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 scheme 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.

Group 1: Acetylcholinesterase (AChE) inhibitors (Only major representatives of the groups are shown)

Aldicarb, Oxamyl, Methiocarb, Carbaryl, Thiodicarb, Methomyl, Carbofuran, Pirimicarb

1A Carbamates

Acephate, Methamidophos, Fenitrothion, Chlorpyrifos, Profenofos, Malathion, Dimethoate, Triazophos

1B Organophosphates

Group 2: GABA-gated chloride channel antagonists

Chlordane, Endosulfan

2A Cyclodiene Organochlorines

2B Phenylpyrazoles (Fiproles)

Ethiprole, Fipronil

Group 3: Sodium channel modulators (Only major representatives of group 3A are shown)

Bifenthrin, Deltamethrin, Esfenvalerate, Permethrin, *Lambda*-cyhalothrin, *Alpha*-cypermethrin, Etofenprox, Tefluthrin

3A Pyrethroids Pyrethrins

DDT, Methoxychlor

3B DDT, Methoxychlor

Group 4: Nicotinic acetylcholine receptor (nAChR) competitive modulators

Dinotefuran, Acetamiprid, Nitenpyram, Imidacloprid, Thiamethoxam, Clothianidin, Thiacloprid

4A Neonicotinoids

Nicotine

4B Nicotine

Sulfoxaflor

4C Sulfoxaflor

Flupyradifurone

4D Flupyradifurone

Group 5: Nicotinic acetylcholine receptor (nAChR) allosteric modulators

Spinetoram (major component R = N-38 stereoisomer, minor component R = D-B, 5,6dihydro); Spinosad (major component R = H, minor component R = CH3)

5 Spinosyns

Group 6: Glutamate-gated chloride channel (GluCl) allosteric modulators

Abamectin R1 = (major component R2 = Dibu, minor component R2 = Meb); Emamectin benzoate R1 = ; Lepimectin (major component R = Dibu, minor component R = Meb); Milbemycin

6 Avermectins, Milbemycins

Group 7: Juvenile hormone mimics

Hydroprene R1 = ethyl, R2 = H; Methoprene R1 = isopropyl, R2 = –OCH3; Kinoprene R1 = propargyl, R2 = H

7A Juvenile hormone analogues

Fenoxycarb

7B Fenoxycarb

Pyriproxyfen

7C Pyriproxyfen

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

Methyl bromide (H_3C^-Br)

8A Alkyl halides

Chloropicrin ($Cl_3C^-NO_2$)

8B Chloropicrin

Sulfuryl fluoride

8C Sulfuryl fluoride

Borax ($Na_2B_4O_7 \cdot 10H_2O$)

8D Borates

Tartar emetic

8E Tartar emetic

Metam, Dazomet

8F Methyl isothiocyanate generators

Group 9: Modulators of Chordotonal Organs

Pymetrozine

9B Pymetrozine

Flonicamid

9C Flonicamid

Group 10: Mite growth inhibitors

Clofentezine, Hexythiazox, Diflovidazin

10A Clofentezine, Hexythiazox, Diflovidazin

Etoxazole

10B Etoxazole

Group 11: Microbial disruptors of insect midgut

{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.

Bacillus thuringiensis and the insecticidal proteins produced: *B.t. israelensis*, *B.t. aizawai*, *B.t. kurstaki*, *Bt. tenebrionis*; Bt crop proteins*: Cry1Ab, Cry1Ac, Cry1Fa, Cry1A.105, Cry2Ab, Vip3A, mCry3A, Cry3Ab, Cry3Bb, Cry34Ab1/Cry35Ab1

11A *Bacillus thuringiensis*

Bacillus sphaericus

11B *Bacillus sphaericus*

Group 12: Inhibitors of mitochondrial ATP synthase

Diafenthiuron

12A Diafenthiuron

Azocyclotin, Cyhexatin, Fenbutatin oxide

12B Organotin miticides

Propargite

12C Propargite

Tetradifon

12D Tetradifon

Group 13: Uncouplers of oxidative phosphorylation via disruption of proton gradient

Chlorfenapyr, DNOC, Sulfluramid

13 Pyrroles, Dinitrophenols, Sulfluramid

Group 14: Nicotinic acetylcholine receptor (nAChR) channel blockers

Bensultap, Cartap hydrochloride, Thiocyclam, Thiosultap-sodium

14 Nereistoxin analogues

Group 15: Inhibitors of chitin biosynthesis, type 0 (Only major representatives of the group are shown)

Diflubenzuron, Flufenoxuron, Lufenuron, Novaluron, Teflubenzuron, Triflumuron

15 Benzoylureas

Group 16: Inhibitors of chitin biosynthesis, type 1

Buprofezin

16 Buprofezin

Group 17: Moulting disruptor, Dipteran

Cyromazine

17 Cyromazine

Group 18: Ecdysone receptor agonists

Chromafenozide, Methoxyfenozide, Halofenozide, Tebufenozide

18 Diacylhydrazines

Group 19: Octopamine receptor agonists

Amitraz

19 Amitraz

Group 20: Mitochondrial complex III electron transport inhibitors

Hydramethylnon

20A Hydramethylnon

Acequinocyl

20B Acequinocyl

Fluacrypyrim

20C Fluacrypyrim

Group 21: Mitochondrial complex I electron transport inhibitors

Fenazaquin, Pyridaben, Tebufenpyrad, Fenpyroximate, Pyrimidifen, Tolfenpyrad, Rotenone

21A METI acaricides and insecticides

21B Rotenone

Group 22: Voltage-dependent sodium channel blockers

Indoxacarb

22A Indoxacarb

Metaflumizone

22B Metaflumizone

Group 23: Inhibitors of acetyl CoA carboxylase

Spirodiclofen, Spiromesifen, Spirotetramat

23 Tetronic & Tetramic acid derivatives

Group 24: Mitochondrial complex IV electron transport inhibitors

Aluminium Phosphide (AlP), Zinc Phosphide (Zn_3P_2), Calcium Phosphide (Ca_3P_2), Phosphine (PH_3)

24A Phosphine

Cyanide (CN^-)

24B Cyanide

Group 25: Mitochondrial complex II electron transport inhibitors

Cyenopyrafen, Cyflumetofen

25A *beta*-Ketonitrile derivatives

Pyflubumide

25B Carboxanilides

Group 28: Ryanodine receptor modulators

Chlorantraniliprole R=Cl, Cyantraniliprole R=CN

Flubendiamide

28 Diamides

Group UN: Compounds of unknown or uncertain mode of action

Azadirachtin, Bromopropylate, Cryolite, Pyrifluquinazon, Bifenazate, Pyridalyl, Benzoximate, Chinomethionat, Dicofol, Sulfur (CaSx, Lime sulfur)

Targeted Physiology

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

Use of Groups and Sub-Groups:

- Alternations, sequences or rotations of compounds between MoA groups reduces 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.
- Actives in groups 8 (Miscellaneous non-specific multi-site inhibitors), 13 (Uncouplers) and UN are thought not to share a common target site and therefore may be freely rotated with each other unless there is reason to expect cross-resistance.
- Sub-groups represent distinct structural classes 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, and the target site for these compounds is unknown. 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.

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.
- Representative compounds are shown. Please visit www.irac-online.org for the complete IRAC classification.

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Poster Edition 5, June 2015. Based on the MoA Classification Version 7.4