Mode of Action Classification

Edition: 10.5

Now including Nematicides

IRAC

Insecticide Resistance Action Committee

The Insecticide Resistance Action Committee

Mode of Action Classification Brochure

Edition: 10.5 – March 2023

Based on the IRAC MoA Classification Version 10.5 and
Nematicide MoA Classification Version 2.1

Foreword

Effective insecticide resistance management (IRM) in conjunction with integrated pest management (IPM) is vital to global crop protection, sustainable agriculture and improved public health, and it is an essential element of responsible product stewardship.

The Insecticide Resistance Action Committee (IRAC) was formed in 1984 and works as a specialist technical group of the industry association CropLife International, to provide a coordinated crop protection industry response to prevent or delay the development of resistance in insect, mite and nematode pests. There are now IRAC country group committees in many parts of the world, researching and responding to local resistance issues, as well as the parent IRAC International group, which provides a coordinating and supporting role at the global level (see also www.irac-online.org).

Developing new products is becoming increasingly difficult and costly, so it is vital to protect those effective products in the marketplace from the development of resistance. Moreover, with fewer new products being discovered and regulatory pressures reducing the number of older commercial control methods available, the 'toolbox' of usable products is being reduced, making effective IRM more important than ever. The Mode of Action Classification Scheme is a key part of IRAC's global resistance management strategy.

Insecticide/Acaricide MoA Classification

The CropLife and IRAC member companies support the inclusion of MoA information on product labels which will ensure growers have simple access to critical information to support implementation of resistance management. Further details on MoA Labelling Guidance can be found on the CropLife website under Resources (https://croplife.org/resources/)

Mode of Action Classification

IRAC promotes the use of a Mode of Action (MoA) Classification of insecticides and acaricides as the basis for effective and sustainable resistance management. Actives are allocated to specific groups based on their target site. Reviewed and re-issued periodically, the IRAC MoA Classification Scheme provides farmers, growers, advisors, extension staff, consultants and crop protection professionals with a guide to the selection of acaricides and insecticides in resistance management programs. Effective resistance management of this type preserves the utility and diversity of available insecticides and acaricides. A complete list of the different MoA groups is shown in the following pages, followed by a breakdown of MoAs available for Lepidoptera, aphids, whitefly, plant- and leafhoppers, mites and mosquitoes. For further information, please refer to the full IRAC MoA Classification Scheme on the IRAC website (www.irac-online.org).

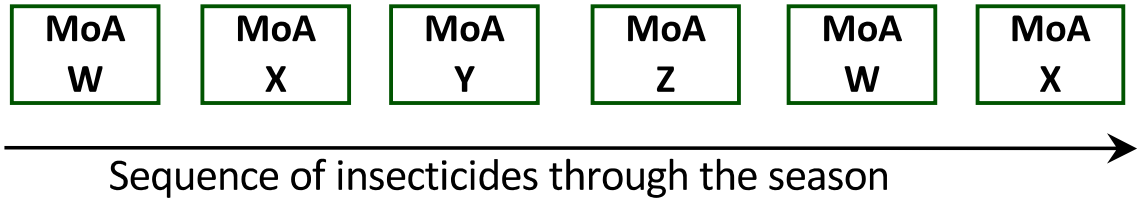
What is Resistance?

Resistance to insecticides may be defined as '*a heritable change in the sensitivity of a pest population that is reflected in the repeated failure of a product to achieve the expected level of control when used according to the label recommendation for that pest species*' (IRAC). Resistance arises through the over-use or misuse of an insecticide or acaricide against a pest species, and results in the Darwinian selection of resistant forms of the pest and the consequent evolution of populations that are resistant to that insecticide or acaricide.

Effective IRM Strategies: Sequences or Alternations of MoA

All effective insecticide resistance management (IRM) strategies seek to minimise the selection of resistance to any one type of insecticide. In practice, alternations, sequences or rotations of compounds from different MoA groups provide sustainable and effective IRM for insect and mite pests. This ensures that selection from compounds in the same MoA group is minimised, and resistance is less likely to evolve.

Example:



Applications are often arranged into MoA spray windows or blocks that are defined by the stage of crop development, together with the biology and phenology of the species of concern. Local expert advice should always be followed with regard to spray windows and timing. Several sprays may be possible within each spray window, but it is generally essential that successive generations of the pest are not treated with compounds from the same MoA group. IRAC also offers specific recommendations for some MoA groups. Metabolic resistance mechanisms may give cross-resistance between MoA groups; where this is known to occur, the above advice should be modified accordingly. For further information on the use of MoA groups and sub-groups, please see the notes at the end of the brochure and in the full MoA Classification Scheme.

IRAC Mode of Action Classification Scheme (Classification Version 10.5)

Targeted Physiology: Nerve & Muscle | Growth & Development | Respiration | Midgut | Unknown or Non-specific

Note: Rotations for resistance management should be based only on the numbered mode of action groups - see table footnotes for details

Main Group/Primary Site of Action	Subgroup, class or Exemplifying active	Active Ingredients
1 Acetylcholinesterase (AChE) inhibitors *See footnotes for further information on use of compounds between sub-groups.*	**1A** Carbamates	Alanycarb, Aldicarb, Bendiocarb, Benfuracarb, Butocarboxim, Butoxycarboxim, Carbaryl, Carbofuran, Carbosulfan, Ethiofencarb, Fenobucarb, Formetanate, Furathiocarb, Isoprocarb, Methiocarb, Methomyl, Metolcarb, Oxamyl, Pirimicarb, Propoxur, Thiodicarb, Thiofanox, Triazamate, Trimethacarb, XMC, Xylylcarb
	1B Organophosphates	Acephate, Azamethiphos, Azinphos-ethyl, Azinphos-methyl, Cadusafos, Chlorethoxyfos, Chlorfenvinphos, Chlormephos, Chlorpyrifos, Chlorpyrifos-methyl, Coumaphos, Cyanophos, Demeton-S-methyl, Diazinon, Dichlorvos/ DDVP, Dicrotophos, Dimethoate, Dimethylvinphos, Disulfoton, EPN, Ethion, Ethoprophos, Famphur, Fenamiphos, Fenitrothion, Fenthion, Fosthiazate, Heptenophos, Imicyafos, Isofenphos, Isopropyl *O*-(methoxyaminothio-phosphoryl) salicylate, Isoxathion, Malathion, Mecarbam, Methamidophos, Methidathion, Mevinphos, Monocrotophos, Naled, Omethoate, Oxydemeton-methyl, Parathion, Parathion-methyl, Phenthoate, Phorate, Phosalone, Phosmet, Phosphamidon, Phoxim, Pirimiphos- methyl, Profenofos, Propetamphos, Prothiofos, Pyraclofos, Pyridaphenthion, Quinalphos, Sulfotep, Tebupirimfos, Temephos, Terbufos, Tetrachlorvinphos, Thiometon, Triazophos, Trichlorfon, Vamidothion
2 GABA-gated chloride channel blockers	**2A** Cyclodiene organochlorines	Chlordane, Endosulfan
	2B Phenylpyrazoles (Fiproles)	Ethiprole, Fipronil

3 Sodium channel modulators *See footnotes for further information on use of compounds between sub-groups.*	**3A** Pyrethroids Pyrethrins	Acrinathrin, Allethrin, d-*cis*-trans Allethrin, d-*trans* Allethrin, Bifenthrin, Bioallethrin, Bioallethrin S-cylclopentenyl, Bioresmethrin, Cycloprothrin, Cyfluthrin, *beta*-Cyfluthrin, Cyhalothrin, *lambda*-Cyhalothrin, *gamma*-Cyhalothrin, Cypermethrin, *alpha*-Cypermethrin, *beta*-Cypermethrin, *theta*-cypermethrin, *zeta*-Cypermethrin, Cyphenothrin [(1*R*)-*trans*- isomers], Deltamethrin, Empenthrin [(*EZ*)- (1*R*)- isomers], Esfenvalerate, Etofenprox, Fenpropathrin, Fenvalerate, Flucythrinate, Flumethrin, *tau*-Fluvalinate, Halfenprox, Imiprothrin, Kadethrin, Permethrin, Phenothrin [(1*R*)-*trans*- isomer], Prallethrin, Pyrethrins (pyrethrum), Resmethrin, Silafluofen, Tefluthrin, Tetramethrin, Tetramethrin [(1*R*)-isomers], Tralomethrin, Transfluthrin
	3B DDT Methoxychlor	DDT Methoxychlor
4 Nicotinic acetylcholine receptor (nAChR) competitive modulators *See footnotes for further information on use of compounds between sub-groups.*	**4A** Neonicotinoids	Acetamiprid, Clothianidin, Dinotefuran, Imidacloprid, Nitenpyram, Thiacloprid, Thiamethoxam
	4B Nicotine	Nicotine
	4C Sulfoximines	Sulfoxaflor
	4D Butenolides	Flupyradifurone
	4E Mesoionics	Triflumezopyrim, Dicloromezotiaz
	4F Pyridylidenes	Flupyrimin
5 Nicotinic acetyl-choline receptor (nAChR) allosteric modulators - Site I	Spinosyns	Spinetoram, Spinosad
6 Glutamate-gated chloride channel (GluCl) allosteric modulators	Avermectins, Milbemycins	Abamectin, Emamectin benzoate, Lepimectin, Milbemectin

Main Group/Primary Site of Action	Subgroup, class or Exemplifying active	Active Ingredients
7 Juvenile hormone mimics	**7A** Juvenile hormone analogues	Hydroprene, Kinoprene, Methoprene
	7B Fenoxycarb	Fenoxycarb
	7C Pyriproxyfen	Pyriproxyfen
8 * Miscellaneous non-specific (multi-site) inhibitors	**8A** Alkyl halides	Methyl bromide and other alkyl halides
	8B Chloropicrin	Chloropicrin
	8C Fluorides	Cryolite (Sodium aluminum fluoride), Sulfuryl fluoride
	8D Borates	Borax, Boric acid, Disodium octaborate, Sodium borate, Sodium metaborate
	8E Tartar emetic	Tartar emetic
	8F Methyl isothiocyanate generators	Dazomet, Metam
9 Chordotonal organ TRPV channel modulators	**9B** Pyridine azomethine derivatives	Pymetrozine, Pyrifluquinazon
	9D Pyropenes	Afidopyropen
10 Mite growth inhibitors affecting CHS1 *10A Sub-grouping information in footnotes*	**10A** Clofentezine Diflovidazin Hexythiazox	Clofentezine, Diflovidazin, Hexythiazox
	10B Etoxazole	Etoxazole

11 Microbial disruptors of insect midgut membranes	***11A*** *Bacillus thuringiensis* and the insecticidal proteins they produce *See footnotes for further sub-grouping information*	*Bacillus thuringiensis* subsp. *israelensis* *Bacillus thuringiensis* subsp. *aizawai* *Bacillus thuringiensis* subsp. *kurstaki* *Bacillus thuringiensis* subsp. *tenebrionis* *Bt* crop proteins: (see footnote) Cry1Ab, Cry1Ac, Cry1Fa, Cry1A.105, Cry2Ab, Vip3A, mCry3A, Cry3Ab, Cry3Bb, Cry34Ab1/Cry35Ab1
	11B *Bacillus sphaericus*	*Bacillus sphaericus*
12 Inhibitors of mitochondrial ATP synthase	**12A** Diafenthiuron	Diafenthiuron
	12B Organotin miticides	Azocyclotin, Cyhexatin, Fenbutatin oxide
	12C Propargite	Propargite
	12D Tetradifon	Tetradifon
13 * Uncouplers of oxidative phosph-orylation via dis-ruption of the proton gradient	Pyrroles Dinitrophenols Sulfluramid	Chlorfenapyr, DNOC, Sulfluramid
14 Nicotinic acetyl-choline receptor (nAChR) channel blockers	Nereistoxin analogues	Bensultap, Cartap hydrochloride, Thiocyclam, Thiosultap-sodium

Main Group/Primary Site of Action	Subgroup, class or Exemplifying active	Active Ingredients
15 Inhibitors of chitin biosynthesis affecting CHS1	Benzoylureas	Bistrifluron, Chlorfluazuron, Diflubenzuron, Flucycloxuron, Flufenoxuron, Hexaflumuron, Lufenuron, Novaluron, Noviflumuron, Teflubenzuron, Triflumuron
16 Inhibitors of chitin biosynthesis, type 1	Buprofezin	Buprofezin
17 Moulting disruptors, Dipteran	Cyromazine	Cyromazine
18 Ecdysone receptor agonists	Diacylhydrazines	Chromafenozide, Halofenozide, Methoxyfenozide, Tebufenozide
19 Octopamine receptor agonists	Amitraz	Amitraz
20 Mitochondrial complex III electron transport inhibitors – Qo site	**20A** Hydramethylnon	Hydramethylnon
	20B Acequinocyl	Acequinocyl
	20C Fluacrypyrim	Fluacrypyrim
	20D Bifenazate	Bifenazate
21 Mitochondrial complex I electron transport inhibitors	**21A** METI acaricides and insecticides	Fenazaquin, Fenpyroximate, Pyridaben, Pyrimidifen, Tebufenpyrad, Tolfenpyrad
	21B Rotenone	Rotenone (Derris)

22 Voltage-dependent sodium channel blockers *See footnotes for further information on sub-grouping*	**22A** Oxadiazines	Indoxacarb
	22B Semicarbazones	Metaflumizone
23 Inhibitors of acetyl CoA carboxylase	Tetronic and Tetramic acid derivatives	Spirodiclofen, Spiromesifen, Spiropidion, Spirotetramat
24 Mitochondrial complex IV electron transport inhibitors	**24A** Phosphides	Aluminium phosphide, Calcium phosphide, Phosphine, Zinc phosphide
	24B Cyanides	Calcium cyanide, Potassium cyanide, Sodium cyanide
25 Mitochondrial complex II electron transport inhibitors *See footnotes for further information on sub-grouping*	**25A** *beta*-Ketonitrile derivatives	Cyenopyrafen, Cyflumetofen
	25B Carboxanilides	Pyflubumide
28 Ryanodine receptor modulators	Diamides	Chlorantraniliprole, Cyantraniliprole, Cyclaniliprole, Flubendiamide, Tetraniliprole
29 Chordotonal organ nicotinamidase inhibitors	Flonicamid	Flonicamid

Main Group/Primary Site of Action	Subgroup, class or Exemplifying active	Active Ingredients
30 GABA-gated channel allosteric modulators	Meta-diamides Isoxazolines	Broflanilide Fluxametamide Isocycloseram
31 Baculoviruses Host-specific occluded pathogenic viruses	Granuloviruses (GVs) Nucleopolyhedroviruses (NPVs)	*Cydia pomonella* GV *Thaumatotibia leucotreta GV* *Anticarsia gemmatalis* MNPV *Heliocoverpa armigera* NPV
32 Nicotinic acetyl-choline receptor (nAChR) allosteric modulators - Site II	GS-omega/kappa HXTX-Hv1a peptide	GS-omega/kappa HXTX-Hv1a peptide
33 Calcium-activated potassium channel (KCa2) modulators	Acynonapyr	Acynonapyr
34 Mitochondrial complex III electron transport inhibitors – Qi site	Flometoquin	Flometoquin
36 Chordotonal organ modulators – undefined target site	Pyridazine pyrazolecarboxamides	Dimpropyridaz

UN Compounds	Azadirachtin	Azadirachtin
	Benzoximate	Benzoximate
	Benzpyrimoxan	Benzpyrimoxan
	Bromopropylate	Bromopropylate
	Dicofol	Dicofol
	Lime sulfur	Lime sulfur
	Mancozeb	Mancozeb
	Oxazosulfyl	Oxazosulfyl
	Pyridalyl	Pyridalyl
	Sulfur	Sulfur
UNB Bacterial agents (non-Bt) *		*Burkholderia spp* *Wolbachia pipientis (Zap)*
UNE Botanical essence including synthetic, extracts and unrefined oils *		*Chenopodium ambrosioides near ambrosioides* extract, Neem oil Fatty acid monoesters with glycerol or propanediol
UNF Fungal agents		*Beauveria bassiana* strains, *Metarhizium brunneum* strain F52, *Paecilomyces fumosoroseus* Apopka strain 97
UNM Non-specific mechanical and physical disruptors *		Diatomaceous earth, Mineral oil
UNP Peptides		

Main Group/Primary Site of Action	Subgroup, class or Exemplifying active	Active Ingredients
UNV * Viral agents (non baculovirus)		

Targeted Physiology: Nerve & Muscle | Growth & Development | Respiration | Midgut | Unknown or Non-specific

The colour scheme in the table associates mode of action into broad categories based on the physiological functions affected, as an aid to understanding symptomology, speed of action and other properties of the insecticides, and not for any resistance management purpose. **Rotations for resistance management should be based only on the numbered mode of action groups.**

Table Notes:

- Inclusion of an insecticidal agent in the classification above does not necessarily signify regulatory approval.
- MoA assignments will usually involve identification of the target protein responsible for the biological effect, although groupings can be made where insecticidal agents share distinctive physiological effects and are structurally related.
- Groups 26 and 27 are unassigned at this time and have therefore been omitted from the table.
- An insecticidal agent with an unknown or controversial MoA or an unknown mode of toxicity will be held in group 'UN' or 'UNB', 'UNE', 'UNF', 'UNM', 'UNP', UNV as applicable until evidence becomes available to enable assignment to a more appropriate MoA class.
- Actives in groups marked with an asterisk are thought not to share a common target site and therefore may be freely rotated with each other unless there is reason to expect cross-resistance. These groups are 8, 13, UN, UNB, UNE, UNF, UNM, UNP and UNV.
- Different baculoviruses that target different insect orders may be used together without compromising their resistance management. Rotation between certain specific baculoviruses may provide resistance management benefits for some pests. Consult product-specific recommendations.

Sub-Groups:

Sub-groups represent distinct chemical classes that are believed to have the same MoA but are different enough in chemical structure or mode of interaction with the target protein that the chance of selection for either metabolic or target-site cross-resistance is reduced compared to close analogs. Sub-groups may also distinguish compounds that are chemically similar but known to bind differently within the target or to have differential selectivity among multiple targets.

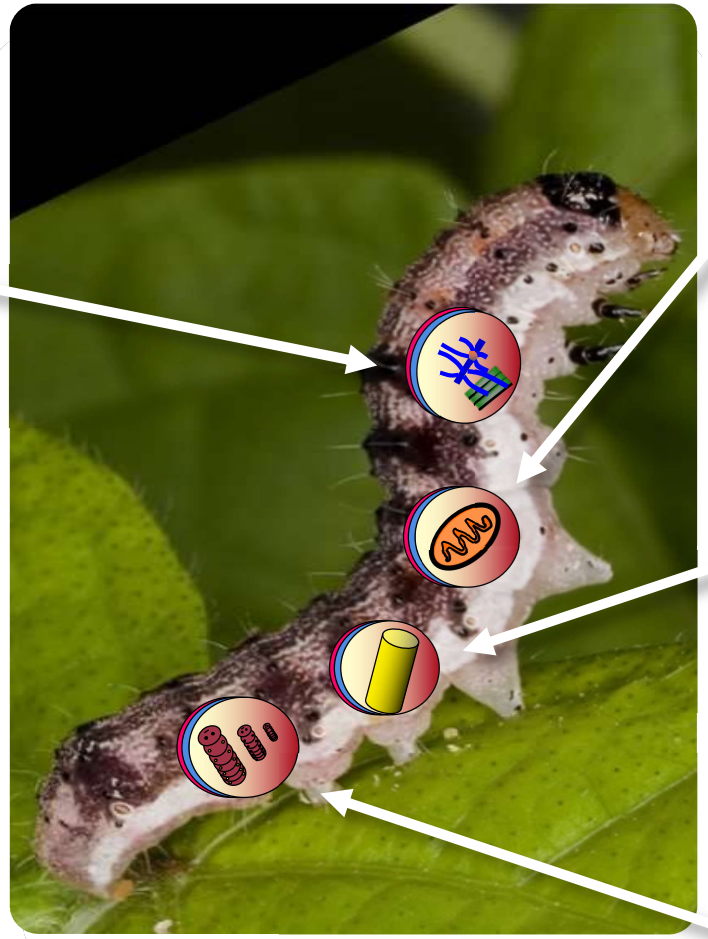
The cross-resistance potential between sub-groups is higher than that between different groups, so rotation between sub-groups should be avoided. In exceptional circumstances (i.e. where effective registered insecticides from other mode of action groups are unavailable) rotation may be considered following consultation with local expert advice and where cross-resistance does not exist. These exceptions should not be considered sustainable resistance management strategies, and alternative options should be sought to maintain pest susceptibility.

Sub-group	Notes
3B	Because DDT is no longer used in agriculture, this is only applicable for the control of human disease vectors such as mosquitoes.
4A, 4B, 4C, 4D, 4E, 4F	Although these compounds are believed to have the same target site, current evidence indicates that the risk of metabolic cross-resistance between subgroups is low.
10A	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.
11A	Different *Bacillus thuringiensis* products that target different insect orders may be used together without compromising their resistance management. Rotation between certain specific *Bacillus thuringiensis* microbial products may provide resistance management benefits for some pests. Consult product-specific recommendations. ***B.t.* Crop Proteins:** Where there are differences among the specific receptors within the midguts of target insects, transgenic crops containing certain combinations of the listed proteins provide resistance management benefits.
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.
22A, 22B	Although these compounds are believed to have the same target site, current evidence indicates that the risk of metabolic cross-resistance between subgroups is low.
25A, 25B	Although these compounds are believed to have the same target site, current evidence indicates that the risk of metabolic cross-resistance between subgroups is low.

Lepidoptera - Mode of Action Classification by Target Site

Nerve & Muscle Targets

1. Acetylcholinesterase (AChE) inhibitors
   1A: Carbamates
   1B: Organophosphates
2. GABA-gated chloride channel blockers
   2A: Cyclodiene Organochlorines
   2B: Phenylpyrazoles
3. Sodium channel modulators
   3A: Pyrethrins, Pyrethroids
4. Nicotinic acetylcholine receptor (nAChR) competitive modulators
   4A: Neonicotinoids
   4F: Pyridylidenes
5. Nicotinic acetylcholine receptor (nAChR) allosteric modulators Site I
   5 Spinosyns
6. Glutamate-gated chloride channel (GluCl) allosteric modulators
   6: Avermectins, Milbemycins
14. Nicotinic acetylcholine receptor (nAChR) channel blockers
    14: Nereistoxin analogues
22. Voltage-dependent sodium channel blockers
    22A: Oxadiazines
    22B: Semicarbazones
28. Ryanodine receptor modulators
    28: Diamides
30. GABA-gated chloride channel allosteric modulators
    30: Meta-diamides, Isoxazolines
32. Nicotinic acetylcholine receptor (nAChR) allosteric modulators Site II
    32: GS-omega/kappa HXTX-HV1a Peptide



Unknown or uncertain MoA

Azadirachtin, Pyridalyl, Beauveria bassiana, *Burkholderia* spp, *Paecilomyces fumosoroseus*

Respiration Targets

13. Uncouplers of oxidative phosphorylation via disruption of the proton gradient
    13: Chlorfenapyr
21. Mitochondrial complex I electron transport inhibitors
    21A: METI acaracides and insecticides (Tolfenpyrad)
34. Mitochondrial complex III electron transport inhibitors – Qi site
    34: Flometoquin

Midgut Targets

11. Microbial disruptors of insect midgut membranes
    11A: Bacillus thuringiensis,
    11B: Bacillus sphaericus
31. Baculoviruses
    31: Host-specific occluded pathogenic viruses Granuloviruses, Nucleopolyhedroviruses

Growth & Development Targets

7. Juvenile hormone mimics
   7A: Juvenile hormone analogues (Hydroprene)
   7B: Fenoxycarb
15. Inhibitors of chitin biosynthesis affecting CHS1
    15: Benzoylureas
18. Ecdysone receptor agonists
    18: Diacylhydrazines

Nerve & Muscle Targets

1. Acetylcholinesterase (AChE) inhibitors
   1A: Carbamates
   1B: Organophosphates
2. GABA-gated chloride channel blockers
   2A: Cyclodiene Organochlorines
   2B: Phenylpyrazoles
3. Sodium channel modulators
   3A: Pyrethrins, Pyrethroids
4. Nicotinic acetylcholine receptor (nAChR) competitive modulators
   4A: Neonicotinoids
   4C: Sulfoximines
   4D: Butenolides
   4E: Mesoionics
   4F: Pyridylidenes

9. Chordotonal organ TRPV channel modulators
   9B: Pyridine azomethine derivatives
   9D: Pyropenes

22. Voltage-dependent sodium channel blockers
   22A: Oxadiazines

28. Ryanodine receptor modulators
   28: Diamides (Cyantraniliprole)

29. Chordotonal organ nicotinamidase inhibitors
   29: Flonicamid

30. GABA-gated chloride channel allosteric modulators
   30: Isoxazolines

32. Nicotinic acetylcholine receptor (nAChR) allosteric modulators Site II
   32: GS-omega/kappa HXTX-HV1a Peptide

36. Chordotonal modulators – undefined target site
   36: Pyridazine pyrazolecarboxamides

Aphids, Whiteflies, Planthoppers and Leafhoppers - Mode of Action Classification by Target Site



MoA Group	Aphids	Whiteflies	Planthoppers Leafhoppers
1A	X	X	X
1B	X	X	X
2A	X	X	X
2B			X
3A	X	X	X
4A	X	X	X
4C	X	X	X
4D	X	X	X
4E			X
4F			X
7A	X	X	
7C		X	
9B	X	X	X
9D	X	X	X
12A	X	X	
15		X	
16		X	X
21A		X	
22A			X
23	X	X	
28	X	X	X
29	X	X	X
30		X	
32	X	X	
34		X	
36	X	X	X

Respiration Targets

12. Inhibitors of mitochondrial ATP synthesis
   12A: Difenthiuron
21. Mitochondrial complex I electron transport inhibitors
   21A: METI acaracides and insecticides (Pyridaben, Tolfenpyrad)
34. Mitochondrial complex III electron transport inhibitors – Qi site
   34: Flometoquin

Growth & Development Targets

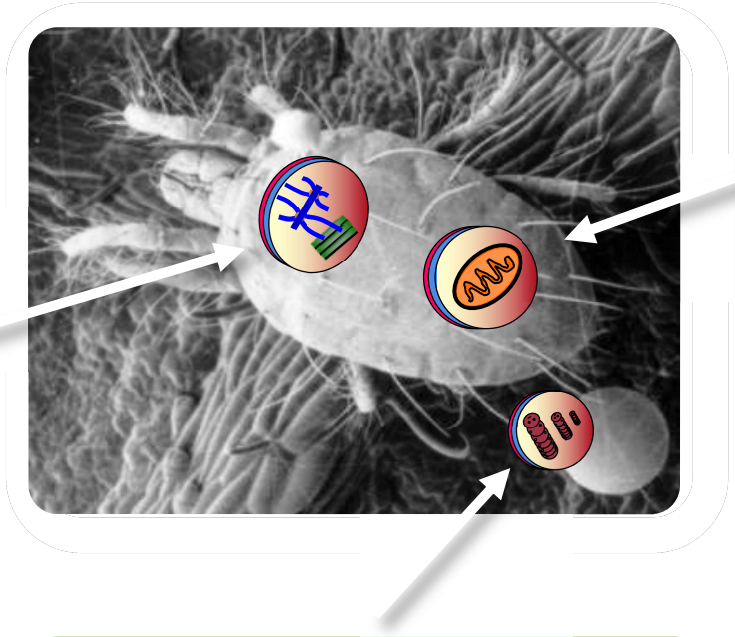
7. Juvenile hormone mimics
   7A: Kinoprene
   7C: Pyriproxyfen
15. Inhibitors of chitin biosynthesis, affecting CHS1
   15: Benzoylureas
16. Inhibitors of chitin biosynthesis, type 1
   16: Buprofezin
23. Inhibitors of acetyl CoA carboxylase
   23: Tetronic & Tetramic acid derivatives

The table lists the main mode of action groups for the control of aphids, whiteflies and hoppers. However, the availability may differ regionally due to registration status.

Mites - Mode of Action Classification by Target Site

Nerve & Muscle Targets

1. Acetylcholinesterase (AChE) inhibitors
   1A: Carbamates
   1B: Organophosphates
2. GABA-gated chloride channel blockers
   2A: Cyclodiene Organochlorines
3. Sodium channel modulators
   3A: Pyrethrins, Pyrethroids
5. Nicotinic acetylcholine receptor (nAChR) allosteric modulators – site I
   5: Spinosyns
6. Glutamate-gated chloride channel (GluCl) allosteric modulators
   6: Avermectins, Milbemycins
19. Octopamine receptor agonists
    19: Amitraz
32. Nicotinic acetylcholine receptor (nAChR) allosteric modulators Site II
    32: GS-omega/kappa HXTX-HV1a Peptide
30. GABA-gated chloride channel allosteric modulators
    30: Isoxazolines
33. Calcium-activated potassium channel (KCa2) modulators
    33: Acynonapyr



Growth & Development Targets

10. Mite growth inhibitors affecting CHS1
    10A: Clofentezine, Diflovidazin Hexythiazox
    10B: Etoxazole
15. Inhibitors of chitin biosynthesis affecting CHS1
    15: Benzoylureas
23. Inhibitors of acetyl CoA carboxylase
    23: Tetronic & Tetramic acid derivatives

Respiration Targets

12. Inhibitors of mitochondrial ATP synthesis
    12A: Difenthiuron
    12B: Organotin miticides
    12C: Propargite
13. Uncouplers of oxidative phosphorylation via disruption of the proton gradient
    13: Chlorfenapyr
20. Mitochondrial complex III electron transport inhibitors – Qo site
    20B: Acequinocyl
    20C: Fluacrypyrim
    20D: Bifenazate
21. Mitochondrial complex I electron transport inhibitors
    21A: METI acaricides
25. Mitochondrial complex II electron transport inhibitors
    25A: Cyenopyrafen, Cyflumetofen
    25B: Pyflubumide
34. Mitochondrial complex III electron transport inhibitors – Qi site
    34: Flometoquin

Unknown or uncertain MoA

Benzoximate, Chinomethionat, Dicofol

Mosquitoes - Mode of Action Classification by Target Site

Nerve & Muscle Targets (Larvae)

1. Acetylcholinesterase (AChE) inhibitors
   1B: Organophosphates
5. Nicotinic acetylcholine receptor (nAChR) allosteric modulators – site I
   5: Spinosyns

Growth & Development Targets (Larvae)

7. Juvenile hormone mimics
   7A: Juvenile hormone analogues
   7C: Pyriproxyfen
15. Inhibitors of chitin biosynthesis, affecting CHS1
   15: Benzoylureas

Midgut Targets (Larvae)

11. Microbial disruptors of insect midgut membranes
   11A: Bacillus thuringiensis,
   11B: Bacillus sphaericus

Nerve & Muscle Targets (Adults)

1. Acetylcholinesterase (AChE) inhibitors
   1A: Carbamates
   1B: Organophosphates
3. Sodium channel modulators
   3A: Pyrethrins, Pyrethroids
4. Nicotinic acetylcholine receptor (nAChR) competitive modulators
   4A: Neonicotinoids
   4D: Butenolides

Growth & Development Targets (Adults)

7. Juvenile hormone mimics
   7C: Pyriproxyfen

Respiration Targets (Adults)

13. Uncouplers of oxidative phosphorylation via disruption of the proton gradient
   13: Chlorfenapyr

Active Ingredients (Alphabetical Order) with MoA Classification: INSECTICIDES / ACARICIDES

Abamectin	6
Acephate	1B
Acequinocyl	20B
Acetamiprid	4A
Acrinathrin	3A
Acynonapyr	33
Afidopyropen	9D
Alanycarb	1A
Aldicarb	1A
Allethrin	3A
alpha-Cypermethrin	3A
Aluminium phosphide	24A
Amitraz	19
Anticarsia gemmatalis MNPV	31
Azadirachtin	UN
Azamethiphos	1B
Azinphos-ethyl	1B
Azinphos-methyl	1B
Azocyclotin	12B
Bacillus thuringiensis	11A
Bacillus sphaericus	11B
Beauveria bassiana strains	UNF
Bendiocarb	1A
Benfuracarb	1A
Bensultap	14
Benzoximate	UN
Benzpyrimoxan	UN
beta-Cyfluthrin	3A
beta-Cypermethrin	3A
Bifenazate	20D

Bifenthrin	3A
Bioallethrin	3A
Bioallethrin S-cyclopentenyl isomer	3A
Bioresmethrin	3A
Bistrifluron	15
Borax	8D
Boric acid	8D
Broflanilide	30
Bromopropylate	UN
Buprofezin	16
Burkholderia spp.	UNB
Butocarboxim	1A
Cadusafos	1B
Calcium cyanide	24B
Calcium phosphide	24A
Carbaryl	1A
Carbofuran	1A
Carbosulfan	1A
Cartap hydrochloride	14
Chenopodium ambrosioides near ambrosioides extract	UNE
Chinomethionat	UN
Chlorantraniliprole	28
Chlordane	2A
Chlorethoxyfos	1B
Chlorfenapyr	13
Chlorfenvinphos	1B
Chlorfluazuron	15
Chlormephos	1B

Chloropicrin	8B
Chlorpyrifos	1B
Chlorpyrifos-methyl	1B
Chromafenozide	18
Clofentezine	10A
Clothianidin	4A
Coumaphos	1B
Cryolite	8C
Cyanide	24B
Cyanophos	1B
Cyantraniliprole	28
Cycloprothrin	3A
Cydia pomonella GV	31
Cyenopyrafen	25A
Cyflumetofen	25A
Cyfluthrin	3A
Cyhalothrin	3A
Cyhexatin	12B
Cypermethrin	3A
Cyphenothrin (1*R*)-*trans*-isomers]	3A
Cyromazine	17
d-*cis-trans* Allethrin	3A
Dazomet	8F
DDT	3B
Deltamethrin	3A
Demeton-S-methyl	1B
Diafenthiuron	12A
Diatomaceous earth	UNM
Diazinon	1B
Dichlorvos/ DDVP	1B

Dicofol	UN
Dicrotophos	1B
Dicloromezotiaz	4E
Diflovidazin	10A
Diflubenzuron	15
Dimethoate	1B
Dimethylvinphos	1B
Dimpropyridaz	36
Dinotefuran	4A
Disodium octaborate	8D
Disulfoton	1B
DNOC	13
d-*trans* Allethrin	3A
Emamectin benzoate	6
Empenthrin [(EZ)-(1*R*)-isomers]	3A
Endosulfan	2A
EPN	1B
Esfenvalerate	3A
Ethiofencarb	1A
Ethion	1B
Ethiprole	2B
Ethoprophos	1B
Etofenprox	3A
Etoxazole	10B
Famphur	1B
Fatty acid monoesters with glycerol or propanediol	UNE
Fenamiphos	1B

Active Ingredients (Alphabetical Order) with MoA Classification: INSECTICIDES / ACARICIDES

Fenazaquin	21A
Fenbutatin oxide	12B
Fenitrothion	1B
Fenobucarb	1A
Fenoxycarb	7B
Fenpropathrin	3A
Fenpyroximate	21A
Fenthion	1B
Fenvalerate	3A
Fipronil	2B
Flonicamid	29
Flometoquin	34
Fluacrypyrim	20C
Flubendimide	28
Flucycloxuron	15
Flucythrinate	3A
Flufenoxuron	15
Flumethrin	3A
Flupyradifurone	4D
Fluxametamide	30
Flupyrimin	4F
gamma-Cyhalothrin	3A
GS-omega/kappa HXTX -Hv1a	32
Halfenprox	3A
Halofenozide	18
Heliocoverpa armigera NPV	31
Heptenophos	1B
Hexaflumuron	15
Hexythiazox	10A

Hydramethylnon	20A
Hydroprene	7A
Imicyafos	1B
Imidacloprid	4A
Imiprothrin	3A
Indoxacarb	22A
Isocylcoseram	30
Isofenphos	1B
Isoprocarb	1A
Isopropyl O- (methoxy -aminothio-phosphoryl) salicylate	1B
Isoxathion	1B
Kadethrin	3A
Kinoprene	7A
lambda-Cyhalothrin	3A
Lepimectin	6
Lime sulfur	UN
Lufenuron	15
Malathion	1B
Mancozeb	UN
Mecarbam	1B
Metaflumizone	22B
Metam	8F
Metarhizium brunneun strain F52	UNF
Methamidophos	1B
Methidathion	1B
Methiocarb	1A
Methomyl	1A

Methoprene	7A
Methoxychlor	3B
Methoxyfenozide	18
Methyl bromide	8A
Metolcarb	1A
Mevinphos	1B
Milbemectin	6
Mineral Oil	UNM
Monocrotophos	1B
Naled	1B
Neem Oil	UNE
Nicotine	4B
Nitenpyram	4A
Novaluron	15
Noviflumuron	15
Omethoate	1B
Oxamyl	1A
Oxazosulfyl	UN
Oxydemeton-methyl	1B
Paecilomyces fumosoroseus Apopka strain 97	UNF
Parathion	1B
Parathion-methyl	1B
Permethrin	3A
Phenothrin [(1*R*)-*trans*- isomer]	3A
Phenthoate	1B
Phorate	1B
Phosalone	1B

Phosmet	1B
Phosphamidon	1B
Phosphine	24A
Phoxim	1B
Pirimicarb	1A
Pirimiphos- methyl	1B
Potassium cyanide	24B
Prallethrin	3A
Profenofos	1B
Propargite	12C
Propetamphos	1B
Propoxur	1A
Prothiofos	1B
Pyflubumide	25B
Pymetrozine	9B
Pyraclofos	1B
Pyrethrins (pyrethrum)	3A
Pyridaben	21A
Pyridalyl	UN
Pyridaphenthion	1B
Pyrifluquinazon	9B
Pyrimidifen	21A
Pyriproxyfen	7C
Quinalphos	1B
Resmethrin	3A
Rotenone (Derris)	21B
Silafluofen	3A
Sodium borate	8D
Sodium cyanide	24B

Active Ingredients (Alphabetical Order) with MoA Classification: INSECTICIDES / ACARICIDES

Sodium metaborate	8D
Spinetoram	5
Spinosad	5
Spirodiclofen	23
Spiromesifen	23
Spiropidion	23
Spirotetramat	23
Sulfotep	1B
Sulfoxaflor	4C
Sulfur	UN
Sulfuramid	13
Sulfuryl fluoride	8C
Tartar emetic	8E
tau-Fluvalinate	3A

Tebufenozide	18
Tebufenpyrad	21A
Tebupirimfos	1B
Teflubenzuron	15
Tefluthrin	3A
Temephos	1B
Terbufos	1B
Tetrachlorvinphos	1B
Tetradifon	12D
Tetramethrin	3A
Tetramethrin [(1*R*)-isomers]	3A
Tetraniliprole	28

Thaumatotibia leucotreta GV	31
theta-cypermethrin	3A
Thiacloprid	4A
Thiamethoxam	4A
Thiocyclam	14
Thiodicarb	1A
Thiofanox	1A
Thiometon	1B
Thiosultap-sodium	14
Tolfenpyrad	21A
Tralomethrin	3A
Transfluthrin	3A

Triazamate	1A
Triazophos	1B
Trichlorfon	1B
Triflumuron	15
Triflumezopyrim	4E
Trimethacarb	1A
Vamidothion	1B
Wolbachia pipientis (Zap)	UNB
XMC	1A
Xylylcarb	1A
zeta-Cypermethrin	3A
Zinc phosphide	24A

Nematicide MoA Classification

This is the first edition to include the newly created Nematicide Mode of Action Classification Scheme. The development of this scheme enables visibility of the modes of action available to control plant-parasitic nematodes. Additionally, the numbering scheme allows clarity of product labelling, supporting the principles of rotation of mode-of-action for resistance management. See the IRAC International website for further information (https://irac-online.org/teams/nematodes/) – including a poster and a statement on nematicide resistance risk.

Nematicide Mode of Action Classification Scheme (Version 2.1)

Targeted Physiology: Nerve & Muscle | Growth & Development | Respiration | Unknown or Non-specific

Main Group/Primary Site of Action	Class or Exemplifying active	Active Ingredients	IRAC/FRAC Group
N-1 Acetylcholinesterase (AChE) inhibitors	A Carbamates	Aldicarb, Benfuracarb, Carbofuran, Carbosulfan, Oxamyl	IRAC: 1A
	B Organophosphates	Cadusafos, Ethoprophos, Fenamiphos, Fosthiazate, Imicyafos, Phorate, Terbufos	IRAC: 1B
N-2 Glutamate-gated chloride channel (GluCl) allosteric modulators	Avermectins	Abamectin	IRAC: 6
N-3 Mitochondrial complex II electron transport inhibitors. Succinate -coenzyme Q reductase.	Pyridinyl-ethyl benzamides; Phenethyl pyridineamides	Fluopyram, Cyclobutrifluram	FRAC: 7
N-4 Inhibitors of acetyl CoA carboxylase	Tetronic and Tetramic acid derivatives	Spirotetramat	IRAC: 23
N-UN Compounds with unknown Mode of Action		Furfural, Fluensulfone, Fluazaindolizine, Iprodione	
N-UNX Presumed multi-site inhibitors		1,2-Dibromo-3-chloropropane (DBCP), 1,3-Dichloropropene, Allyl isothiocyanate, Carbon Disulfide, Chloropicrin, Dazomet, Dimethyl Disulfide (DMDS), Ethylene Dibromide, Metam Potassium, Metam Sodium, Methyl Bromide, Methyl Iodide (Iodomethane), Sodium tetrathiocarbonate	IRAC: 8

N-UNB Bacterial agents (non-Bt) *		*Bacillus spp.*, *Burkholderia spp.*, *Pasteuria spp.*, *Pseudomonas spp.*, *Streptomyces spp.*	
N-UNF Fungal agents *		*Actinomyces spp.*, *Arthrobotrys spp.*, *Aspergillus spp.*, *Muscodor spp.*, *Myrothecium spp.*, *Pochonia spp.*, *Purpureocillium lilacinum* (syn. *Paecilomyces lilacinus*), *Trichoderma spp.*	
N-UNE Botanical or animal derived agents including synthetic, extracts and un-refined oils		Azadirachtin, Camellia Seed Cake, Essential oils, Garlic extract, Pongamia oil, *Quillaja saponaria* extract, Chitin, Terpenes	

* Only species with proven nematicidal activity

Nematodes - Mode of Action Classification by Target Site

Nerve & Muscle Targets

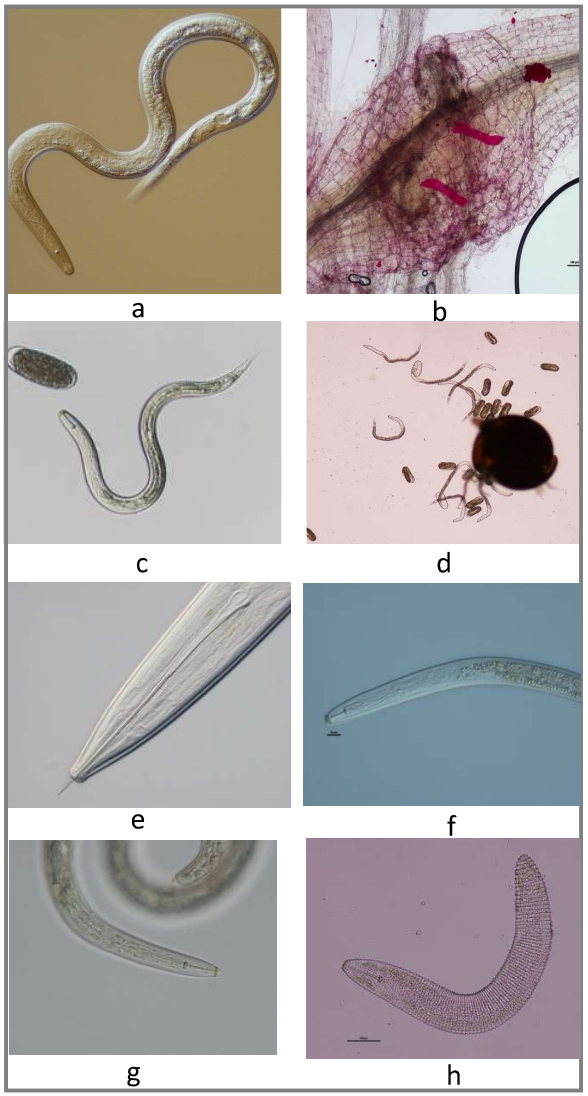
N-1 Acetylcholinesterase (AChE) inhibitors
1A: Carbamates
1B: Organophosphates

N-2 Glutamate-gated chloride channel (GluCl) allosteric modulators
Avermectins

Respiration Targets

N-3 Mitochondrial complex II electron transport inhibitors. Succinate-coenzyme Q reductase.
Fluopyram, Cyclobutrifluram

a – Root-knot nematode J2, b – Root-knot nematode J3's in root galls, c – SCN J2 and egg, d – PCN cyst, eggs and J2's, e – Dagger nematode, f – Root lesion nematode, g – Spiral nematode, h – Ring nematode



Growth & Development Targets

N-4 Inhibitors of acetyl CoA carboxylase
Tetronic & Tetramic acid derivatives

Unknown or uncertain MoA

N-UN Compounds with unknown Mode of Action

N-UNX Presumed multi-site inhibitors

N-UNB Bacterial agents (non-Bt)

N-UNF Fungal agents

N-UNE Botanical or animal derived agents including synthetic, extracts and unrefined oils

Active Ingredients (Alphabetical Order) with MoA Classification: NEMATICIDES

Benfuracarb	N-1A
1,2-Dibromo-3-chloropropane (DBCP)	N-UNX
1,3-Dichloropropene	N-UNX
Abamectin	N-2
Actinomyces spp.	N-UNF
Aldicarb	N-1A
Allyl isothiocyanate	N-UNX
Arthrobotrys spp.	N-UNF
Aspergillus spp.	N-UNF
Azadirachtin	N-UNE
Bacillus spp.	N-UNB
Burkholderia spp.	N-UNB
Cadusafos	N-1B
Camellia Seed Cake	N-UNE
Carbofuran	N-1A

Carbon Disulfide	N-UNX
Carbosulfan	N-1A
Chloropicrin	N-UNX
Cyclobutrifluram	N-3
Dazomet	N-UNX
Dimethyl Disulfide (DMDS)	N-UNX
Essential oils	N-UNE
Ethoprophos	N-1B
Ethylene Dibromide	N-UNX
Fenamiphos	N-1B
Fluazaindolizine	N-UN
Fluensulfone	N-UN
Fluopyram	N-3
Fosthiazate	N-1B
Furfural	N-UN

Garlic extract	N-UNE
Imicyafos	N-1B
Iprodione	N-UN
Metam Potassium	N-UNX
Metam Sodium	N-UNX
Methyl Bromide	N-UNX
Methyl Iodide (Iodomethane)	N-UNX
Muscodor spp.	N-UNF
Myrothecium spp.	N-UNF
Oxamyl	N-1A
Purpureocillium lilacinum (syn. Paecilomyces lilacinus)	N-UNF
Pasteuria spp.	N-UNB
Phorate	N-1B

Pochonia spp.	N-UNF
Pongamia oil	N-UNE
Pseudomonas spp.	N-UNB
Quillaja saponaria extract	N-UNE
Chitin	N-UNE
Sodium tetrathiocarbonate	N-UNX
Spirotetramat	N-4
Streptomyces spp.	N-UNB
Terbufos	N-1B
Terpenes	N-UNE
Trichoderma spp.	N-UNF

Table Notes:

- Inclusion of a nematode control agent in the table above does not necessarily signify regulatory approval.
- The list is not aimed at being comprehensive but gives key representatives by group.
- N-UNB and N-UNF includes only species with proven nematicidal activity.

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Further information is available from the IRAC website at:
www.irac-online.org

or by email at:
enquiries@irac-online.org

IRAC Insecticide/Acaricide
Mode of Action Classification

IRAC Nematicide Mode of
Action Classification

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Based on Insecticide MoA Classification Scheme, Version 10.3 and
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IRAC

Insecticide Resistance Action Committee

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