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

MACE Resistance

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

APHOX

Carbamates: Carbofuran, Carbosulfan, Methomyl

1B Organophosphates: Acephate, Chlorpyrifos, Phorate

Nemathorin

Group 2: GABA-gated chloride channel antagonists

2A Cyclodiene Organochlorines: Chlordane, Endosulfan

2B Phenylpyrazoles (Fiproles): Ethiprole, Fipronil

KDR & Super KDR Resistance

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

Decis

Bifenthrin, Esfenvalerate, Deltamethrin, Permethrin, *lambda*-cyhalothrin, alpha-cypermethrin, Etofenprox, Tefluthrin

Hallmark

Spruzit

3A Pyrethroids Pyrethrins

DDT, Methoxychlor

3B DDT, Methoxychlor

Group 4: Nicotinic acetylcholine receptor (nAChR) competitive modulators

Gazelle

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

4A Neonicotinoids

Nicotine

4B Nicotine

Sequoia

Sulfoxaflor

4C Sulfoximines

Flupyradifurone

4D Butenolides

Dicloromezotiaz, Fenmezoditiaz, Triflumezopyrim

4E Mesoionics

4F Pyridylidenes

Flupyrimin

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

Conserve

Spinetoram, Spinosad

5 Spinosyns

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

Abamectin R1 =, Emamectin benzoate R1 =, Lepimectin, Milbemectin

6 Avermectins & Milbemycins

Group 7: Juvenile hormone receptor modulators

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

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

8A Alkyl halides: H_3C-Br (Methyl bromide), Cl_3C-NO_2 (Chloropicrin)

8B Chloropicrin

Cryolite, Sulfuryl fluoride

8C Fluorides

$Na_2B_4O_7 \cdot 10H_2O$ (Borax)

8D Borates

Tartar emetic

8E Tartar emetic

Dazomet, Metam

8F Methyl isothiocyanate generators

Group 9: Chordotonal organ TRPV channel modulators

Pymetrozine, Pyrifluquinazon

9B Pyridine azomethine derivatives

Afidopyropen

9D Pyropenes

Group 10: Mite growth inhibitors affecting CHS1

Apollo

Clofentezine, Diflovidazin, Hexythiazox

10A Clofentezine, Diflovidazin,Hexythiazox

Etoxazole

10B Etoxazole

Borneo

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.

Bacillus thuringiensis and the insecticidal proteins produced *B.t. ailzawai, B.t. israelensis, B.t. kurstaki, B.t. tenebrionis*

11A *Bacillus thuringiensis*

Dipel

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 affecting CHS1
(Only representative actives of group are shown)

Diflubenzuron, Flufenoxuron, Lufenuron, Novaluron, Teflubenzuron

15 Benzoylureas

Group 16: Inhibitors of chitin biosynthesis, type 1

Applaud

Buprofezin

16 Buprofezin

Group 17: Moulting disruptors, Dipteran

Cyromazine

17 Cyromazine

Group 18: Ecdysone receptor agonists

Chromafenozide, Halofenozide, Methoxyfenozide, Tebufenozide

18 Diacylhydrazines

Group 19: Octopamine receptor agonists

Amitraz

19 Amitraz

Group 20: Mitochondrial complex III electron transport inhibitors – Qo site

Hydramethylnon

20A Hydramethylnon

Acequinocyl

20B Acequinocyl

Fluacrypyrim

20C Fluacrypyrim

Floramite

Bifenazate

20D Bifenazate

Group 21: Mitochondrial complex I electron transport inhibitors

Fenazaquin, Pyridaben, Pyrimidifen, Tebufenpyrad, Tolfenpyrad

21A METI acaricides and insecticides

Rotenone

21B Rotenone

Group 22: Voltage-dependent sodium channel blockers

Indoxacarb

22A Oxadiazines

Metaflumizone

22B Semicarbazones

Group 23: Inhibitors of acetyl-CoA carboxylase

Spidoxamat, Spiromesifen, Spirodiclofen

23 Tetronic & Tetramic acid derivatives

Batavia

Spiropidion, Spirotetramat

Group 24: Mitochondrial complex IV electron transport inhibitors

AlP (Aluminium phosphide), PH_3 (Phosphine), Ca_3P_2 (Calcium phosphide), Zn_3P_2 (Zinc phosphide), CN^- (Cyanide salts)

24A Phosphides

24B Cyanides

Group 25: Mitochondrial complex II electron transport inhibitors

Cyenopyrafen, Cyflumetofen

25A *beta*-Ketonitrile derivatives

Pyflubumide

25B Carboxanilides

Nealta

Group 28: Ryanodine receptor modulators

Chlorantraniliprole R=Cl, Cyantraniliprole R=CN, Cyclaniliprole, Flubendiamide, Tetraniliprole

Mainspring

28 Diamides

Group 29: Chordotonal organ nicotinamidase inhibitors

Flonicamid

29 Flonicamid

Mainman

Group 30: GABA-gated chloride channel allosteric modulators

Broflanilide, Fluxametamide, Isocycloseram

30 Isoxazolines & Meta-diamides

Group 31: Baculoviruses

Cydia pomonella GV, *Thaumatotibia leucotreta* GV, *Anticarsia gemmatalis* MNPV, *Helicoverpa armigera* NPV

31 Granuloviruses & Nucleopolyhedroviruses

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

GS-omega/kappa HXTX-Hv1a peptide

32 GS-omega/kappa HXTX-Hv1a peptide

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

Acynonapyr

33 Acynonapyr

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

Flometoquin

34 Flometoquin

Group 35: RNA interference mediated target suppressors

Ledprona

35 Ledprona

Group 36: Chordotonal organ modulators – undefined target site

Dimpropyridaz

36 Dimpropyridaz

Group 37: Vesicular acetylcholine transporter (VAChT) inhibitor

37 Oxazosulfyl

UN: Unknown or uncertain mode of action

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

Naturalis L

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

UNF Fungal agents

Burkholderia spp, *Wolbachia pipientis* (Zap)

UNB Bacterial agents (non-Bt)

Diatomaceous earth Mineral oil Polydimethylsiloxane (PDMS)

UNM Non-specific mechanical and physical disruptors

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

UNE Botanical essence including synthetic, extracts and unrefined oils

Flipper

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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