IPM Strategies for Vegetable Crops

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Common pests of vegetables

Coleoptera

- Click beetle
- Colorado potato beetle
- Flea beetle
- Japanese beetle
- Pepper weevil
- Spotted cucumber beetle
- Striped cucumber beetle
- Wireworms

Dermaptera

- Earwig

Diptera

- Cabbage maggot
- Carrot rust fly
- Leafminers
- Seedcorn maggot

Hemiptera

- Aphids
- Bagrada bug
- Brown marmorated stink bug
- False chinch bug
- Leafhopper
- Lygus bug
- Psyllids
- Squash bug
- Tomato bug
- Whiteflies

Lepidoptera

- Armyworms
- Budworms
- Cutworms
- Diamondback moth
- Earworms
- Fruitworms
- Hornworms
- Imported cabbageworm
- Leafrollers
- Loopers
- Potato tuberworm
- Tomato pinworm

Orthoptera

- Grasshopper

Acarina

- Bulb mite
- Spider mites

Thysanoptera

- Thrips

Others

- Symphylans
- Spotted snake millipedes
- Slugs

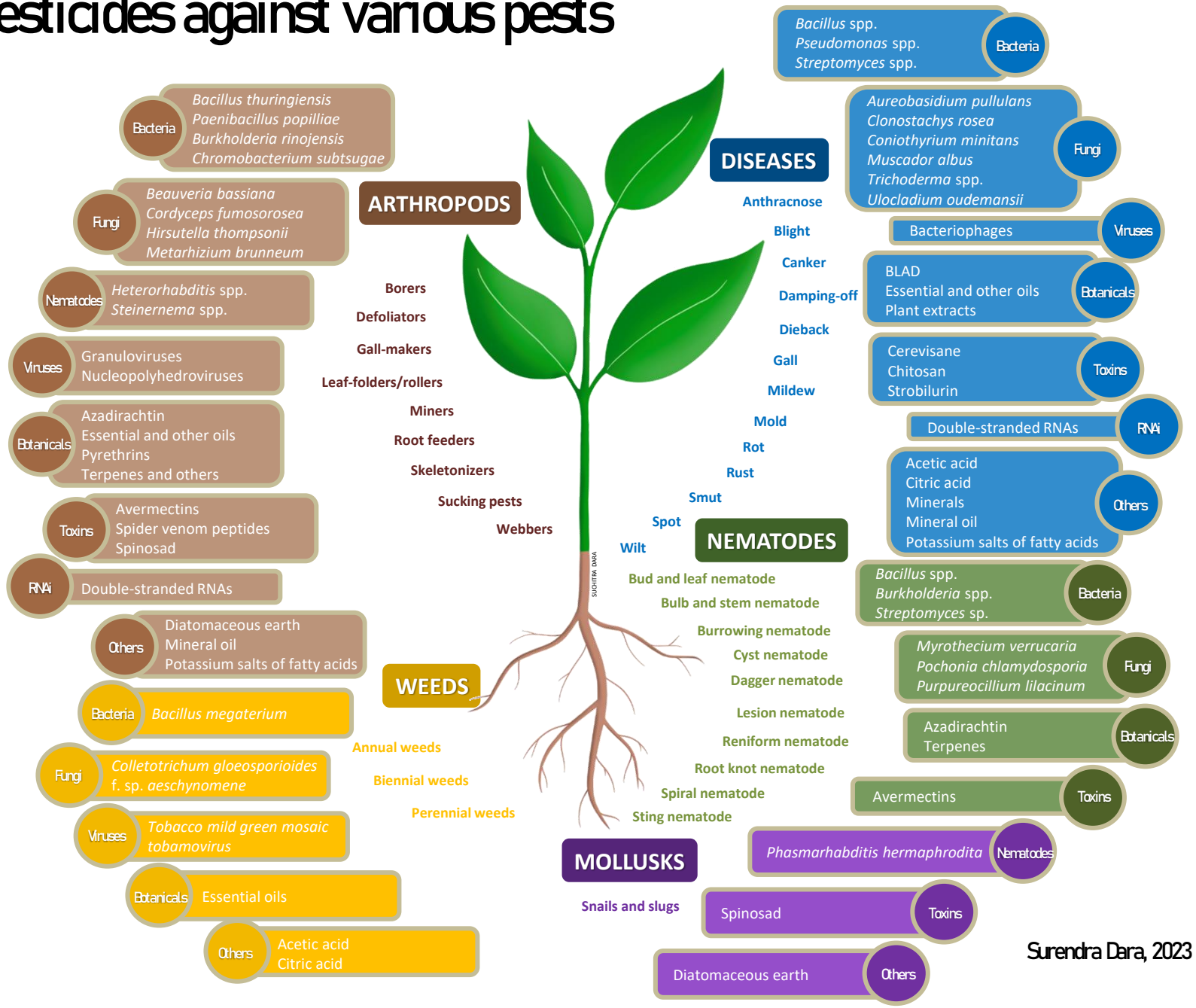
Feeding habit: Chewing, boring, rasping/scraping, piercing and sucking, etc.

Feeding habitat: Surfaces or bored plant tissues (leaves, roots, stems, or fruits), mines, rolls, folds, etc.

Control option: Based on pest biology, feeding behavior/habitat, mode of action of the control option, prevention/cure, environmental conditions, and others

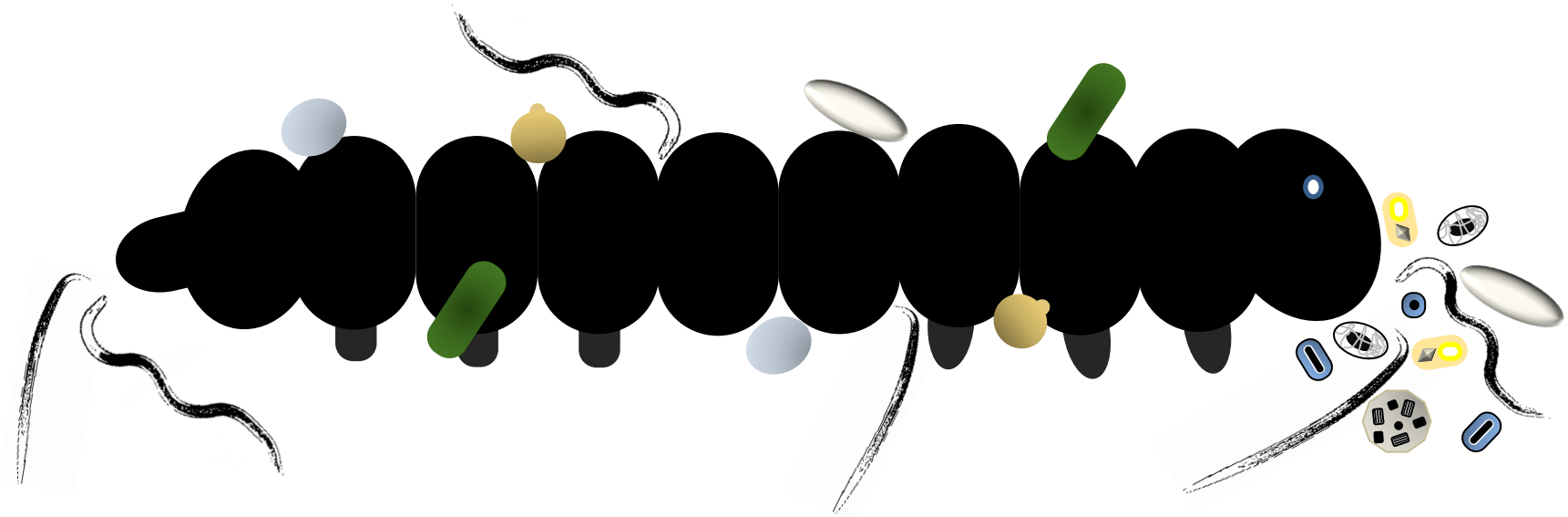
Biopesticides

Biopesticides against various pests



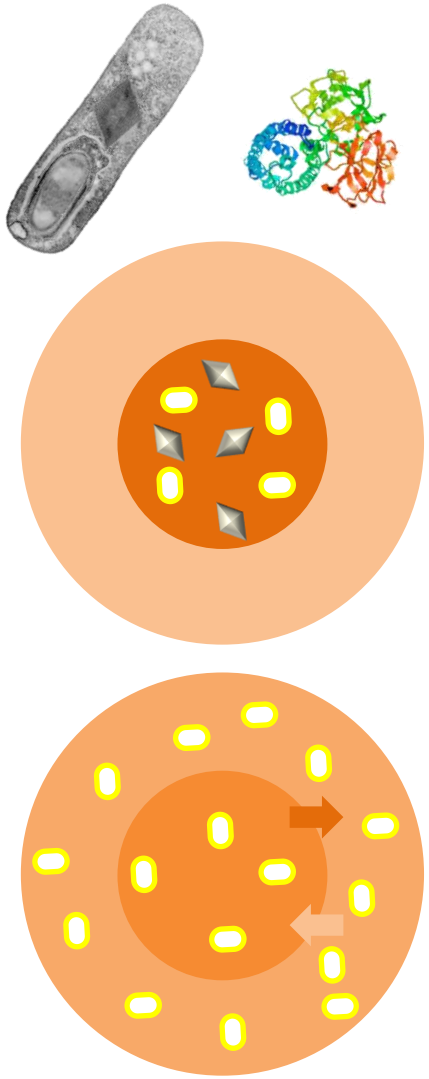
Surendra Dara, 2023

Entomopathogens



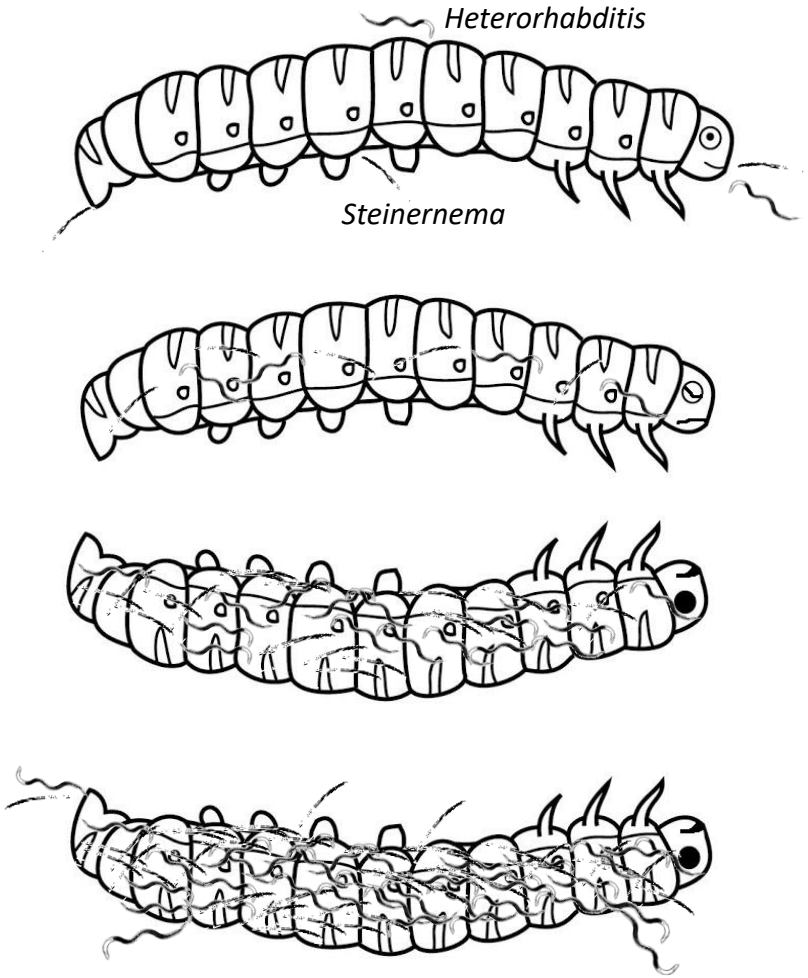
Mechanisms of infection

Bacillus thuringiensis

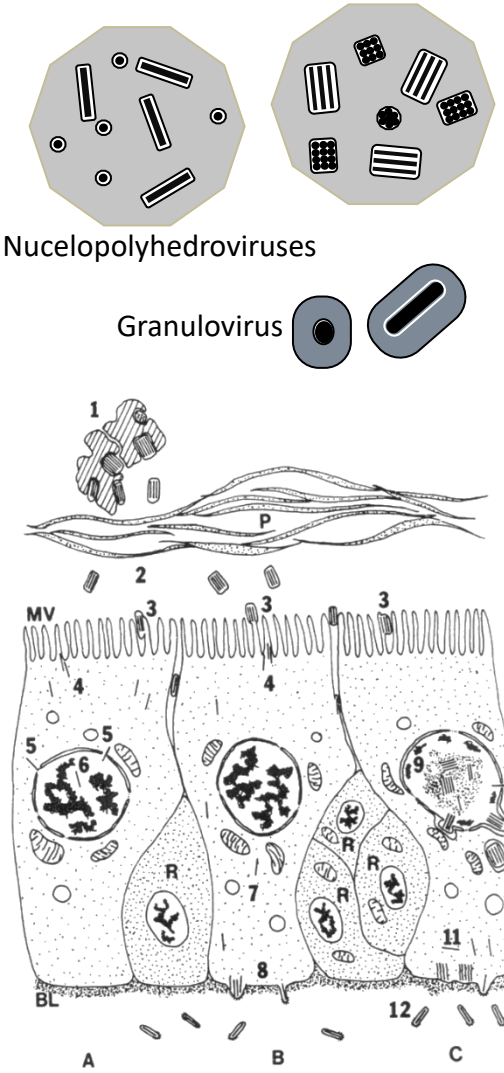


Entomopathogenic Fungi

Entomopathogenic Nematodes



Baculoviruses



Modes of action

AI	IRAC	Mode of Action
Pyrethrins (*Chrysanthemum cinerariaefolium*)	3	Sodium channel modulators causing hyperexcitation and sometimes nerve block
Spynosyns (*Polysaccharospora spinosa*)	5	Nicotinic acetylcholine receptor allosteric modulators – Site I causing hyperexcitation of the nervous system
Avermectins (*Streptomyces avermitilis*)	6	Glutamate-gated chloride channel allosteric modulators causing paralysis
Spider venom peptide (GS-omega/kappa HXTX-Hv1a peptide) (Australian funnel-web spider)	32	Nicotinic acetylcholine receptor allosteric modulators – Site II causing hyperexcitation of the nervous system
Azadirachtin (*Azadirachta indica*)	UN	Unknown/uncertain Insecticide/antifeedant/repellent/IGR
Botanical extracts/oils	UNE	Unknown/uncertain Insecticide/antifeedant/repellent

Modes of action

AI	IRAC	Mode of Action
Diatomaceous earth	UNM	Cuticle abrasion and absorption of lipids
Mineral oil	UNM	Asphyxiation
RNAi	(35)	Targeted protein suppression

IRAC
Insecticide Resistance Action Committee

https://irac-online.org/documents/moa-classification/

IRAC

Insecticide Resistance Action Committee

Mode of Action Classification

Key to Targeted Physiology

- Nerve & Muscle
- Growth & Development
- Respiration
- Midgut
- 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, Endosulfen

2B Phenylpyrazoles (Fiproles): Ethiprole, Fipronil

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

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

3B DDT, Methoxychlor: DDT, Methoxychlor

Group 4: Nicotinic acetylcholine receptor (nAChR) competitive modulators

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

4B Nicotine: Nicotine

4C Sulfoximines: Sulfoxaflor

4D Butenolides: Flupyradifurone

4E Mesoionics: Triflumezopyrim, Dicloromezotiaz

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, Emamectin benzoate, Lepimectin, Milbemectin

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

8C Fluorides: Cryolite, Sulfuryl fluoride

8D Borates: $Na_2B_4O_7 \cdot 10H_2O$, Borax

8E Tartar emetic: Tartar emetic

8F Methyl isothiocyanate generators: Dazomet, Metam

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.

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. israelensis, B.t. aizawai, 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

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Group 21: Mitochondrial complex I electron transport inhibitors

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

Group 24: Mitochondrial complex IV electron transport inhibitors

24A Phosphides: Aluminium phosphide, Phosphine, Calcium phosphide, Zinc phosphide

24B Cyanides: Cyanide salts

Group 25: Mitochondrial complex II electron transport inhibitors

25B Carboxanilides: 25A *beta*-Ketonitrile derivatives, Cyenopyrafen, Cyflumetofen, Pyflubumide

Group 28: Ryanodine receptor modulators

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

Group 29: Chordotonal organ nicotinamidase inhibitors

29 Flonicamid: Flonicamid

Group 30: GABA-gated chloride channel allosteric modulators

30 Meta-diamides & Isoxazolines: Broflanilide, 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 36: Chordotonal organ modulators – undefined target site

36 Dimpropyridaz: Dimpropyridaz

UN: Unknown or uncertain mode of action

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

UNF Fungal agents

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

Burkholderia spp, *Wolbachia pipientis* (Zap)

UNB Bacterial agents (non-Bt)

UNM Non-specific mechanical and physical disruptors

Diatomaceous earth Mineral oil

UNE Botanical essence including synthetic, extracts and unrefined oils

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

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 and 35 are unassigned.
- In some cases, only representative actives are shown.
- Please visit www.irac-online.org for the complete IRAC classification.

Poster Edition 10.6, September 2023. Based on the MoA Classification Ver.10.6

New IPM Model

Dara, 2019

Effective management strategies

- Integrated pest management
  - Take advantage of all available options
  - Consider additive and synergistic effect of multiple control options
  - Combine and rotate synthetic and biological pesticides
  - Follow IPM principles beyond pest management
- When using biopesticides, understand their mode of action, compatibility, storage and handling, and other use strategies
- IPM = GAP (Good Agricultural Practices) = CCC (Comprehensive Crop Care)
- Insecticide resistance management
  - Pests develop resistance to all kinds of pesticides
  - Avoid repetitive use of the same control option that has a risk of resistance development
- Balanced approach for both short-term and long-term benefits
- Use of modern technologies that enhance pest control efficacy


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