IRAC

Insecticide Resistance Action Committee

Mode of Action Classification

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

1A Carbamates: Aldicarb, Oxamyl, Methiocarb, Carbaryl, Thiodicarb, Methomyl, Carbofuran, Pirimicarb

1B Organophosphates: Acephate, Methamidophos, Fenitrothion, Chlorpyrifos, Profenofos, Malathion, Dimethoate, Triazophos

Group 2: GABA-gated chloride channel antagonists

2A Cyclodiene Organochlorines: Chlordane, Endosulfan

2B Phenylpyrazoles (Fiproles): Ethiprole, Fipronil

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

3A Pyrethroids Pyrethrins: Bifenthrin, Deltamethrin, Esfenvalerate, Etofenprox, Permethrin, lambda-cyhalothrin, Tefluthrin, alpha-cypermethrin

3B DDT, Methoxychlor: DDT, Methoxychlor

Group 4: Nicotinic acetylcholine receptor (nAChR) competitive modulators

4A Neonicotinoids: Acetamiprid, Dinotefuran, Imidacloprid, Nitenpyram, Thiamethoxam, Clothianidin, Thiacloprid

4B Nicotine: Nicotine

4C Sulfoximines: Sulfoxaflor

4D Butenolides: Flupyradifurone

4E Mesoionics: Triflumezopyrim

Group 5: Nicotinic acetylcholine receptor (nAChR) allosteric modulators site I

5 Spinosyns: Spinetoram (major component R = H, 5,6 single minor component R = CH3, 5,6 double), Spinosad (major component R = H minor component R = CH3)

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

6 Avermectins & Milbemycins: Abamectin R1 = (major component R2 = Ethyl minor component R2 = Methyl), Emamectin benzoate R1 =, Lepimectin (major component R = Ethyl minor component R = Methyl), Milbemectin

Group 7: Juvenile hormone mimics

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

7A Juvenile hormone analogues

7B Fenoxycarb: Fenoxycarb

7C Pyriproxyfen: 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-group10A: 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: Methyl bromide (H_3C-Br)

8B Chloropicrin: Chloropicrin (Cl_3C-NO_2)

8C Fluorides: Cryolite, Sulfuryl fluoride

8D Borates: Borax ($Na_2B_4O_7 \cdot 10H_2O$)

8E Tartar emetic: Tartar emetic

8F Methyl isothiocyanate generators: Dazomet, Metam

Group 9: Chordotonal organ TRPV channel modulators

9B Pyridine azomethine derivatives: Pymetrozine, Pyriflquinazon

9D Pyropenes: Afidopyropen

Group 10: Mite growth inhibitors affecting CHS1

10A Clofentezine, Diflovidazin, Hexythiazox: Clofentezine, Diflovidazin, Hexythiazox

10B Etoxazole: 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*: *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

11B *Bacillus sphaericus*: *Bacillus sphaericus*

Group 12: Inhibitors of mitochondrial ATP synthase

12A Diafenthiuron: Diafenthiuron

12B Organotin miticides: Azocyclotin, Cyhexatin, Fenbutatin oxide

12C Propargite: Propargite

12D Tetradifon: Tetradifon

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

13 Pyrroles, Dinitrophenols, Sulfluramid: Chlorfenapyr, DNOC, Sulfluramid

Group 14: Nicotinic acetylcholine receptor (nAChR) channel blockers

14 Nereistoxin analogues: Bensultap, Cartap hydrochloride, Thiocyclam, Thiosultap-sodium

Group 15: Inhibitors of chitin biosynthesis affecting CHS1) (Only major representatives of group are shown)

15 Benzoylureas: Diflubenzuron, Flufenoxuron, Lufenuron, Novaluron, Teflubenzuron

Group 16: Inhibitors of chitin biosynthesis, type 1

16 Buprofezin: Buprofezin

Group 17: Moulting disruptors, Dipteran

17 Cyromazine: Cyromazine

Group 18: Ecdysone receptor agonists

18 Diacylhydrazines: Chromafenozide, Halofenozide, Methoxyfenozide, Tebufenozide

Group 19: Octopamine receptor agonists

19 Amitraz: Amitraz

Group 20: Mitochondrial complex III electron transport inhibitors

20A Hydramethylnon: Hydramethylnon

20B Acequinocyl: Acequinocyl

20C Fluacrypyrim: Fluacrypyrim

20D Bifenazate: Bifenazate

Group 21: Mitochondrial complex I electron transport inhibitors

21A METI acaricides and insecticides: Fenazaquin, Pyridaben, Pyrimidifen, Tolfenpyrad, Tebufenpyrad, Fenpyroximate

21B Rotenone: Rotenone

Group 22: Voltage-dependent sodium channel blockers

22A Oxadiazines: Indoxacarb

22B Semicarbazones: Metaflumizone

Group 23: Inhibitors of acetyl CoA carboxylase

23 Tetronic & Tetramic acid derivatives: Spirodiclofen, Spiromesifen, Spirotetramat, Spiropidion

Group 24: Mitochondrial complex IV electron transport inhibitors

24A Phosphides: AlP Aluminium phosphide; Ca_3P_2 Calcium phosphide; Zn_3P_2 Zinc phosphide; PH_3 Phosphine

24B Cyanides: CN^- Cyanide salts

Group 25: Mitochondrial complex II electron transport inhibitors

25A *beta*-Ketonitrile derivatives: Cyenopyrafen, Cyflumetofen

25B Carboxanilides: Pyflubumide

Group 28: Ryanodine receptor modulators

28 Diamides: Chlorantraniliprole R=Cl Cyantraniliprole R=CN, Cyclaniliprole, Flubendiamide, Tetraniliprole

29: Chordotonal organ modulators – undefined target site

29 Flonicamid: Flonicamid

30 GABA-gated chloride channel allosteric modulators

Meta-diamides & Isoxazolines: Broflanilide, Fluxametamide

31 Baculoviruses

Granuloviruses & Nucleopolyhedroviruses: *Cydia pomonella* GV, *Thaumatotibia leucotreta* GV, *Anticarsia gemmatalis* MNPV, *Helicoverpa armigera* NPV

32 Nicotinic Acetylcholine Receptor (nAChR) Allosteric Modulators - Site II

GS-omega/kappa HXTX-Hv1a peptide

Group UN: Compounds of unknown or uncertain mode of action

Azadirachtin, Bromopropylate, Dicofol, Pyridalyl, S CaSx (Lime sulfur) Sulfurs, Benzoximate, Chinomethionat, Mancozeb

UNB Bacterial agents (non-Bt) of unknown or uncertain MoA

Burkholderia spp, *Wolbachia pipientis* (Zap)

UNE Botanical essence including synthetic, extracts and unrefined oils with unknown or uncertain MoA

Chenopodium ambrosioides near ambrosioides extract
Fatty acid monoesters with glycerol or propanediol
Neem oil

UNF Fungal agents of unknown or uncertain MoA

Beauveria bassiana strains
Metarhizium anisopliae strain F52, *Paecilomyces fumosoroseus* Apopka strain 97

UNM Non-specific mechanical disruptors

Diatomaceous earth

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.

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