Mode of Action Classification

IRAC

Insecticide Resistance Action Committee

The Key to Resistance Management

More information on IRAC and the Mode of Action Classification is available from:
www.irac-online.org or enquiries@irac-online.org

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

Aldicarb, Benfuracarb, Carbaryl, Carbofuran, Carbosulfan, Fenobucarb, Methiocarb, Methomyl, Oxamyl, Thiodicarb, Triazamate

1A Carbamates

Acephate, Chlorpyrifos, Dimethoate, Diazinon, Malathion, Methamidophos, Monocrotophos, Parathion-methyl, Profenofos, Terbufos

1B Organophosphates

Group 2: GABA-gated chloride channel antagonists

Chlordane, Endosulfan

2A Cyclodiene Organochlorines

Ethiprole, Fipronil

2B Phenylpyrazoles (Fiproles)

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

Bifenthrin, Cypermethrin, Zeta-cypermethrin, Alpha-cypermethrin, Cyfluthrin, Esfenvalerate, Etofenprox, Deltamethrin, Lambda-cyhalothrin, Pyrethrins (Pyrethrum), Tefluthrin

3A Pyrethroids Pyrethrins

DDT, Methoxychlor

3B DDT, Methoxychlor

Group 4: Nicotinic acetylcholine receptor (nAChR) agonists

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

4A Neonicotinoids

Nicotine

4B Nicotine

Sulfoxaflor

4C Sulfoxaflor

Group 5: Nicotinic acetylcholine receptor (nAChR) allosteric modulators

Spinetoram, Spinosad

5 Spinosyns

Group 6: Chloride channel activators

Abamectin, Emamectin benzoate, Lepimectin, Milbemectin

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

CH_3Br Methyl bromide

8A Alkyl halides

Cl_3C-NO_2 Chloropicrin

8B Chloropicrin

Sulfuryl fluoride

8C Sulfuryl fluoride

$Na_2B_4O_7 \cdot 10H_2O$ Borax

8D Borax

Tartar emetic

8E Tartar emetic

Group 9: Selective homopteran feeding blockers

Pymetrozine

9B Pymetrozine

Flonicamid

9C Flonicamid

Group 10: Mite growth inhibitors

Clofentezine, Hexythiazox

10A Clofentezine, Hexythiazox

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, B.t. tenebrionis*

Bt crop proteins *
Cry1Ab, Cry1Ac, Cry1Fa, Cry1A.105, Cry2Ab, Vip3A, mCry3A, Cry3Ab, Cry 3Bb, 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

Bistrifluron, Chlorfluazuron, Diflubenzuron, Flucycloxuron, Flufenoxuron, Hexaflumuron, Lufenuron, Novaluron, Noviflumuron, 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, Halofenozide, Methoxyfenozide, Tebufenozide

18 Diacyl-hydrazines

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, Fenpyroximate, Pyridaben, Pyrimidifen, Tebufenpyrad, Tolfenpyrad

21A METI acaricides and insecticides

Rotenone

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

Al P Aluminium Phosphide
Ca_3P_2 Calcium Phosphide

24A Phosphine

Zn_3P_2 Zinc Phosphide
PH_3 Phosphine

CN- Cyanide

24B Cyanide

Group 25: Mitochondrial complex II electron transport inhibitors

Cyenopyrafen, Cyflumetofen

25 *beta*-Ketonitrile derivatives

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, Benzoximate, Bifenazate, Chinomethionat, Cryolite, Dicofol, Pyridalyl, Pyrifluquinazon

- **Successive generations of a pest should not be treated with compounds from the same MoA Group.**
- **In the absence of other alternatives it may be possible to rotate compounds between sub-groups if it is clear that cross-resistance mechanisms do not exist in the target populations.**
- **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.**

Guidance on the use of Sub-Groups:

- Represent distinct structural classes believed to have the same mode of action.
- Provides differentiation between compounds that may bind at the same target site.
- Are structurally different such that risk of metabolic cross-resistance is lower than for close chemical analogs.
- Are likely to be metabolized by different enzymes - may bind differently enough within the target site that the chance of selection for metabolic/target-site resistance is reduced compared to close analogs.
- 1A & 1B - If there are no other alternatives, compounds may be rotated in situations where cross-resistance mechanisms are known to be absent in the insect populations to be treated.
- 3A & 3B - If there are no other alternatives, compounds may be rotated in situations where cross-resistance mechanisms (e.g. kdr) are known to be absent in the insect populations to be treated. 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.
- 4A, 4B & 4C - Although these compounds are believed to have the same target site, they have been sub-grouped because they are chemically distinct, and current evidence indicates that the risk of metabolic cross-resistance is low. If there are no other alternatives, compounds from groups 4A & 4C may be rotated in situations where cross-resistance mechanisms are known to be absent in the insect population to be treated.
- 10A - Clofentezine & Hexythiazox are grouped because they commonly exhibit cross-resistance even though they are structurally distinct, and the target site for neither compound is known.
- 22A & 22B - Although these compounds are believed to have the same target site, they have been sub-grouped because they are chemically distinct, and current evidence indicates that the risk of metabolic cross-resistance is low.

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Poster Edition 3, February 2012. Based on the Mode of Action Classification - Version 7.2 February 2012
For further information visit the IRAC website: www.irac-online.org