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Role of Nematicides in Plant Parasitic Nematode Management

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SUMMARY

The nematodes cause a range of diseases individually or causes disease complexes along with pathogenic bacteria and fungi. A nematicide is any agent lethal to nematodes. A wide range of nematicides are available to control them right from chemicals to biochemicals. The oldest classification of nematodes was based on mode of action as fumigants and non-fumigants. Nematicides classification based on mode of action by IRAC (Insecticide Resistance Action Committee) is widely adapted. Based on mechanism of action they are classified as respiration inhibitors, neurotoxic and steroid metabolism inhibitors.

INTRODUCTION

Nematodes are nonsegmented, bilaterally symmetric worm-like invertebrates that possess a body cavity and a complete digestive system but lack respiratory and circulatory systems. A nematicide is any agent lethal to nematodes. A nematistat or nemastat is chemical, situation, or phenomenon which holds a nematode population in equilibrium, but this term is frequently used to refer to sublethal dosages of nematicides which disrupt nematode behaviour.

Some diseases caused by nematodes:

Nematode	Crop	Disease
Anguina triticii	Wheat	Tundu disease
Aphelenchoides ritzembosi	Strawberry	Cauliflower disease
Bursaphelenchus xylophilus	Black pine	Pine wilt
Cacopaurus pestis	Walnut	Dieback of walnut
Ditylenchus angustus	Rice	Ufra disease
Ditylenchus destructor	Potato	Tuber dry rot of potato
Heterodera avenae	Wheat & barley	Molya disease
Meloidogyne spp.	Vegetables and other crops	Root knot disease

IRAC Nematicide mode of action classification:

1.Group N-1: Acetylcholinesterase (AChE) inhibitors:

a) N-1A Carbamates: Aldicarb, oxamyl, carbofuran, carbosulfan, benfuracarb thiodicarb.

b) N-1B Organophosphates: Fenamiphos, Cadusafos, Ethoprofos, Phorate, Terbufos, Fosthiazate, Imicyafos.

2. Group N-2: Glutamate-gated chloride channel (GluCl) allosteric modulators: Abamectin, Emamectin benzoate

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

4. Group N-4: Lipid synthesis, growth regulation. Inhibitors of acetyl CoA carboxylase:
They are tetroic and tetramic acid derivatives: Spirotetramat

5. Group N-UN: Unknown: Furfural, Fluazaindolizine, Iprodione, Fluensulfone, Tioxazafen

6. Group N-UNX: Presumed multi-site inhibitor

a) Volatile sulphur generator: Carbon disulfide, Dimethyl disulfide (DMDS)

b) Carbon disulfide liberator: Sodium tetrathiocarbonate

c) Alkyl halides: Methyl bromide Methyl Iodide (Iodomethane)

d) Halogenated hydrocarbon: 1,2-Dibromo-3chloropropane (DBCP), Dichloropropene

e) Chloropicrin: Chloropicrin

f) Methyl isothiocyanate generator: Dazomet, Allyl isothiocyanate, Metam Potassium, Metam Sodium.

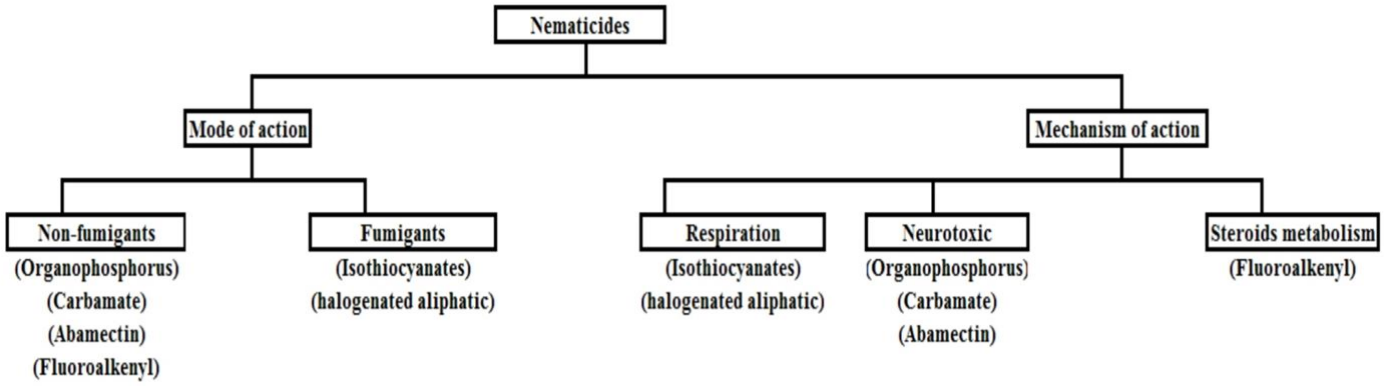
7. Group N-UNB: Bacterium:

Bacillus spp. **e.g.** *firmus, licheniformis, amyloliquefaciens, subtilis etc*

Burkholderia spp. **e.g**. *rinojensis A396*

Pasteuria spp. ***e.g****. penetrans, nishizawae*
Streptomyces spp. **e.g**. *lydicus, dicklowii, albogriseolus*
Pseudomonas spp. **e.g**. *chlororaphis, fluorescens*
8. Group N-UNF: Fungus:
*Arthrobotrys spp***. e.g**. *oligospora*
*Pochonia spp***. e.g**. *chlamydosporia*
Trichoderma spp. **e.g.** *harzianum, virens, atroviride, viride*
*Muscodor spp***. e.g.** *albus*
*Paecilomyces spp***. e.g.** *lilacinus (Purpureocillium lilacinum), carneus, fumosoroseus*
9. Group N-UNE: Botanical/animal derivates:
Azadirachtin, Camellia Seed Cake, Garlic extract, Pongamia oil, *Quillaja saponaria* extract
Terpenes, **e.g.** Carvacrol

Other classification:



1. Fumigants: Fumigant nematicides are generally chemicals with high volatility. Several general-purpose fumigants give excellent control of nematodes in soil.
MOA: Broad spectrum fumigant nematicides penetrate the body wall of the nematode directly and do not have to be eaten to be effective. Once getting inside the nematode's body cavity, different internal organs are affected since they are bathed by body fluids containing the nematicide.
Examples:

Chemical name	Trade name	Formulation
Methyl bromide	Dowfume	Gas
1,3 dichloropropene	Telone/DD-95	Liquid
Ethylene dibromide	Dowfume W-85	Liquid
Metam-sodium	Vapam	Liquid
Dazomet	Basamid	Dust (prill)
Methyl isothiocyanate	Di-Trapex	Liquid
Chloropicrin	Larvacide	Liquid

(a) Chloropicrin- it is the oldest soil fumigant, chloropicrin's primary agricultural use in soils is as a fungicide, although it has herbicidal and nematicidal activity.

(b) DD-Mixture- It is a mixture of 1,2-dichloropropane and 1,3-dichloropropene. 1,3-Dichloropropene has the primary use of the compound as a nematicide, although it also has fungicidal and insecticidal activity against wireworms.

(c) Ethylene dibromide (EDB)- A primary effect of halogenated hydrocarbons is to serve as alkylating agents. The sulfhydryl groups of proteins, in particular, are labile to methyl bromide-induced methylation. EDB alkylated proteins and oxidized Fe^{+2} centres in the cytochrome-mediated electron transport chain are attacked in nematodes, thereby blocking respiration.

(d) 1,2-Dibromo-3-Chloropropane- Applied at planting or after planting, excessively used on perennials. The discovery that over one-third of the male workers at a DBCP manufacturing plant in California were sterile led to the immediate 1977 prohibition of its use in the United States, except for usage in pineapple production.

(e) Methyl Bromide (MB): Christie and Cobb used MB to control *Aphelenchoides fragaria* in chrysanthemum. It is agronomically useful against soil fungi, nematodes, insects, and weeds. Methyl bromide is used as a gas; because of its lack of odour, small amounts of chloropicrin are often added as an indicator of exposure to applicators.

(f) Metam Sodium, Dazomet and Methyl Isothiocyanate (MITC): Metam sodium is a soil fumigant used to control nematodes, fungi, insects, and weeds. When applied to soils, metam sodium is converted to MITC, which is the active biocidal agent that inactivates certain parts of amino acids, the molecular building blocks from which proteins are made.

(g) Sodium tetrathiocarbonate: A preplant soil fumigant active against fungi, insects, and nematodes. It is supplied as a liquid formulation and may be applied via drip or surface irrigation. It rapidly degrades in soil into **carbon disulfide**, sodium hydroxide, hydrogen sulfide, and sulphur. **Carbon disulfide** is the active principle.

2. Non-Fumigants: Non-fumigants have low volatility and diffuse through the soil dissolved in the soil solution.

MOA: Non-fumigants also penetrate the body wall of nematodes directly. Inhibit nematode acetylcholinesterase, symptoms induced in nematodes reflect nervous system dysfunction. **Symptoms**: stylet thrusting, twitching, trembling, convulsions, coiling and uncoiling, other uncoordinated movements, inhibited penetration, and eventual paralysis if the concentration is sufficiently high.

Recommended nematicidal dosages and treatments for some important crops

Grape	Meloidogyne spp.	Fenamiphos (e.c.formulation)	10.0	In bands for nursery use
	Xiphinema index	Aldicarb	5-10	In bands for nursery use
Banana	Radopholus similis and/or	Carbofuran	2-4 g a.i. per plant	Applied around plant 2-3 times per year
	Helicotylenchus multicinctus and/or	Ethoprophos	2-4 g a.i. per plant	Applied around plant 2-3 times per year
	Pratylenchus spp. and/or	Fenamiphos	2-4 g a.i. per plant	Applied around plant 2-3 times per year
	Meloidogyne spp.	Isazofos	2-4 g a.i. per plant	Applied around plant 2-3 times per year
		Ebufos	2-4 g a.i. per plant	Applied around plant 2-3 times per year

Crop	Nematode pest	Nematicide	Application rate **	Application techniques
Potato	*Globodera spp.*	Aldicarb	2.24-3.36	Incorporated in row
		Oxamyl	4.0-5.5	
		Carbofuran	4.0-5.5	
Tomato, cucurbits	*Meloidogyne spp.*	Aldicarb	3.36	Incorporated in 30-cm bands
		Ethoprophos	0.9-2.9	Incorporated in bands
		Oxamyl	0.6-1.2	Incorporated in bands
		Fenamiphos	1.6-3.3	Incorporated in bands
		Dazomet	30-50 g/m^2	Incorporated in bands and irrigated Time interval before planting
Citrus	*Tylenchulus semipenetrans*	Fenamiphos	10.8-21.6	Annual treatment applied along drip-line
		Aldicarb	5.5-11.0	Annual treatment applied along drip-line

3) Biochemicals:

(a) Di-Tera: It is a biological based nematicide produced by **nematode-parasitic** fungus ***Myrothecium verrucaria***. Toxic effects observed with ***G. rostochiensis*** include disruption of hatching, movement, and response to potato root diffusate.

(b) Votivo: Votivo is the first significant **bacterium-based** product for control of nematodes containing the unique bacteria strain ***B. firmus*** as active ingredient.

(c) Clariva: ***Pasteuria*** spp. is an obligate parasite of plant-parasitic nematodes; individual strains are highly selective to a specific nematode species or genus. *Pasteuria* spp. spores attaches, penetrates, infects, attacks and parasitizes the nematode, leading to decrease of female fecundity before ultimately leading to its death.

(d) ClandoSan: ClandoSan is a granular product made from processed crab and crawfish exoskeletons. The material contains large amounts of chitin and urea and was registered in 1998 as a nematicide.

(e) Sincocin: The trade name of the mixture registered in 1997 as **''Plant Extract 620''** with the U.S. EPA. It is blend of extracts from prickly pear (*Opuntia lindheimeri*), oak (*Quercus falcata*), sumac (*Rhus aromatica*), and the mangrove (*Rhizophora mangle*). Sincocin has provided control of the citrus nematode, reniform nematode and sugarbeet cyst nematode.

(f) ***Paecilomyces lilacinus:*** It is a soil saprophyte and a facultative fungus attacking sedentary stages of nematodes. It protects root system against diseases caused by nematodes.

4) Modern nematicides:

(a) Abamectin:

- They are one of the newest classes of active substances (macroscopic lactones) and have insecticidal as well as nematicidal properties.
- They are produced from bacteria *Streptomyces avermetilis*. Avermectin B1 (24; abamectin), which is a mixture of avermectin B1a (≥80%) and B1b (≤20%), demonstrated the greatest efficacy as a nematicide**.**

(b) Fluensulfone:

- It is a nematicide belonging to the **fluoroalkenyl** group, which demonstrate far lower toxicities than the OP or carbamates.
- Fluensulfone demonstrated slow and irreversible nematicidal activity against J2 juveniles of *M. javanica* in vitro**.**

(c) Fluopyram:
- It is a new broad-spectrum nematicide belonging to the **pyridinyl ethyl benzamide** class. Fluopyram is a succinate dehydrogenase inhibitor (SDHI).
- In nematodes, it has been described to inhibit mitochondrial respiration quinone dependent succinate reductase (complex II – SQR inhibition), which leads to a quick and severe depletion of cellular energy in the nematodes.

(d) Fluazaindolizine:
- It is an **acylsulfonamide** of imidazopyridine displaying nematicidal activity.
- Fluazaindolizine provides control of a broad range of plant-parasitic nematodes and most probably a new MoA for nematode control.

(e) Tioxazafen:
- It is a nematicide belonging to the **oxadiazole** class and is Monsanto's new broad-spectrum seed treatment nematicide**.**

(f) Spirotetramat:
- It is a novel active ingredient from the new chemical class of ketoenols.
- Spirotetramat demonstrates both insecticidal and nematicidal activities.
- As off-target effect spirotetramat also provides suppression of nematodes.
- It was demonstrated that spirotetramat causes an arrest of juvenile's development.

CONCLUSION

Limited number high yielding nematode resistant cultivars are available and the economic and practical limitations to crop rotation, nematicides continue to be the primary means of managing nematodes. Soil fumigants alone or in combination with non-fumigant nematicides can provide effective and reliable control options for PPNs management, profitable yield and product quality, and increased profits. Treating soil with fumigant nematicides has been very beneficial to farmers but environmental concerns restricted the broad usage of these products and moreover, many fumigants have been banned. Relying on biochemicals (biocontrol agents) or modern nematodes (non-fumigants) has been proven effective to manage nematodes.

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