IRAC

Insecticide Resistance Action Committee

Mode of Action Classification

Key to Targeted Physiology

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

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

1A Carbamates: Carbofuran, Carbosulfan, Methomyl

1B Organophosphates: Acephate, Chlorpyrifos, Phorate

Group 2: GABA-gated chloride channel antagonists

2A Cyclodiene Organochlorines: Chlordane, Endosulfan

2B Phenylpyrazoles (Fiproles): Ethiprole, Fipronil

Group 3: Sodium channel modulators
(Only representative actives of group 3A are shown)

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

3B DDT, Methoxychlor: DDT, Methoxychlor

Group 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: Dicloromezotiaz, Fenmezoditiaz, Triflumezopyrim

4F Pyridylidenes: Flupyrimin

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

5 Spinosyns: Spinetoram, Spinosad

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

6 Avermectins & Milbemycins: Abamectin R1 = ..., Emamectin benzoate R1 = ..., Lepimectin, Milbemectin

Group 7: Juvenile hormone receptor modulators

7A Juvenile hormone analogues: Hydroprene R1 = ethyl, R2 = H; Methoprene R1 = isopropyl, R2 – OCH_3; Kinoprene R1 = propargyl, R2 = H

7B Fenoxycarb: Fenoxycarb

7C Pyriproxyfen: Pyriproxyfen

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

8A Alkyl halides: H_3C-Br (Methyl bromide); CI_3C-NO_2 (Chloropicrin)

8B Chloropicrin

8C Fluorides: Cryolite ($3Na^+$ AlF_6^{3-}), Sulfuryl fluoride

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

8E Tartar emetic: Tartar emetic

8F Methyl isothiocyanate generators: Dazomet, Metam

Group 9: Chordotonal organ TRPV channel modulators

9B Pyridine azomethine derivatives: Pymetrozine, Pyrifluquinazon

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)

Rotation between certain specific *B.t.* microbial products may provide resistance management benefits for some pests.
Consult product-specific recommendations.

11A *Bacillus thuringiensis*: *Bacillus thuringiensis* and the insecticidal proteins produced *B.t. aizawai, B.t. israelensis, B.t. kurstaki, B.t. tenebrionis*

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 representative actives 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 – Qo site

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, Fenpyroximate, Pyridaben, Pyrimidifen, Tebufenpyrad, Tolfenpyrad

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: Spidoxamat, Spiromesifen, Spirodiclofen, Spiropidion, Spirotetramat

Group 24: Mitochondrial complex IV electron transport inhibitors

24A Phosphides: AlP (Aluminium phosphide), PH_3 (Phosphine), Ca_3P_2 (Calcium phosphide), Zn_3P_2 (Zinc phosphide)

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

Group 29: Chordotonal organ nicotinamidase inhibitors

29 Flonicamid: Flonicamid

Group 30: GABA-gated chloride channel allosteric modulators

30 Isoxazolines & Meta-diamides: Broflanilide, Cyproflanilide, Fluxametamide, Isocycloseram

Group 31: Baculoviruses

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

Group 32: Nicotinic Acetylcholine receptor (nAChR) allosteric modulators site II

32 GS-omega/kappa HXTX-Hv1a peptide: GS-omega/kappa HXTX-Hv1a peptide

Group 33: Calcium-activated potassium channel (KCa2) modulators

33 Acynonapyr: Acynonapyr

Group 34: Mitochondrial complex III electron transport inhibitors – Qi site

34 Flometoquin: Flometoquin

Group 35: RNA interference mediated target suppressors

35 Ribonucleic Acids (RNA): Ledprona, Vadescana

Group 36: Chordotonal organ modulators – undefined target site

36 Dimpropyridaz: Dimpropyridaz

Group 37: Vesicular acetylcholine transporter (VAChT) inhibitor

37 Oxazosulfyl: Oxazosulfyl

UN: Unknown or uncertain mode of action

UNF Fungal agents: *Akanthomyces muscarius* Ve6, *Beauveria bassiana* strains, *Metarhizium brunneum* strain F52, *Paecilomyces fumosoroseus* Apopka strain 97

UNB Bacterial agents (non-Bt): *Burkholderia* spp., *Wolbachia pipientis* (Zap)

UNM Non-specific mechanical and physical disruptors: Azadirachtin, Benzoximate, Bromopropylate, Benzpyrimoxan, Chinomethionat, Dicofol, Mancozeb, Pyridalyl, S CaS_x (Lime sulfur) Sulfurs; Diatomaceous earth, Mineral oil, Polydimethylsiloxane (PDMS)

UNE Botanical essence including synthetic, extracts and unrefined oils: *Chenopodium ambrosioides* near *ambrosioides* extract, *Citrioa ternatea* extract, Fatty acid monoesters with glycerol or propanediol, Neem oil, Nonanoic acid, Sabadilla extract

Use of 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 on spray windows and timings should always be followed.
- Groups in the classification whose members do not act at a common target site are exempt from the proscription against rotation within the group (Group 8, 13 and all UN groups: UN, UNB, UNE, UNF, UNM, UNP & UNV).

Use of Sub-Groups:
- 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.

Poster Notes:
- 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.
- Group 20: While there is strong evidence that Bifenazate acts on the Qo site of Mitochondrial Complex III and some Bifenazate resistance mutations confer cross-resistance to Acequinocyl, the sites of action of Fluacrypyrim and Hydramethylnon have not been determined.
- Groups 26 & 27 are unassigned
- In some cases, only representative actives are shown.
- Because of documented cross-resistance between Dicofol, Bromopropylate and Abamectin, these active ingredients should not be rotated after each other in an IRM program

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