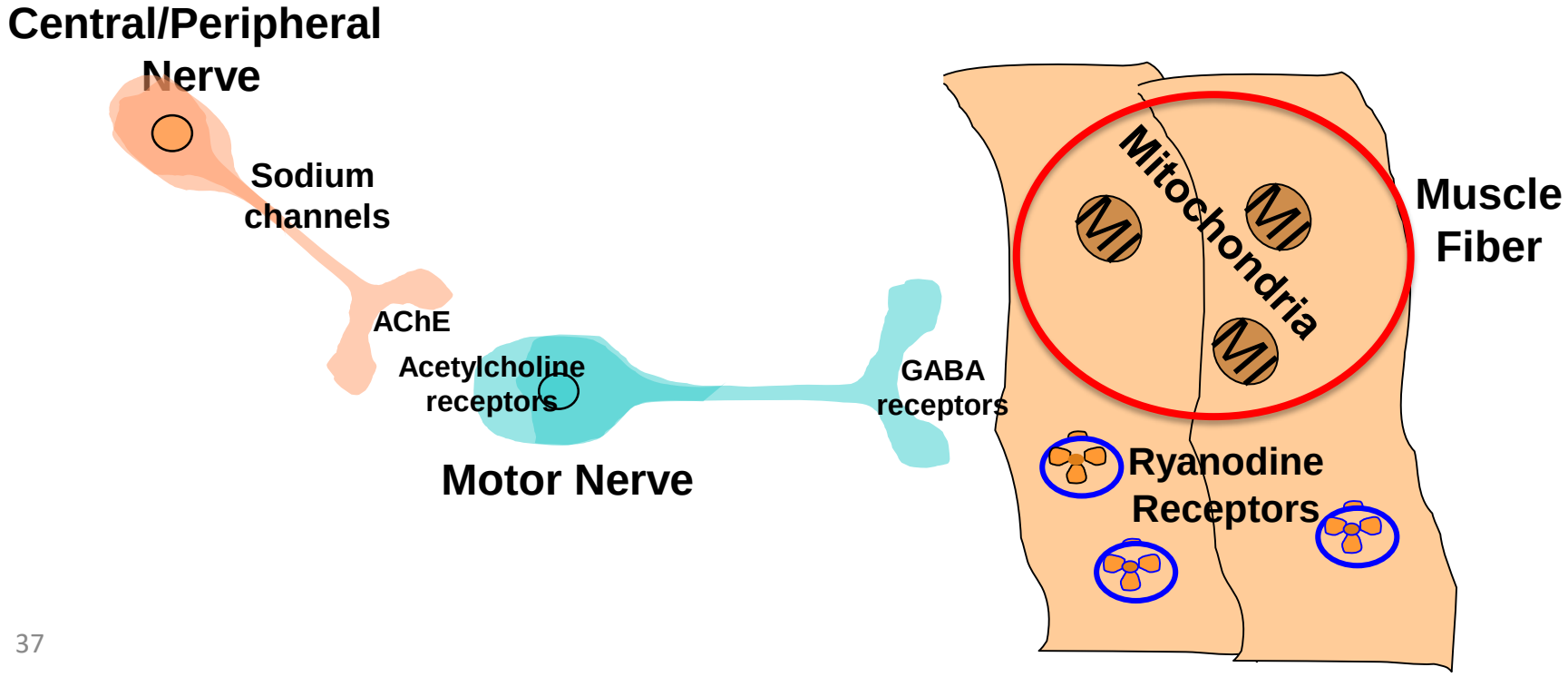
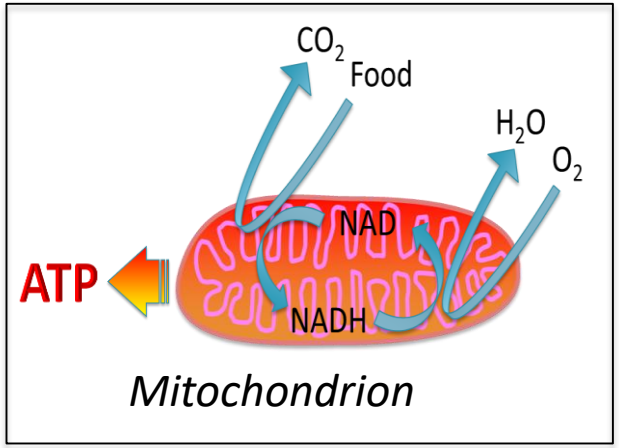
Mode of Action (Growth and Development Target)		Chemical Group	Active ingredients	MoA #
Moulting disruptors (dipterans)	Interfere with the production of insect cuticle. Insect fails to grow and dies	Cyromazine	Cyromazine	17
Inhibitors of chitin biosynthesis, type 1	Interfere in the chitin formation process (homopterans)	Buprofesin	Buprofesin	16
Inhibitors of chitin biosynthesis,type O	Interfere in the chitin formation process (lepidopterans)	Benzoylureas	Lufenuron Chlorfuazuron	15
Inhibitors of acetyl CoA carboxylase	Prevent the process of lipid biosynthesis . Affect insect development at the egg and nymphal stages	Tetronic and Tetramic acid derivataves	Spirotetramat	23
Juvenile hormone mimics	Target protein responsible for biological activity is unknown, or uncharacterized}	Pyriproxyfen	Pyriproxyfen	7C

Insecticide Mode of Action Major Classes

Mode of Action (Respiration Target)		Chemical Group	Active ingredients	MoA #
Inhibitor of Mitochondrial ATP synthase	Carbodiamide binds to mitochondrial ATPase and inhibits its function resulting in shutdown of insect respiration system leading to paralysis and mortality	Diafenthiuron	Diafenthiuron	12 A
Mitochondrial complex I electron transport inhibitors	Energy metabolism	METI acaricides & insecticides	Fenazaquin, Pyridaben, Tolfenpyrad	21 A



Cells get energy by "oxidizing" food such as fat and sugars to produce carbon dioxide and water



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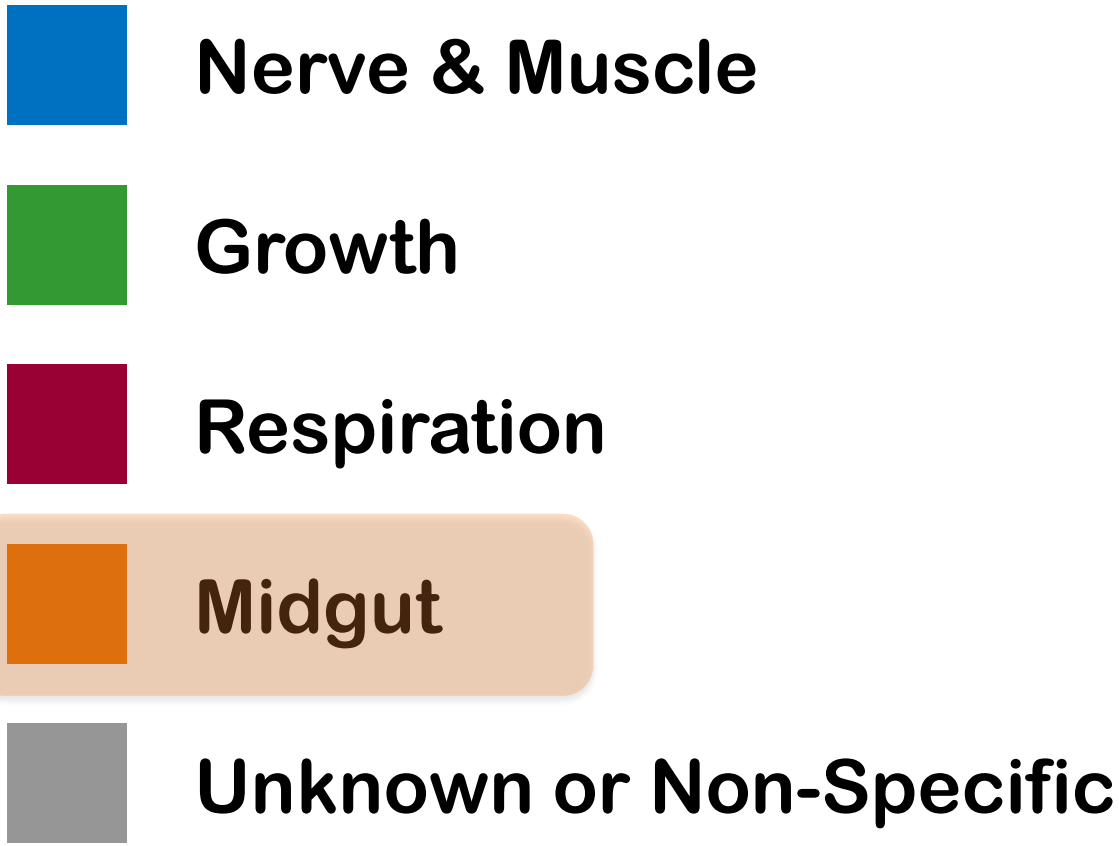
Insecticide Mode of Action Major Classes

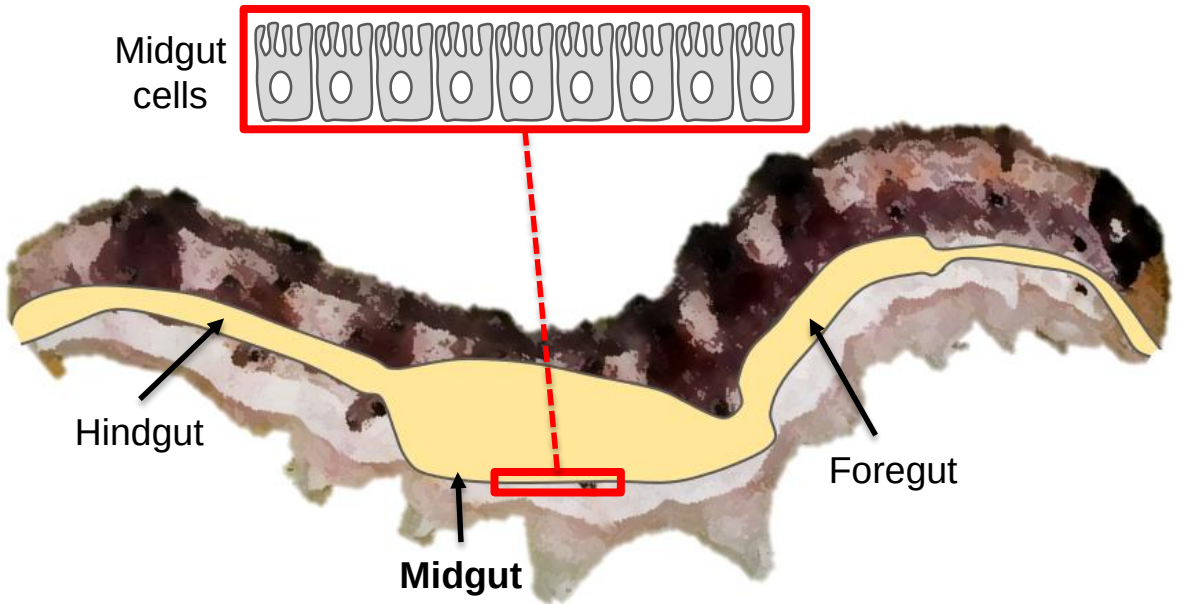


Mode of Action (Midgut Target)		Chemical Group	Active ingredients	MoA #
Microbial disruptors of insect midgut membranes	After ingestion this crystalline inclusion solubilizes in the midgut, releases proteins called S-endotoxins. These proteins (protoxins) are activated by midgut proteases, and the activated toxins interact with the larval midgut epithelium causing a disruption in membrane integrity and kill the insect.	Bacillus thuringiensis	Bacillus thuringiensis	11

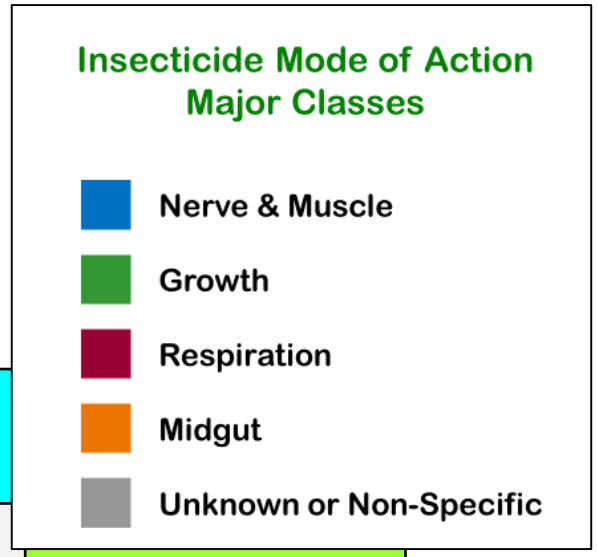
Bacillus thuringensis **derived toxins**

- Released in the insect midgut
- Cause lysis of midgut epithelial cells
- Loss of midgut integrity and death

Baculoviruses (Group 31)



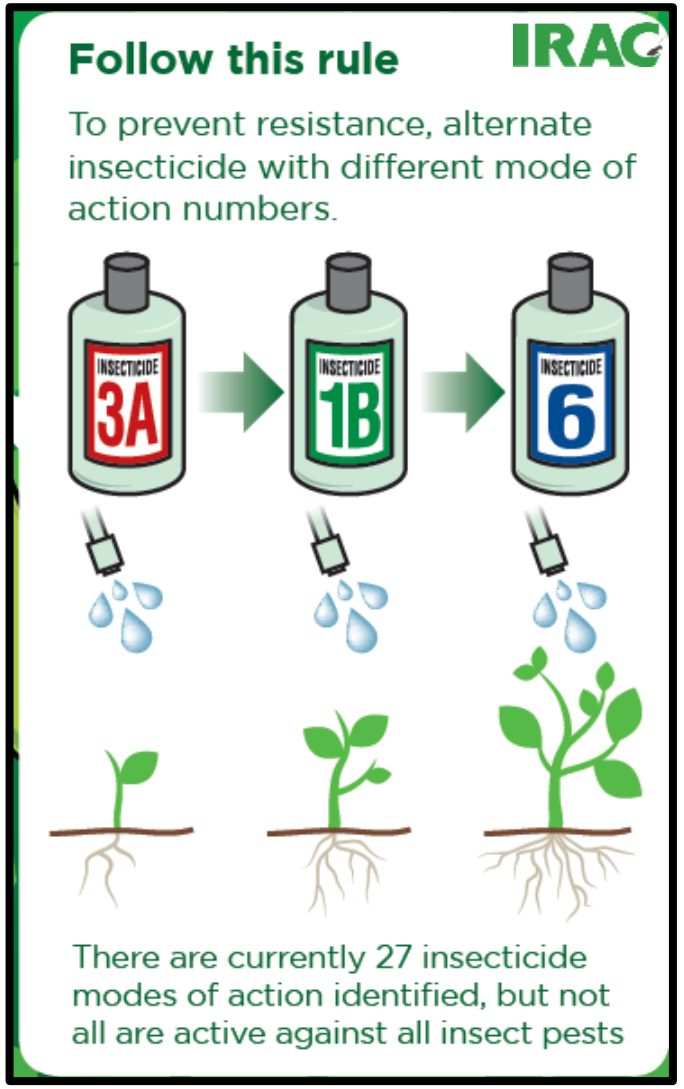
Using “Mode of Action” to Manage Insecticide Resistance



CONCLUSION	
Must specific MoA products within the “Nerve and Muscle” classes be rotated with each other?	**NO**
Must specific “Nerve and Muscle” class products be rotated with specific “Respiration” or “Growth” class products?	**NO**
Rotate all different MoA products within and across the major classes using the 30 day window rotation strategy. Ideally do not treat successive generations with the products from the same MoA.	**YES**

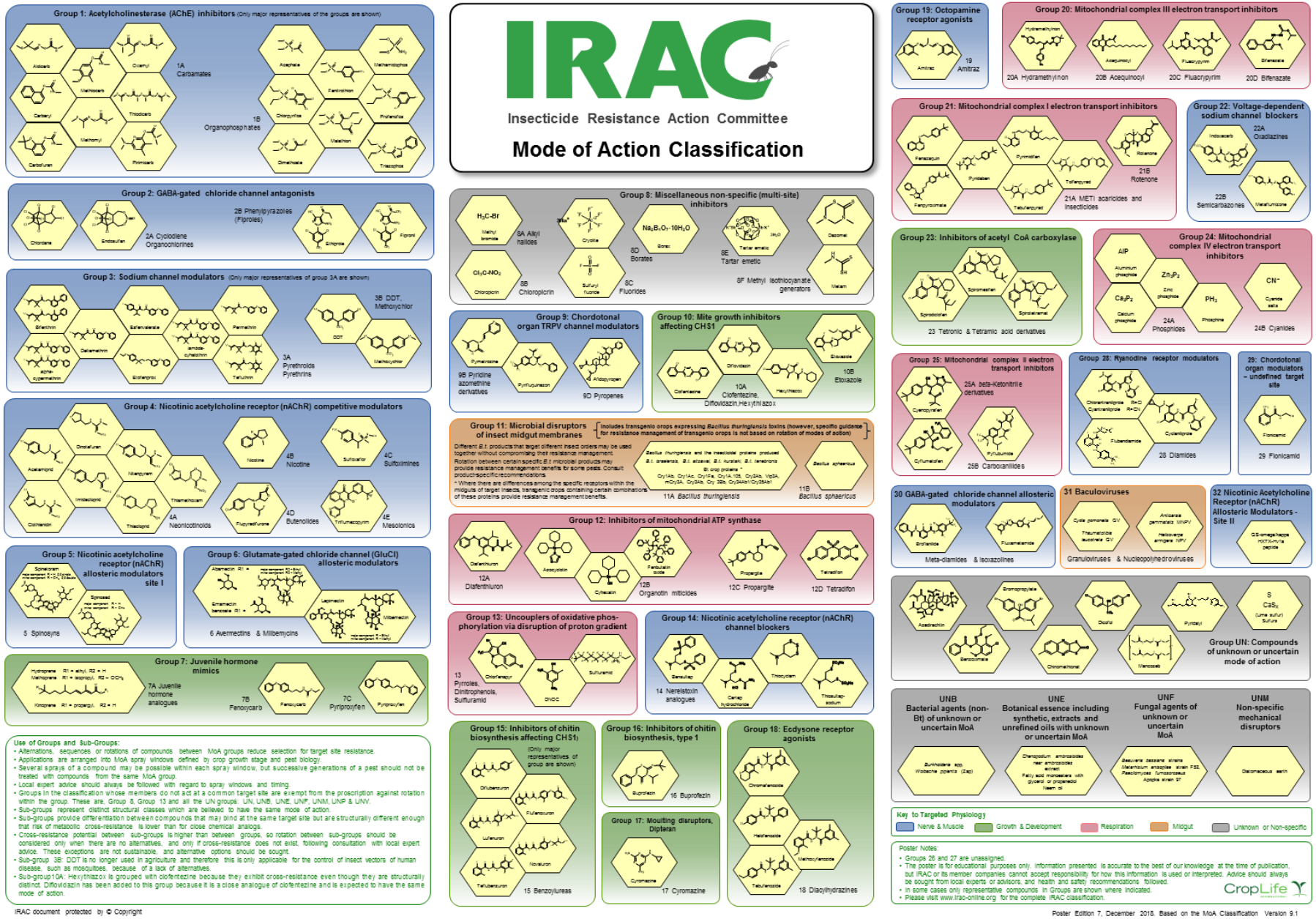
Rotate insecticides with different modes of action to reduce selection pressure for resistance

- **Two successive insect generations shouldn't be treated with the same MoA insecticides.**
- **Repeated exposure of pest populations to insecticides with the same Mode of Action will select for resistant insects.**



Managing Resistance Is Much More Difficult Than…….. Preventing Resistance

john.andaloro@fmc.com


IRAC
Insecticide Resistance Action Committee
Mode of Action Classification
Group 1: Acetylcholinesterase (AChE) inhibitors (Only major representatives of the groups are shown)
1A Carbamates
1B Organophosphates
Group 2: GABA-gated chloride channel antagonists
2A Cyclodiene Organochlorines
2B Phenylpyrazoles (Fiproles)
Group 3: Sodium channel modulators (Only major representatives of group 3A are shown)
3A Pyrethroids Pyrethrins
3B DDT, Methoxychlor
Group 4: Nicotinic acetylcholine receptor (nAChR) competitive modulators
4A Neonicotinoids
4B Nicotine
4C Sulfoximines
4D Butenolides
4E Mesoionics
Group 5: Nicotinic acetylcholine receptor (nAChR) allosteric modulators site I
5 Spinosyns
Group 6: Glutamate-gated chloride channel (GluCl) allosteric modulators
6 Avermectins & Milbemycins
Group 7: Juvenile hormone mimics
7A Juvenile hormone analogues
7B Fenoxycarb
7C Pyriproxyfen
Use of Groups and Sub-Groups:
• Alternations, sequences or rotations of compounds between MoA groups reduce selection for target site resistance.
• Applications are arranged into MoA spray windows defined by crop growth stage and pest biology.
• Several sprays of a compound may be possible within each spray window, but successive generations of a pest should not be treated with compounds from the same MoA group.
• Local expert advice should always be followed with regard to spray windows and timing.
• Groups in the classification whose members do not act at a common target site are exempt from the proscription against rotation within the group. These are, Group 8, Group 13 and all the UN groups: UN, UNB, UNE, UNF, UNM, UNP & UNV.
• Sub-groups represent distinct structural classes which are believed to have the same mode of action.
• Sub-groups provide 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.
• Sub-group 3B: DDT is no longer used in agriculture and therefore this is only applicable for the control of insect vectors of human disease, such as mosquitoes, because of a lack of alternatives.
• Sub-group 10A: Hexythiazox is grouped with clofentezine because they exhibit cross-resistance even though they are structurally distinct. Diflovidazin has been added to this group because it is a close analogue of clofentezine and is expected to have the same mode of action.
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Group 8: Miscellaneous non-specific (multi-site) inhibitors
8A Alkyl halides
8B Chloropicrin
8C Fluorides
8D Borates
8E Tartar emetic
8F Methyl isothiocyanate generators
Group 9: Chordotonal organ TRPV channel modulators
9B Pyridine azomethine derivatives
9D Pyropenes
Group 10: Mite growth inhibitors affecting CHS1
10A Clofentezine, Diflovidazin, Hexythiazox
10B Etoxazole
Group 11: Microbial disruptors of insect midgut membranes [Includes transgenic crops expressing Bacillus thuringiensis toxins (however, specific guidance for resistance management of transgenic crops is not based on rotation of modes of action)]
Different B.t. products that target different insect orders may be used together without compromising their resistance management.
Rotation between certain specific B.t. microbial products may provide resistance management benefits for some pests. Consult product-specific recommendations.
* Where there are differences among the specific receptors within the midguts of target insects, transgenic crops containing certain combinations of these proteins provide resistance management benefits.
11A Bacillus thuringiensis
11B Bacillus sphaericus
Group 12: Inhibitors of mitochondrial ATP synthase
12A Diafenthiuron
12B Organotin miticides
12C Propargite
12D Tetradifon
Group 13: Uncouplers of oxidative phosphorylation via disruption of proton gradient
13 Pyrroles, Dinitrophenols, Sulfluramid
Group 14: Nicotinic acetylcholine receptor (nAChR) channel blockers
14 Nereistoxin analogues
Group 15: Inhibitors of chitin biosynthesis affecting CHS1 (Only major representatives of group are shown)
15 Benzoylureas
Group 16: Inhibitors of chitin biosynthesis, type 1
16 Buprofezin
Group 17: Moulting disruptors, Dipteran
17 Cyromazine
Group 18: Ecdysone receptor agonists
18 Diacylhydrazines
Group 19: Octopamine receptor agonists
19 Amitraz
Group 20: Mitochondrial complex III electron transport inhibitors
20A Hydramethylnon
20B Acequinocyl
20C Fluacrypyrim
20D Bifenazate
Group 21: Mitochondrial complex I electron transport inhibitors
21A METI acaricides and insecticides
21B Rotenone
Group 22: Voltage-dependent sodium channel blockers
22A Oxadiazines
22B Semicarbazones
Group 23: Inhibitors of acetyl CoA carboxylase
23 Tetronic & Tetramic acid derivatives
Group 24: Mitochondrial complex IV electron transport inhibitors
24A Phosphides
24B Cyanides
Group 25: Mitochondrial complex II electron transport inhibitors
25A beta-Ketonitrile derivatives
25B Carboxanilides
Group 28: Ryanodine receptor modulators
28 Diamides
29: Chordotonal organ modulators – undefined target site
29 Flonicamid
30 GABA-gated chloride channel allosteric modulators
Meta-diamides & isoxazolines
31 Baculoviruses
Granuloviruses & Nucleopolyhedroviruses
32 Nicotinic Acetylcholine Receptor (nAChR) Allosteric Modulators - Site II
Group UN: Compounds of unknown or uncertain mode of action
UNB Bacterial agents (non-Bt) of unknown or uncertain MoA
UNE Botanical essence including synthetic, extracts and unrefined oils with unknown or uncertain MoA
UNF Fungal agents of unknown or uncertain MoA
UNM Non-specific mechanical disruptors
Key to Targeted Physiology
Nerve & Muscle
Growth & Development
Respiration
Midgut
Unknown or Non-specific
Poster Notes:
• Groups 26 and 27 are unassigned.
• The poster is for educational purposes only. Information presented is accurate to the best of our knowledge at the time of publication, but IRAC or 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 recommendations followed.
• In some cases only representative compounds in Groups are shown where indicated.
• Please visit www.irac-online.org for the complete IRAC classification.
CropLife
Poster Edition 7, December 2018. Based on the MoA Classification Version 9.1