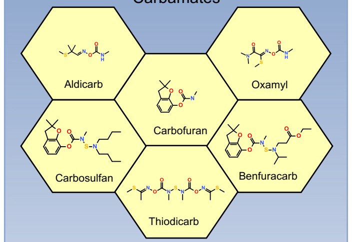
IRAC

Nematode Working Group

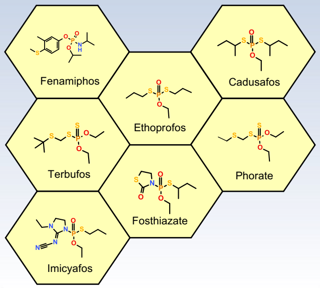
Nematicide Mode of Action Classification

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

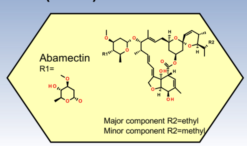
N-1A Carbamates



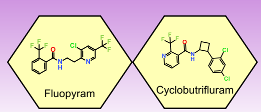
N-1B Organophosphates



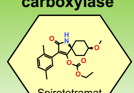
Group N-2: Glutamate-gated chloride channel (GluCl) allosteric modulators



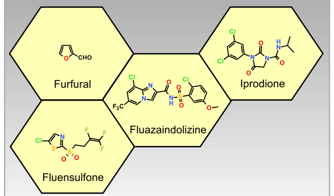
Group N-3: Mitochondrial complex II electron transport inhibitors. Succinate-coenzyme Q reductase



Group N-4: Lipid synthesis, growth regulation. Inhibitors of acetyl CoA carboxylase

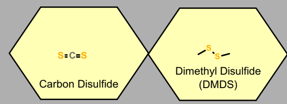


Group N-UN: Unknown

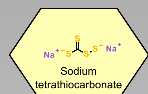


Group N-UNX: Presumed multi-site inhibitor

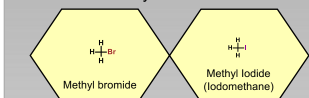
Volatile sulphur generator



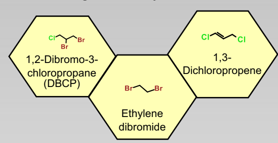
Carbon disulfide liberator



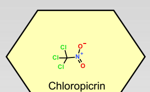
Alkyl halides



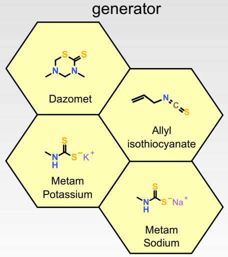
Halogenated hydrocarbon



Chloropicrin



Methyl isothiocyanate generator



Nematicide resistance risk statement

There are no substantiated examples in the scientific literature from the last century documenting cases of significant tolerance shifts or suspected resistance leading to failure of commercial agricultural nematicides against plant parasitic nematodes (PPN) under natural field conditions. Instances of these phenomena occurring have only been reported for some products under controlled laboratory conditions(1). Product usage approaches and nematode ecology also reduce the potential that sustained selection pressure on PPN populations occurs under field conditions. Thus overall, it can be considered that the development of resistance in PPN species to nematicides under natural field conditions is currently unconfirmed, theoretically unlikely, and poses a low risk.

The reasons underpinning this conclusion are explained below.

Unlike other plant protection products (e.g. herbicides, fungicides and insecticides), several factors limit the potential for nematicides to create high and sustained selection pressure on plant parasitic nematode (PPN) populations under field conditions.
These factors include the:

- relatively low frequency of nematicide use in a single cropping cycle, as a proportion of the duration of the crop and the number of PPN generations. Typically, one nematicide application is made per growing season, and occasionally more in long season or perennial crops.
- primary application methods used for nematicides in the field often target a small soil volume (e.g. crop root zone, crop beds or rows, or seed only), leaving untreated areas and host plants (weeds) that can act as refuge or source of recolonization for unexposed PPNs;
- various nematode species have life stages (dormant or living) in host plants (e.g. crop or weeds) that may remain in the field and not be exposed to or affected by nematicide treatments. It is noteworthy to mention that very few nematicides are effective systemically in the plant against nematodes;
- complexity of the soil environment and chemical interactions with nematicides frequently reduces product persistence, mobility and/or bioavailability, thus minimizing the likelihood of a chemical product to reach a high percentage of the plant parasitic nematode population present in the field, e.g. at different soil depths or distances from the point of application, or causing exposure to multiple generations;
- large diversity of naturally occurring organisms that may attack surviving life-stages of PPNs in soil, reducing the overall selection pressure from a single nematicide application;

Plant parasitic nematodes occur in a variety of pressures (soil population density levels) under field conditions. In some countries, and in some species, local threshold levels may be available to assess the risk of economic crop loss. Nematode management programs should be used in cases where populations of PPNs are deemed high or very high, employing multiple tactics to provide effective control and population reduction. These programs may include cultural practices, e.g. crop rotations or fallow periods, solarization, nematode resistant or tolerant varieties and the application of nematicides. In cropping systems which require multiple nematicide applications within one crop cycle or on the same field over several cycles, rotation to a nematicide with a different mode of action is recommended to reduce the risk of sustained selection pressure on PPN populations.

Nematicidal products with fungicidal or insecticidal activity require additional resistance management considerations and labelling according to FRAC or IRAC guidelines.

Reduced performance of chemical nematicides can be caused by the phenomenon of Enhanced Microbial Biodegradation (EMB)(2). This is well documented in the scientific literature and EMB should not be confused with resistance development in plant parasitic nematodes. EMB affects the level of product availability and duration of exposure of PPNs to the product, thus reducing the apparent efficacy of a nematicide application. Rotation of nematicides from different chemical classes, as well as employing other control methods such as resistant varieties and cultural methods (e.g. crop rotations) should be considered.

(1) Tolerance shifts or resistance development in PPNs under laboratory conditions:
Although few cases have been reported, continuous exposure to sub-lethal levels of a single nematicide or mode of action may lead to the development of resistant populations under laboratory conditions. This however cannot be extrapolated to field conditions.
(2) Enhanced microbial biodegradation (EMB):
Repeated or frequent use of the same chemical nematicide in the same field soil may lead to an apparent reduction in PPN control through enhanced microbial biodegradation (EMB) of the product. EMB is the result of adaptation and increase of microbial populations that break down a particular product, therefore changing the amount of product available and/or duration of exposure of PPN's. The microbes responsible for EMD in soil may be different for different chemical classes or products, thus rotation of different nematicide types, or a reduction in the frequency of applications may decrease the likelihood of EMB occurrence.

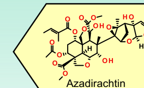
Group N-UNB: Bacterium (Only major representatives of the groups are shown)

- *Burkholderia spp. e.g. rinojensis A396*
- *Bacillus spp. e.g. firmus, licheniformis, amyloliquefaciens, subtilis etc.*
- *Streptomyces spp. e.g. lydicus, dicklowii, albogriseolus*
- *Pasteuria spp. e.g. penetrans, Nishizawae, strain SYM00257*
- *Pseudomonas spp. e.g. chlororaphis, fluorescens, oryzihabitans strain SYM23945*

Group N-UNF: Fungus (Only major representatives of the groups are shown)

- *Arthrobotrys spp. e.g. oligospora*
- *Muscodor spp. e.g. albus*
- *Pochonia spp. e.g. chlamydosporia*
- *Myrothecium spp. e.g. verrucaria*
- *Paecilomyces spp. e.g. lilacinus (Purpureocillium lilacinum), carneus, fumosoroseus*
- *Actinomyces spp. e.g. streptococcus*
- *Trichoderma spp. e.g. harzianum, virens, atroviride, viride*
- *Aspergillus spp. e.g. niger*

Group N-UNE: Botanical/animal derivates (Only major representatives of the groups are shown)



- Camellia Seed Cake
- Garlic extract
- Terpenes, e.g. Carvacrol
- Pongamia oil
- *Quillaja saponaria extract*
- Essential oils
- Chitin

Poster Notes:

- In some cases, only representative actives are shown.
- Please visit www.irac-online.org for the complete IRAC classification.
- While CropLife International and IRAC make every effort to present accurate and reliable information, they do not guarantee the accuracy, completeness, efficacy, timeliness, or correct sequencing of such information. Inclusion of active ingredients on the IRAC Code Lists is based on scientific evaluation of their modes of action; it does not provide any kind of testimonial for the use of a product or a judgment on efficacy. CropLife International and IRAC are not responsible for, and expressly disclaim all liability for, damages of any kind arising out of use, reference to, or reliance on information provided. Listing of chemical classes or modes of action must not be interpreted as approval for use of a compound in a given country. Prior to implementation, each user must determine the current registration status in the country of use and strictly adhere to the uses and instructions approved in that country.

Colour Key

The colour scheme provides a key to targeted physiology and not for resistance management purpose. Rotations for resistance management should be based only on the numbered MoA groups

- Nerve and muscle (Carbamates, Organophosphates and Avermectins)
- Pyridinylmethyl-benzamides
- Tetronic and Tetramic acid derivatives
- Unknown
- Biologicals

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Colour key:

Nerve and muscle (Carbamates, Organophosphates and Avermectins)	Unknown
Pyridinylmethyl-benzamides	Biologicals
Tetronic and Tetramic acid derivatives	