

Chapter 13

Plant Parasitic Nematodes Management Through Natural Products: Current Progress and Challenges



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Abstract The devastating effect of huge crop losses to field and storage pest brings about a downturn in the availability of food, thus subjecting the citizens to poverty and hunger. The plant-parasitic nematodes (PPN) are important agricultural pests, which are hidden enemies of the farmers. Their existence in soil and the gravity of the potential loss which accrues to them are not known to the lay farmers. Significant quantitative and qualitative economic losses are attributed to their infestation world-wide on a yearly basis. The damage posed by plant-parasitic nematodes is steadily on the increase and is at times not reported, but oftentimes associated with factors such as nutrient deficiency and extreme weather conditions. Nematodes are a big challenge to food production in an overpopulated world. They are listed as an important crop pest in the world, largely because of their wide geographical distribution and their ability to parasitize virtually all crops. Export trade restrictions are often imposed due to the presence of quarantine nematode pests. Different integrated pest management (IPM) strategies have been employed in the control of plant-parasitic nematodes with various degrees of success. The use of synthetic nematocides, though an established internationally recognized effective approach, is largely negated by the toxicity and adverse effects on humans and the environment. Thus, the need for concerted worldwide intensive research for safer alternatives has become imperative. However, there are several challenges in the control of plant-parasitic nematodes, majorly the adoption of new approach to control by the farmers, large-scale production hiccups, government policies, and potential toxicity of the new approach. This work reviews the various strategies used in combating plant-parasitic nematodes. Based on the resultant toxicities reported for chemical control and the effectiveness of biological control (bio-control) which is considered safer, more discussions were made on bio-control. Biological control, application of botanicals, and soil amendment methods rank high among others owing to their

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environmental safety. Over 2400 plant species worldwide are known to be pesticidal. Some tested plants and phytochemical isolates with reported in vitro or in vivo nematocidal properties were listed. The merits and demerits of the bio-control method were also discussed. It was suggested that although the bio-control method is affordable and effective, it should be performed with caution as many emerging reports indicated that many plant materials contain phytochemicals that could induce carcinogenicity, endocrine disruption, and various degrees of toxicities with end-points such as hepatotoxicity, cytotoxicity, ecotoxicity, carcinogenicity, mutagenicity, and immunotoxicity which finally result into morbidity and mortality.

Keywords Chemical control · Biological control · Losses · Yield · Phytonematodes

13.1 Introduction

Nematodes which inhabit the entire ecosystem are known to cause various plant and animal diseases leading to enormous losses annually. In the plant kingdom, a whopping US\$80 billion or more in loss is associated with the effect of plant-parasitic nematodes globally (Coyne et al. 2018). The root-knot nematodes of the genus *Meloidogyne* are the most important as they have a wide range of hosts and also induce several crop damages to a wide range of both annual and perennial crops as well as horticultural and field crops (Ansari and Khan 2012a, b; Ansari and Mahmood 2017b). The genus *Meloidogyne* has over 90 species of which *M. incognita*, *M. javanica*, *M. arenaria*, and *M. hapla* are of paramount economic importance (Maurice et al. 2009). *M. incognita* alone is reported to cause about 30% crop yield losses under field condition (Jain et al. 1994; Renčo et al. 2014). In the tropics and semi-warm temperate regions, crop losses of up to 20% are sometimes recorded despite the use of nematicides, while total crop loss could be obtained when no nematicides are used against *Meloidogyne* infestation (Stirlin and Stanton 1997). However, *Meloidogyne chitwoodi* and *M. fallax* are also becoming a major threat to field vegetables in some regions due to their potential to provoke massive damage (Wesemael et al. 2006; Wesemael and Moens 2008). They were resultantly placed in the A2 list of EPPO (European and Mediterranean Plant Protection Organization) as quarantine organisms (Holgador and Magnusson 2012). Therefore, emphasis on the genus *Meloidogyne* cannot be overemphasized. *Meloidogyne* spp. infest many important food and economic crops like vegetables such as, tomatoes, bean, beet-root, carrot, celery, cucumber, eggplant, lettuce, okra, onion, potato, sweet potato, and pumpkin; field crops such as peanut, clover, tobacco, cowpea, kenaf, soybean, lucerne, lupin, pigeon pea, tea, and sugarcane; ornamental crops including *Ozothamnus*, *Gladiolus*, *Chrysanthemum*, *Dahlia*, *Gerbera*, *Protea*, and rose; and horticultural crops such as passion fruit, kiwi fruit, almond, nectarine, peach, plum, banana, ginger, pineapple, strawberry, *Aloe vera*, grape, and pawpaw (Stirlin and Stanton 1997). The control of plant-parasitic nematodes (PPN) is an excruciating task. Various techniques have been adopted. These techniques are generally

classified as (1) cultural practices, (2) chemical control, (3) biological control, (4) host resistance methods, and (5) mechanical methods (Bakker 1993; Kratochvil et al. 2004; Viaene et al. 2013a, b; Dutta et al. 2019). This chapter reviews the various strategies adopted in combating plant-parasitic nematodes while examining the merits and challenges of the options.

13.2 Cultural Practices

This involves crop rotation, use of tolerant varieties, cover crop plantation, resistant species, fallowing, spread prevention, and other techniques. The crop which is highly susceptible to a particular nematode is replaced from the field with a less or non-susceptible crop for a number of years. While this has been successfully applied, it prevents monocropping. Also when the soil is multi-parasite (nematode) infested, crop rotation success is minimized. Some cultural practices also adopt the cultivation of plants secreting compounds that are toxic to the nematodes in the soil. However, this cultural method is less successful as there is no single plant that may inhibit or minimize the growth of varieties of nematodes (Coyne et al. 2018). Mechanical methods which involve the repeated tilling of fallow soil yield some success, though their implementation on a large scale is quite cumbersome and not economically viable (Kratochvil et al. 2004; Dutta et al. 2019).

13.3 Chemical Control

This method adopts the application of chemical substances known as fumigants (gas) and non-fumigants (liquid or solid) to soil to inhibit or kill the nematodes within a certain depth of the soil (Lambert and Bekal 2002). Since a large amount of chemical substances is involved in this method, the associated risks are also huge especially in the treatment of root-knot nematodes such as *Meloidogyne incognita* which survives at depth below 90 cm in the soil in harsh conditions (Stapleton and DeVay 1983; Starr and Jeger 1985). Depending on the soil type and other environmental factors, some persistent nematode species survive for many months and years without food supply (Steiner and Albin 1946; McSorley 2003) thereby warranting the application of a large amount of chemical nematicide with extended retention in the soil. While many broad-spectrum nematicidal agents such as dibromochloropropane (DBCP), methyl bromide, methyl isothiocyanate, and dibenzofuran are banned from use as nematicides for food products, many other synthetic nematicidal agents such as carbofuran, aldicarb, and oxamyl are still in use in many developing countries. Many of the synthetics are reported to possess medium or average to fatal, toxic, and harmful effects to the entire ecosystem especially when used at increased concentration (Kottogoda 1985; USAEPA 2019). Water bodies, soil, and food are easily contaminated with the application of some of the chemical

nematicides. When the chemicals are passed on to humans via the consumption of nematicide-contaminated foods (plant), they could induce toxicity with endpoints such as hepatotoxicity, cytotoxicity, carcinogenicity, mutagenicity, and immunotoxicity, among others (USEPA 2009; WHO 2009; Bouagga et al. 2019). Beside humans, many other non-target organisms in the soil, land, and air which are important for ecosystem balancing are destroyed, denatured, and eliminated with the application of high doses of the chemicals (Loveridge et al. 2019).

13.3.1 Toxicities Challenge of Chemical Control: Carbofuran as a Case Study

Carbofuran, an anticholinesterase carbamate, is one of the most used pesticides for nematode control. Chemically, it is known as 2,3-dihydro-2,2-dimethyl-1-benzofuran-7-yl methylcarbamate. It is widely used in many developing countries due to its potency but has been banned in many countries as a result of associated toxicities to human and non-target organisms (Goad et al. 2004; USEPA 2009; Seth et al. 2019). It is in most cases labeled as moderately toxic to highly toxic. In fact, the World Health Organization labeled carbofuran as a highly dangerous product (WHO 2009). Some reports indicated that carbofuran persists in soil, is leached to water bodies, and also gets absorbed by plants (Sharom et al. 1980). In human, it is metabolized through oxidation reaction to 3-hydroxycarbofuran which is further oxidized to 3-ketocarbofuran (USEPA 1990). Carbofuran is also known to undergo various other metabolic reactions including hydrolysis under alkaline conditions to produce toxic metabolites such as 3-ketocarbofuran, N-hydroxymethylcarbofuran, carbofuran phenol, 3-ketocarbofuran-7-phenol, and 3-hydroxycarbofuran-7-phenol (Fig. 13.1) (Eisler 1985; Goad et al. 2004; USEPA 2009; Seth et al. 2019; Fabiyi et al. 2012b).

Carbofuran, a broad-spectrum carbamate nematicide, is further reported to induce acute intoxication in cattle (Choez and Evaristo 2018). The accidental inclusion in food, uptake by plants, discharge in water bodies, and overdose have led to many reported cases of toxicities of the chemical (Novtoný et al. 2011; Zeinsteger et al. 2014; Ferré et al. 2015; Caloni et al. 2016). The rapid absorption by roots of plants and transport to site of high transpiration is a subject of major concern with respect to food poisoning and air pollution. As demonstrated in various in vivo studies, acute carbamate poisoning results into morbidity and mortality induced by respiratory failure caused by pulmonary edema (Ferslew et al. 1992). Carbofuran is also known to exhibit acute toxicity to both aquatic and terrestrial organisms (Dobšíková 2003). It degrades in 1 to 8 weeks in alkaline environment via chemical hydrolysis but it remains stable in acidic condition (Gupta 1994). Apparently, as a result of the high water solubility, it has high potential to migrate and contaminate water bodies

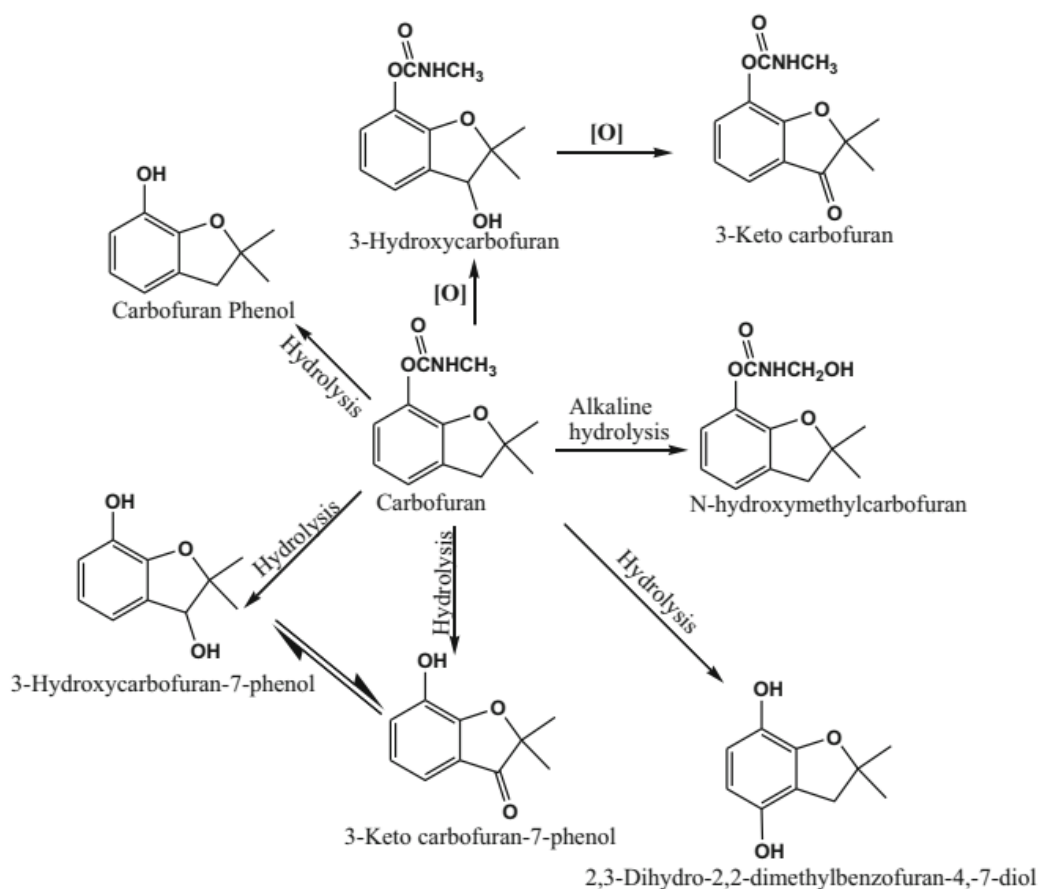


Fig. 13.1 Some metabolic products of carbofuran

through leaching (Sharom et al. 1980). The various reports of the toxicities of the synthetic pesticides obviously underscore the need for safer and greener alternatives.

13.4 Biological Control of Phytonematodes

This control measure involves the adoption of methods such as soil amendments, use of natural nematicides, use of predatory fungi, and application of green manure. Sometimes, the bio-control method also make use of natural techniques that improve the health of the plant which invariably increases the resistance of the plant to nematode infestation (Viaene et al. 2013a; Ansari et al. 2017a, b; Coyne et al. 2018; Ansari and Mahmood 2019b). Nematode resistance genes are crossbred into cultivated plant species to improve their resistance to nematodes. Natural substances such as seed oils and extracts are prepared and applied to control the spread and multiplication of nematodes at various growth stages of the targeted plant. Sometimes, some predatory fungi are also used to trap nematodes especially the root-knot nematodes (Stirlin 1991). The method is generally known to be benign, having little

side effects on the plant and the environment (Viaene et al. 2013a, b; Coyne et al. 2018). The biological control is used as a complement to other methods for effective result. The introduction of some quantity of organic matter into the soil impairs the populations of some types of plant-feeding nematodes as the decomposing matter releases some chemical products which destroy or retard the growth of nematodes. The method is considered easy, affordable, and pollution-free. For instance, the decomposition of rye (*Secale cereale*) produces butyric acid, while the decomposition of rapeseed (*Brassica napus*) produces isothiocyanates which possess anti-nematicidal potential particularly against root-knot nematodes (*Meloidogyne* spp.), a major class of nematodes associated with huge global economic losses (Bridge 1996; Talwana et al. 2016; Coyne et al. 2018; Sikora et al. 2018).

13.5 Utilization of Plant Materials for Nematode Control

Several plants have been identified with nematicidal or nematostatic properties in their seeds, fruits, leaves, barks, and roots or root exudates (Fuglie 1998; Stoll 2000; Atolani et al. 2014; Ansari and Mahmood 2017b, 2019a, b; Ansari et al. 2019). Extracts from *Parinari polyandra* were found to be useful in ameliorating the multiplication of *Meloidogyne incognita* infesting *Celosia argentea*; there was an increase in vegetative growth of the leafy vegetable with the highest dose of *P. polyandra* extract (Fabiyi et al. 2014). Extracts from cypress shrub, *Lawsonia inermis*, caused significant reduction in nematode egg hatch and juvenile mortality of *M. incognita*, while *Daniellia oliveri* leaf extracts with ozoic and daniellic acids as main constituents showed viable nematicidal action and reduction in root galling of okra plants under *M. incognita* infection (Fabiyi and Atolani 2011; Fabiyi 2014). Similarly, *Enantia chlorantha* extract metal complex significantly reduced *M. incognita* population on groundnut with notable increase in yield. (Fabiyi et al. 2019). Application of chopped green leaves of *Chromolaena odorata* is known to be toxic to *Meloidogyne incognita*; at 15 t/ha the population of *Meloidogyne incognita* was reduced, while an increase in yield of about 135% was recorded in okra plants. Increase in yield of *Musa* species was equally recorded with the use of *C. odorata* as soil amendment (Subramaniyan 1985; Ajith and Sheela 1996; Kashaja et al. 1999). Karanj leaves at 20,000, 40,000, and 80,000 ppm compared with carbofuran at 2.0 kg a.i/ha provided a significant reduction in the population of *Aphelenchoides composticola* by 80% (Rao and Pandey 1991). The extracts of *Ipomea fistulosa* effectively controlled *Meloidogyne incognita* in eggplant with improved plant growth (Alam et al. 1995). *Helicotylenchus dihystra* population was reduced by 52–62% with a significant increase in tomato yield with the use of *Azadirachta indica*, *Datura fastuosa*, and *Calotropis procera* leaves as soil amendments; the nematode population decrease was directly proportional to the quantity of leaves used. *Anacardium occidentale* and *Gmelina arborea* exhibited dose-dependent nematicidal activity on *Meloidogyne incognita* infecting cowpea cv. Ife Brown and okra. There was a general increase in growth and vigor without toxicity to the cowpea and okra plants (Firoza and Maqbool 1996; Onifade and Fawole 1996;

Fadeyi et al. 2016). The general practice of incorporating leaves of botanicals into the soil has proved effective in the control of plant-parasitic nematodes. *Brassica campestris*, *Catharanthus roseus*, *Pedilanthus tithymaloides*, *Ricinus communis*, *Azadirachta indica*, and *Calotropis procera* at 80 g/kg soil were compared favorably with carbofuran application at 2 kg a.i/ha, while *Aloe arborescens* and *Cymbopogon citratus* were compared with fenamiphos; they effectively reduced nematode population by 64.8%, 55.4%, and 87.9%, respectively; moderate nematicidal activity was exhibited by thermally degraded products of *C. citratus* at 90 mL (Sweelam 1989; Rao and Reddy 1991; Fabiyi et al. 2018). Several plant families have provided nematicidal metabolites and phytochemicals. A great variety of potent compounds with elucidated structures have suppressive effect on the proliferation of plant-parasitic nematodes in vitro and in vivo (Gommers and Voorin'tholt 1976; Chitwood 2002; Atolani et al. 2014). α -Terthienyl and related compounds were isolated from *Tagetes* spp. and have been established to be nematicidal (Uhlenbroek and Bijloo 1958). Chromatographic fractions isolated from *Alstonia boonei* and *Bridelia ferruginea* exhibited toxicity to *Meloidogyne incognita* eggs and juveniles under laboratory conditions; the relatively non-polar compounds from *A. boonei* and *B. ferruginea* include n-hexadecanoic acid, tetradecane, and pentadecanone, 6,10,14-trimethyl, while eicosanoic acid methyl ester, 1-nonadecanal, 1-cyclohexene-1-butanol, 2,6,6-trimethyl, and octadecane-1-(etheneloxo) fall within the relatively medium polar compounds. Friedlan-3-one, dichloroacetic acid, heptadecyl ester, and tetratetracontane are relatively polar compounds, and this explains partly the basis for the comparatively higher toxicity of the fractions to *Meloidogyne incognita* juveniles and eggs (Fabiyyi et al. 2012a, b). Indoles and substituted methoxy-indoles are the mainframe of most of the compounds identified in *A. boonei* (Cook 1990). Nonanoic acid, a C₉ fatty acid, exhibited substantial toxicity against root-knot nematode and soybean cyst nematode. Methyl ester derivative of nonanoic acid reduced significantly tomato root galling of *M. javanica*; the physical properties of methyl esters of fatty acids as compared to ethyl esters promote increased permeation into nematodes with a resultant increase in toxicity. The methyl esters were substantially more effective, producing reduced galling of plants at one-eighth the concentration at which the ethyl ester was active (Dijan et al. 1994). A variety of fatty acid esters have been used to control nematodes in vitro and in vivo (Pinkerton and Kitner 2006). A mixture of sodium lauryl sulfate and citric acid immobilized some of the nematodes; this mixture also reduced nematode reproduction significantly when applied at planting. Some fatty acids and fatty acid derivatives in the group of short carbon chains (including C₈ to about C₁₄) that can be in the epoxide, cyclopropane, methylated, or hydroxylated forms have also been confirmed to be toxic to some nematodes (Pinkerton and Kitner 2006). Twelve fatty acids (C₃ to C₁₈) and some of their derivatives, seven methyl esters, and four primary alcohols were investigated in vitro, with a few additional greenhouse tests. Toxicity increased with carbon number (C₃ to C₁₁); decanoic acid killed all second-stage juveniles of the plant-parasitic nematode *Meloidogyne hapla*. In 24 h, at a concentration of 50 ppm for methyl esters and primary alcohols, toxicity increased with chain length up to C₁₀

(Vrain 1980). The inhibitory effects of fatty acids of intermediate chain length that have been observed in biological activities may involve a direct interaction between fatty acids and lipophilic regions of the target nematode plasma membranes; *p*-methoxy isomers of propionic acid derivatives are known to be more active than *o*- and *m*-methoxy isomers on nematodes (Hayashi et al. 1983; Jalal and Reed 1986; Davis et al. 1997). Compounds like acetylenes, terpenoids, aldehydes, sesquiterpenoids, and phenoxypropanonic acid are known to have nematocidal activity against some nematodes (Mori et al. 1982). Lactones, ketones, phenolic aldehydes, and carboxylic acids have been indicated to be nematocidal. Leaf extracts from *Anthocephalus chinensis* and *Eichornia crassipes* and bulb extracts of *Allium sativum* were reported to be effective against *M. incognita* on banana in the field. The active nematocidal ingredients were identified to be a phenolic aldehyde from *A. chinensis*, a carboxylic acid from *E. crassipes*, and a ketone from *A. sativum* (Waele and Romulo 1998). The levels of naturally occurring phenols in roots have been correlated with resistance in certain plant cultivars to nematodes (Narayana and Reddy 1980). A number of phenolic compounds and aromatic acids have been studied for their nematocidal activity and their effect on juvenile and egg hatch of *Meloidogyne incognita*. Phenolic compounds like 2-OH naphthoic acid, 3,4-dihydroxyphenyl acetic acid, chlorogenic acid, caffeic acid, and aromatic acids like trans-cinnamic acid are effective in suppressing egg hatch of *M. incognita* (Mahajan et al. 1986). Plant metabolites such as oleanolic acid, β -sitosterol, lupeol, quercetin, 3, 3-dimethyl hexanone, and octadecanoic acid, 2-hydroxy-1,3-propanediyl ester from *Acanthus ilicifolius* hold promise as natural biodegradable crop protectants against *Pratylenchus* spp. infecting maize (Fabiyi 2015). Plant essential oils, most especially terpenes, triterpenes, and monoterpenes, have been associated with control of plant-parasitic nematodes; sesquiterpenoid lactones such as alantolactone and sesquiterpenic acids which consist of costic and isocostic acids are known to have exhibited nematocidal activities (Mahajan et al. 1986; Bourrel et al. 1993; Oka et al. 2000; Oka 2001). Essential oil from *Hyptis suaveolens* with sabinene, beta-caryophyllene, terpinolene, and 1,8-cineole as major constituents expressed a promising bioactivity on eggs and second-stage juveniles of *Heterodera sacchari* (Fabiyi et al. 2015). Some plant materials possessing potent phytochemical compounds with nematocidal activities are shown in Table 13.1. Phytochemicals such as alkaloids, terpenoids, flavonoids, and tannins play a vital role in the bio-control of many nematodes (Fig. 13.2). Generally, plants with high alkaloid content seem to possess more nematocidal properties (Renčo et al. 2014). Methyl benzoate obtained from the aerial parts of *Buddleja crispa* was reported to exhibit more nematocidal activity than *Azadirachta indica* at the same concentration (Sultana et al. 2010).

Table 13.1 Some confirmed natural plant metabolites with nematicidal activities against *Meloidogyne* species

S. no.	Natural sources	Natural nematicidal constituents	Nematode type	References
1	<i>Acorus calamus</i> rhizome	Synergy of compounds	<i>Meloidogyne incognita</i>	Wiratno et al. (2009)
2	<i>Alstonia boonei</i> leaves	Fatty acids and triterpenes	<i>Meloidogyne incognita</i>	Fabiyi et al. (2012b), Fabiyi et al. (2012a, b), Fabiyi et al. (2016)
3	<i>Armoracia rusticana</i> roots	Allyl isothiocyanate	<i>Meloidogyne incognita</i>	Aissani et al. (2013)
4	<i>Artemisia herba-alba</i>	Synergy of compounds	<i>Meloidogyne incognita</i>	Al-Banna et al. (2003)
5	<i>Artemisia vulgaris</i> rhizome	Synergy of compounds	<i>Meloidogyne megadora</i>	Costa et al. (2003)
6	<i>Azadirachta indica</i> leaves	Synergy of compounds	<i>Meloidogyne incognita</i>	Bawa et al. (2014)
7	<i>Azadirachta indica</i> seeds	Synergy of compounds	<i>Meloidogyne javanica</i>	Moosavi (2012)
8	<i>Berberis brevissima</i> roots	Berberine	<i>Meloidogyne javanica</i>	Ali et al. (2019)
9	<i>Bridelia ferruginea</i> leaves	Fatty acids and triterpenes	<i>Meloidogyne incognita</i>	Fabiyi et al. (2012b), Fabiyi et al. (2012a, b), Fabiyi et al. (2016)
10	<i>Buddleja crispa</i> aerial parts	Methyl benzoate	<i>Meloidogyne incognita</i>	Sultana et al. (2010)
11	<i>Calea urticifolia</i> leaves and roots	Synergy of compounds	<i>Meloidogyne incognita</i>	Alejo et al. (2006)
12	<i>Capsicum annuum</i> fruits	Synergy of compounds	<i>Meloidogyne incognita</i>	Bawa et al. (2014)
13	<i>Castanea sativa</i>	Tannins	<i>Meloidogyne javanica</i>	Maistrello et al. (2010)
14	<i>Chenopodium ambrosioides</i> leaves	Essential oil	<i>Meloidogyne incognita</i>	Bai et al. (2011)
15	<i>Chromolaena odorata</i> roots	Synergy of compounds	<i>Meloidogyne incognita</i>	Adegbite and Adesiyani (2005)
16	<i>Chrysanthemum cinerariaefolium</i> flower	Synergy of compounds	<i>Meloidogyne incognita</i>	Perez et al. (2003)
17	<i>Cymbopogon citratus</i> root	Synergy of compounds	<i>Meloidogyne incognita</i>	Adegbite and Adesiyani (2005)
18	<i>Cymbopogon citratus</i> leaves	Synergy of compounds	<i>Meloidogyne incognita</i>	Fabiyi et al. (2018)
19	<i>Cymbopogon nardus</i> leaves and stem	Synergy of compounds	<i>Meloidogyne incognita</i>	Varma and Dubey (1999)
20	<i>Derris elliptica</i> roots	Synergy of compounds	<i>Meloidogyne incognita</i>	Feng (2001)

(continued)

Table 13.1 (continued)

S. no.	Natural sources	Natural nematocidal constituents	Nematode type	References
21	<i>Eugenia winzerlingii</i> leaves	Synergy of compounds	<i>Meloidogyne incognita</i>	Alejo et al. (2006)
22	<i>Euphorbia macroclada</i> leaves	Synergy of compounds	<i>Meloidogyne incognita</i>	Al-Banna et al. (2003)
23	<i>Helianthus annuus</i> leaves	Synergy of compounds	<i>Meloidogyne incognita</i>	Fabiyi and Atolani (2013)
24	<i>Kigelia africana</i> leaves	Atolaside	<i>Meloidogyne incognita</i>	Atolani et al. (2014a)
25	<i>Kigelia africana</i> leaves	Isovitexin	<i>Meloidogyne incognita</i>	Atolani et al. (2014b)
26	<i>Lavandula luisieri</i> aerial parts	Rosmarinic acid Necrodane	<i>Meloidogyne javanica</i>	Julio et al. (2016)
27	<i>Lawsonia inermis</i> leaf	Synergy of compounds	<i>Meloidogyne incognita</i>	Fabiyi and Atolani (2011)
28	<i>Melia azedarach</i>	Synergy of compounds	<i>Meloidogyne incognita</i>	Cavoski et al. (2012)
29	<i>Mentha pulegium</i> aerial parts	Salicylic acid, pulegone	<i>Meloidogyne incognita</i>	Caboni et al. (2013)
30	<i>Mentha spicata</i> aerial parts	Salicylic acid, carvone	<i>Meloidogyne incognita</i>	Caboni et al. (2013)
31	<i>Myrothecium verrucaria</i> (fungi)	Verrucaric A	<i>Meloidogyne incognita</i>	Nguyen et al. (2018)
32	<i>Myrothecium verrucaria</i> (fungi)	Roridin A	<i>Meloidogyne incognita</i>	Nguyen et al. (2018)
33	<i>Parkia biglobosa</i> seeds	Synergy of compounds	<i>Meloidogyne incognita</i>	Bawa et al. (2014)
34	<i>Pelargonium graveolens</i> leaves	Essential oil	<i>Meloidogyne incognita</i>	Leela et al. (1992)
35	<i>Petroselinum crispum</i> aerial parts	Xanthotoxol	<i>Meloidogyne incognita</i>	Caboni et al. (2014)
36	<i>Piper betle</i> leaves	Synergy of compounds	<i>Meloidogyne incognita</i>	Wiratno et al. (2009)
37	<i>Pulsatilla koreana</i> root	Hederacolchiside E, hederacoside B	<i>Meloidogyne incognita</i>	Li et al. (2013)
38	<i>Ricinus communis</i> roots	Synergy of compounds	<i>Meloidogyne incognita</i>	Adegbite and Adesiyun (2005)
39	<i>Ricinus communis</i> seeds	Synergy of compounds	<i>Meloidogyne incognita</i>	Cavoski et al. (2012)
40	<i>Syzygium aromaticum</i> bud	Synergy of compounds	<i>Meloidogyne incognita</i>	Wiratno et al. (2009)

(continued)

Table 13.1 (continued)

S. no.	Natural sources	Natural nematocidal constituents	Nematode type	References
41	<i>Tephrosia cinerea</i> stems	Synergy of compounds	<i>Meloidogyne incognita</i>	Alejo et al. (2006)
42	<i>Terminalia nigrovenulosa</i> bark	3,4-Dihydroxybenzoic acid	<i>Meloidogyne incognita</i>	Nguyen et al. (2013)
43	<i>Triumfetta gradidens</i> aerial parts	Waltherione E Waltherione A	<i>Meloidogyne incognita</i>	Jang et al. (2015)
44	<i>Xenorhabdus budapestensis</i> SN84	Rhabdopeptide J	<i>Meloidogyne incognita</i>	Bi et al. (2018)
45	<i>Zanthoxylum alatum</i>	Synergy of compounds	<i>Meloidogyne incognita</i>	Mukhtar et al. (2013)
46	<i>Zingiber officinale</i> rhizomes	Synergy of compounds	<i>Meloidogyne incognita</i>	Bawa et al. (2014)

13.6 Impact of Some Organic (Natural) Nematicides on the Environment

Obviously, most phytochemicals are generally accepted as being safe for human consumption, animal health, and the environment. This concept has led to a wide range of applications of phytochemicals for various purposes such as pesticides, nutraceuticals, and cosmeceuticals, among others. The phytochemicals in current use are not subjected to rigorous toxicity scrutiny and they are not adequately controlled by law enforcement agents (Bode and Dong 2014). However, there are growing concerns about the safety of the wide use of some bio-nematicides particularly of plant origin. Many phyto-nematicides are reportedly toxic or produce metabolites or degraded products that are toxic to other economically important soil microfauna and microflora. Some of the toxic phyto-constituents in bio-nematicides are leached to lakes and rivers where they contaminate the water bodies and kill aquatic organisms. Some endocrine disruptors, especially phytoestrogens such as genistein and daidzein (both isoflavones), have been identified in some plants (Zin et al. 2013, 2014; Delclos et al. 2001; Ripamonti et al. 2018). Kojic acid obtained in some plant extracts is known to interfere with the thyroid function in humans (Higa et al. 2002; Ota et al. 2009). Methylazoxymethanol from *Cycas* seed, safrole from sassafras plant, and ptaquiloside from bracken fern are some examples of phytochemicals reportedly indicated to be carcinogenic (Bode and Dong 2014). Some of the natural products such as capsaicin from *Capsicum* spp. have generated a lot of debate with respect to the claim that they are carcinogenic (Perry et al. 2007). While many natural organic compounds have been proven to have potency as pesticides, some of the compounds are persistent in the environment (not easily degraded) and are potentially carcinogenic, neurotoxic, genotoxic, ecotoxic, mutagenic, and

nephrotoxic agents (Bode and Dong 2014; Klaschka 2016). Interestingly, natural crude extracts of many plants such as *Tanacetum vulgare*, *Nicotiana tabacum*, *Eucalyptus* species, *Ricinus communis*, and *Melilotus officinalis* contain toxic

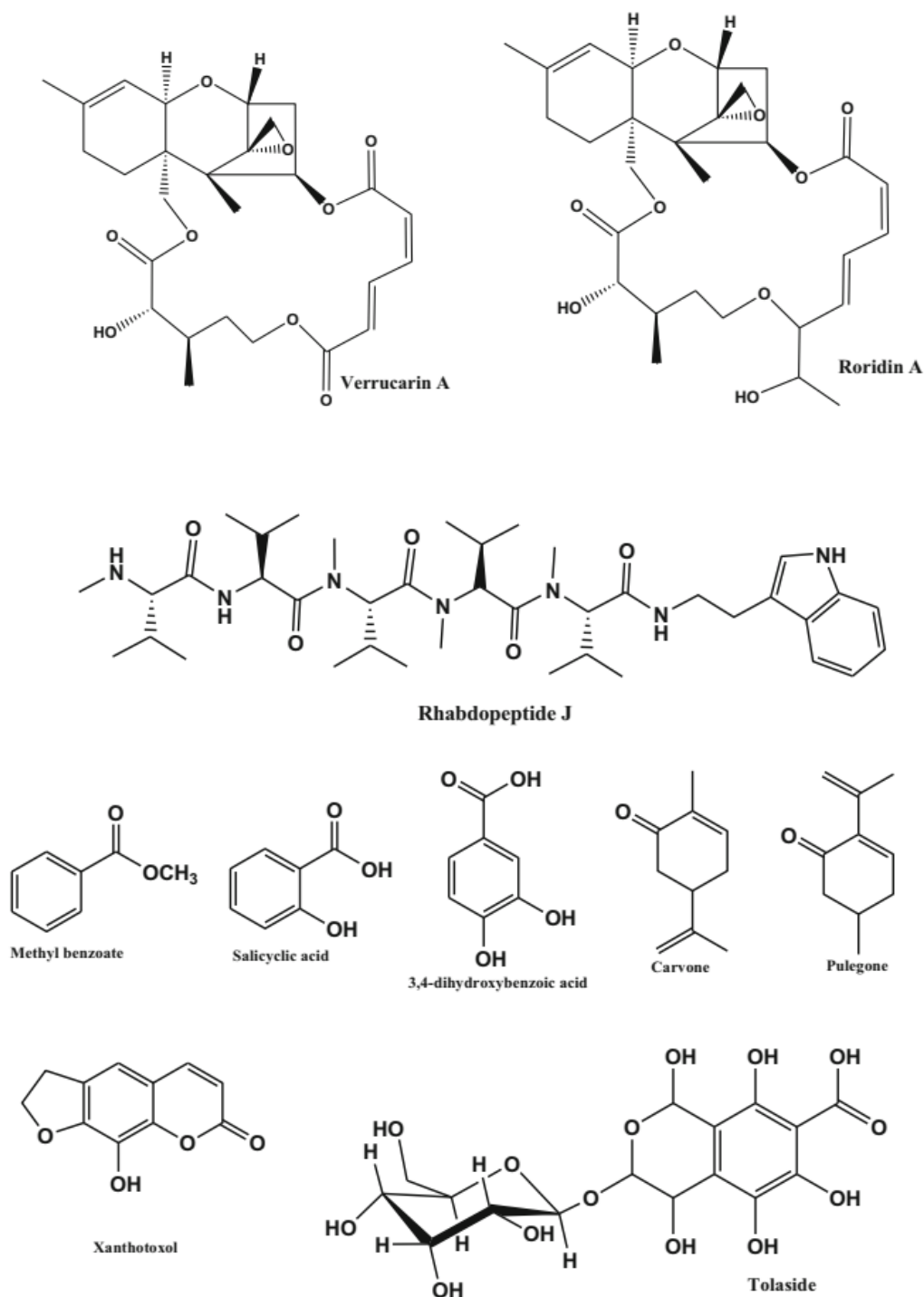


Fig. 13.2 Some potential bio-nematicides from natural sources

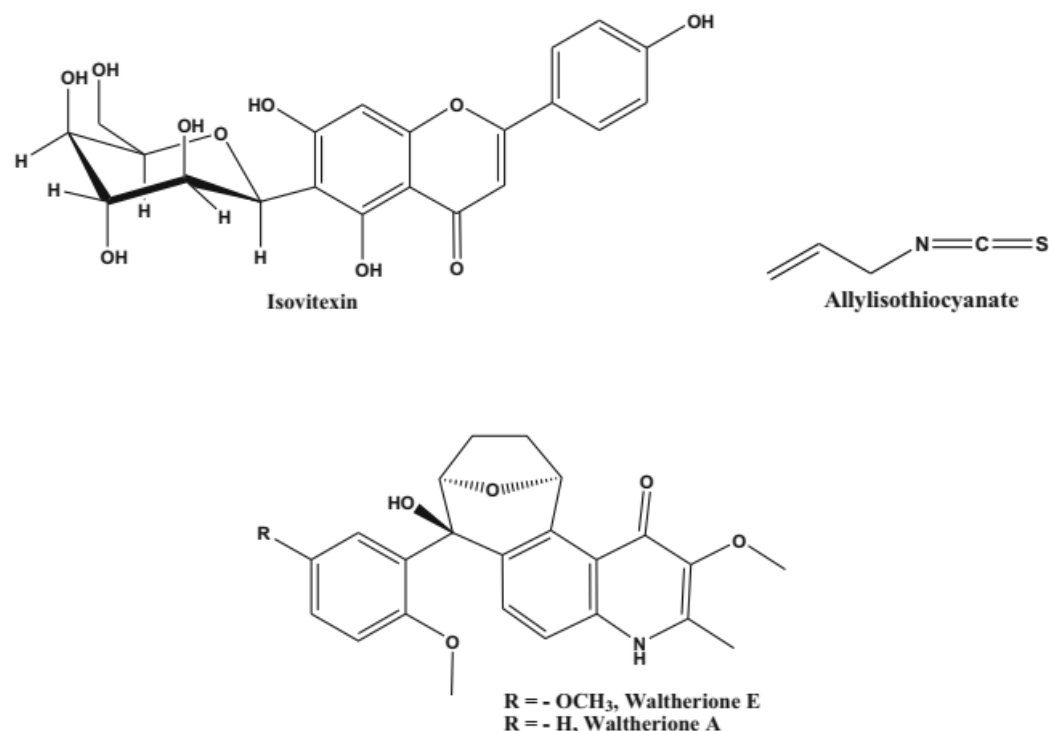


Fig. 13.2 (continued)

constituents that could affect farm animals, other organisms, and humans (Badawy et al. 2010; Phillips et al. 2010). Likewise, pure natural isolates (compounds) such as digitoxin from *Digitalis purpurea*, ephedrine from *Ephedra* spp., nicotine from *Nicotiana tabacum*, colchicine from *Colchicum* spp., atropine from *Atropa belladonna*, physostigmine from *Physostigma venenosum*, strychnine from *Strychnos nux-vomica*, aconitine from *Aconitum* spp., hyoscyamine from *Hyoscyamus niger* and other Solanaceae species, and papaverine from various Papaveraceae species have been reported to be toxic (Klaschka 2016). These reports clearly reveal that plant materials may not be absolutely safe in the environment if not carefully selected or screened before use.

13.7 Conclusions, Caution, and Future Prospects

Obviously, natural products have numerous compounds with potential as nematocidal agents. While crude extracts or raw plant materials have exhibited nematocidal potential, purified isolates and compounds have also demonstrated such capabilities. However, with the growing and increasing interest in the application of phyto-based nematicides for a greener environment, caution should be exercised to prohibit the indiscriminate proliferation of phytotoxic endocrine disruptors, xenobiotics, and other dangerous natural chemicals which could inadvertently induce micro-

resistance and toxicities in living organisms as well as destabilize the ecosystem. Apparently, the careful bio-control of nematode infestation has many advantages over other options. While making such selection for nematicide options, the consideration of affordability, availability, and effectiveness should be evaluated alongside environmental safety. If a bio-nematicide is well adopted, the huge annual or perennial loss could be grossly minimized.

References

- Adegbite AA, Adesiyon SO (2005) Root extracts of plants to control root-knot nematode on edible soybean. *World J Agric Sci* 1(1):18–21
- Aissani N, Tedeschi P, Maietti A, Brandolini V, Garau VL, Caboni P (2013) Nematicidal activity of allyl isothiocyanate from horseradish (*Armoracia rusticana*) roots against *Meloidogyne incognita*. *J Agric Food Chem* 61(20):4723–4727
- Al-Banna L, Darwish R, Aburjai T (2003) Effect of plant extracts and essential oils on root-knot nematode. *Phytopathol Mediterr* 42(2):123–128
- Ajith K, Sheela MS (1996) Utilization of green leaves of neem and Eupatorium for the management of soil organisms in okra and cowpea. *Indian J Nematol* 26(2):139–143
- Alam KS, Ahmed M, Hossain I, Haque AK (1995) Efficacy of dholkalmi (*Ipomoea fistulosa*) and Furadan to control root knot of okra. *Bangladesh J Plant Path* 11(1-2):33–35
- Alejo JC, Suárez JMT, Catzin SM, Mendoza MN, Baizabal LM, Polanco PS, Sánchez SRP, Angulo MMG (2006) In vitro sensitivity of *Meloidogyne incognita* to extracts from native Yucatanian plants. *Nematropica* 36:89–97
- Ali S, Naz I, Alamzeb M, Urrashid M (2019) Activity guided isolation of nematicidal constituents from the roots of *Berberis brevissima* Jafri and *Berberis parkeriana* Schneid. *Tarim Bilimlari Dergisi* 25(1):108–114
- Ansari RA, Khan TA (2012a) Parasitic association of root-knot nematode, *Meloidogyne incognita* on guava. *e-J Sci Technol (e-JST)* 5:65–67
- Ansari RA, Khan TA (2012b) Diversity and community structure of phytonematodes associated with guava in and around Aligarh, Uttar Pradesh, India. *Trends Biosci* 5(3):202–204
- Ansari RA, Mahmood I (2017a) Optimization of organic and bio-organic fertilizers on soil properties and growth of pigeon pea. *Sci Hortic* 226:1–9
- Ansari RA, Mahmood I (2017b) Determination of disease incidence caused by *Meloidogyne* spp. and or *Fusarium udum* on pigeonpea in Aligarh district: a survey. *Trends Biosci* 10(24):5239–5243
- Ansari RA, Mahmood I (2019a) Plant health under biotic stress: volume 2: Microbial interactions. Springer, Singapore. <https://doi.org/10.1007/978-981-13-6040-4>
- Ansari RA, Mahmood I (2019b) Plant health under biotic stress: volume 1: Organic strategies. Springer, Singapore. <https://doi.org/10.1007/978-981-13-6043-5>
- Ansari RA, Rizvi R, Sumbul A, Mahmood I (2017a) PGPR: current vogue in sustainable crop production. In: Kumar V, Kumar M, Sharma S, Prasad R (eds) Probiotics and plant health. Springer, Singapore, pp 455–472
- Ansari RA, Mahmood I, Rizvi R, Sumbul A (2017b) Siderophores: Augmentation of soil health and crop productivity. In: Kumar V, Kumar M, Sharma S, Prasad R (eds) Probiotics in agroecosystem. Springer, Singapore, pp 291–312
- Ansari RA, Sumbul A, Rizvi R, Mahmood I (2019) Organic Soil Amendments: Potential tool for soil and plant health management. In: Ansari RA, Mahmood I (eds) Plant health under biotic stress. Springer, Singapore, pp 1–35

- Atolani O, Fabiyi OA, Olatunji GA (2014) Nematicidal isochromane glycoside from *Kigelia pinnata* leaves. *Acta Agric Slov* 104(1):25–31. <https://doi.org/10.14720/aas.2014.104.1.3>
- Atolani O, Fabiyi OA, Olatunji GA (2014a) Nematicidal isochromane glycoside from *Kigelia pinnata* leaves. *Acta Agri Slovenica* 104(1):25–31
- Atolani O, Fabiyi OA, Olatunji GA (2014b) Isoviteixin from *Kigelia pinnata*, a potential eco-friendly nematicidal agent. *Trop Agric* 91(2):67–74
- Badawy ME, El-Arami SA, Abdelgaleil SA (2010) Acaricidal and quantitative structure activity relationship of monoterpenes against the two-spotted spider mite, *Tetranychus urticae*. *Exp Appl Acarol* 52:261–274
- Bai CQ, Liu ZL, Liu QZ (2011) Nematicidal constituents from the essential oil of *Chenopodium ambrosioides* aerial parts. *J Chem* 8:143–148
- Bakker J (1993) Current state of nematicides. In: Zadoks JC (ed) *Modern crop protection: developments and perspectives*. Wageningen Agric. Univ. Press, Wageningen, pp 21–26
- Bawa JA, Mohammed I, Liadi S (2014) Nematicidal effect of some plants extracts on root-knot nematodes of tomato. *World J Life Sci Med Res* 3(3):82
- Bi Y, Gao C, Yu Z (2018) Rhabdopeptides from *Xenorhabdus budapestensis* SN84 and their nematicidal activities against *Meloidogyne incognita*. *J Agric Food Chem* 66(15):3833–3839
- Bode AM, Dong Z (2014) Toxic phytochemicals and their potential risks for human cancer. *Cancer Prev Res (Phila)* 8(1):1–8
- Bouagga A, Chaabane H, Toumi K, Mougou Hamdane A, Nasraoui B, Joly L (2019) Pesticide residues in Tunisian table grapes and associated risk for consumer's health. *Food Addit Contam Part B Surveill* 12:135–144. <https://doi.org/10.1080/19393210.2019.1571532>
- Bourrel C, Vilarem G, Perineau F (1993) Chemical analysis, bacteriostatic and fungistatic properties of the essential oil of Elecampane (*Inula helenium* L.). *J Essent Oil Res* 5:411–417
- Bridge J (1996) Nematode management in sustainable and subsistence agriculture. *Annu Rev Phytopathol* 34:201–225
- Caboni P, Saba M, Tocco G, Casu L, Murgia A, Maxia A, Menkissoglu-Spiroudi U, Ntalli N (2013) Nematicidal Activity of Mint Aqueous Extracts against the Root-Knot Nematode *Meloidogyne incognita*. *J Agric Food Chem* 61(41):9784–9788
- Caboni P, Saba M, Oplos C, Aissani N, Maxia A, Menkissoglu-Spiroudi CL, Ntalli N (2014) Nematicidal activity of furanocoumarins from parsley against *Meloidogyne* spp. *Pest Manag Sci* 71(8):1099–1105
- Caloni F, Cortinovis C, Rivolta M, Davanzo F (2016) Suspected poisoning of domestic animals by pesticides. *Sci Total Environ* 539:331–336
- Cavoski I, Chami ZA, Bouzebboudja F, Sasanelli N, Simeone V, Mondelli D, Miano T, Sarais G, Ntalli NG, Caboni P (2012) *Melia azedarach* controls *Meloidogyne incognita* and triggers plants defence mechanisms on cucumber. *Crop Prot* 35:85–90
- Chitwood DJ (2002) Phytochemical-based strategies for nematode control. *Annu Rev Phytopathol* 40:221–249
- Choez AK, Evaristo RR (2018) Acute intoxication by carbofuran in cattle. *J Vet Med Surg* 2(1):20–22
- Cook PW (1990) Alkaloids in *A. boonei*. *J Org Chem* 79:631
- Costa PA, Bohlmann F, Schulz J, Buhlmann U (2003) Pathogenicity study and nematotoxic properties of some plant extracts on root knot nematodes of tomato. Blackwell Publishing Ltd, New York, p 22
- Coyne DL, Cortada L, Dalzell JJ, Claudius-Cole AO, Haukeland S, Luambano N, Talwana H (2018) Plant-parasitic nematodes and food security in sub-Saharan Africa. *Annu Rev Phytopathol* 56(1):381–403
- Davis EL, Meyers DM, Dullum CJ, Feitelson JS (1997) Nematicidal activity of fatty acid esters on soyabean cyst and root-knot nematodes. *J Nematol* 29(45):677–684
- Delclos KB, Bucci TJ, Lomax LG, Latendresse JR, Warbritton A, Weis CC, Newbold RR (2001) Effects of dietary genistein exposure during development on male and female CD (Sprague-Dawley) rats. *Reprod Toxicol* 15:647–663

- Dijan, N; Hasan, S.M. and Madanlar, H. (1994). Nematocidal properties of carboxylic-acids and derivatives. *Pestic Biochem Phys* 50:229–239. www.faqs.org/faqs/doc. Accessed 4Apr 2012
- Dobšíková R (2003) Acute toxicity of carbofuran to selected species of aquatic and terrestrial organisms. *Plant Protect Sci* 39:103–108
- Dutta TK, Khan MR, Phani V (2019) Plant-parasitic nematode management via biofumigation using brassica and non-brassica plants: current status and future prospects. *Curr Plant Biol* 17:17–32
- Eisler R (1985) Carbofuran hazards to fish, wildlife, and invertebrates: a synoptic review. *US Fish Wildl Serv Biol Rep* 85:36
- Fabiyi OA (2014) Characterization, phytochemical analysis and nematocidal activity of *Daniellia oliveri* leaves against *Meloidogyne incognita*. *Pak J Nematol* 32(1):91–100
- Fabiyi OA (2015) Toxicity of *Acanthus ilicifolius* (L) fractions against *Pratylenchus* spp. on maize (*Zea mays*). *Albanian J Agric Sci* 14(2):149–156
- Fabiyi OA, Atolani O (2011) *Lawsonia inermis* in the control of *Meloidogyne* spp. on *Corchorus olitorius*. *J Environ Agric Food Chem* 10(3):2000–2006
- Fabiyi OA, Atolani O (2013) Varietal response of sunflower *Helianthus annuus* (L) to root-knot nematode *Meloidogyne* spp and other field pathogens. *Agric Biol J North Am* 4(1):14–18
- Fabiyi OA, Olatunji GA, Atolani O (2012a) Nematicidal activities of chromatographic fraction from *Alstonia boonei* and *Bridelia ferruginea* on *Meloidogyne incognita*. *Pak J Nematol* 30 (2):189–198
- Fabiyi OA, Atolani O, Olatunji GA (2012b) The nematocidal activity of *Alstonia boonei* and *Bridelia ferruginea* leaves on *Meloidogyne incognita* infecting *Corchorus olitorius*. *Albanian J Agric Sci* 11:105–114
- Fabiyi OA, Olatunji GA, Olabiyi TI (2014) Toxicity of the constituents of *Parinari polyandra* on *Meloidogyne incognita* infecting *Celosia argentea*. *Nigerian J Pure Appl Sci* 27:2552–2561
- Fabiyi OA, Osunlola OS, Olatunji GA (2015) In vitro toxicity of extracts from *Hyptis suaveolens* (L.) Poit. on eggs and second-stage juveniles of *Heterodera sacchari*. *Agrosearch* 15(1):89–99
- Fabiyi OA, Atolani O, Olatunji GA (2016) Identification of some chemical constituents of the leaves of *Alstonia boonei* and *Bridelia ferruginea*. *Selçuk Tarım ve Gıda Bilimleri Dergisi* 30 (1):21–28
- Fabiyi OA, Olatunji GA, Adebayo MO, Atolani O (2018) Effect of thermal degraded products of *Cymbopogon citratus* on the in vitro survival of *Meloidogyne incognita* eggs and juveniles. *Ceylon J Sci* 47(3):235–239
- Fabiyi OA, Olatunji GA, Daodu IO (2019) Nematicidal effect of organic extract metal complex on *Meloidogyne incognita* infecting groundnuts (*Arachis hypogea*). *Scient Agric Bohem* 50(3):191–196
- Fadeyi OE, Fabiyi OA, Olatunji GA, Ahmed O (2016) Comparative in vitro and screenhouse response of *Abelmoschus esculentus* infected with *Meloidogyne incognita* to *Anacardium occidentale* fractions. *Univ Maurit Res J* 22:359–379
- Fabiyi OA, Olatunji GA, Daodu IO (2019) Nematicidal effect of organic extract metal complex on *Meloidogyne incognita* infecting groundnuts (*Arachis hypogea*). *Sci Agric Bohem* 50(3):191–196. <https://doi.org/10.2478/sab-2019-0026>
- Feng Y-HW (2001) Plant extracts of several plant pathogenic nematodes kill line screening activity. *Huazhong Agric Univ J* 3:235–238
- Ferré D, Saldeña E, Albarracín L, Neuilly V, Gorla N (2015) Inhibition of butyrylcholinesterase in two intoxicated dogs and analytical confirmation of carbofuran as the causative agent. *Rev Vet* 26:43–48
- Ferslew K, Hagardorn A, McCormick W (1992) Poisoning from oral ingestion of carbofuran (Furadan 4F), a cholinesterase-inhibiting carbamate insecticide, and its effects on cholinesterase activity in various biological fluids. *J Forensic Sci* 37:337–344
- Firoza K, Maqbool MA (1996) Effect of plant extracts in the control of *Helicotylenchus dihystra*. *Pak J Nematol* 14(1):61–66

- Fuglie LJ (1998) Producing food without pesticides: local solutions to crop pest control in West Africa. CTA, Wageningen, The Netherlands, p 158
- Goad RT, Goad JT, Atieh BH, Gupta RC (2004) Carbofuran-induced endocrine disruption in adult male rats. *Toxicol Mech Methods* 14(4):233–239
- Gommers FJ, Voorin'tholt DJM (1976) Chemotaxonomy of compositae related to their host suitability for *Pratylenchus penetrans*. *Netherlands J Plant Path* 82:1–8
- Gupta RC (1994) Carbofuran toxicity. *J Toxicol Environ Health* 43:383–418
- Hayashi M, Wada K, Munakata K (1983) Synthesis and nematocidal activity of phenoxypropionic acid derivatives. *Agric Biol Chem* 47:2653–2655
- Higa Y, Ohkubo A, Kitajima S, Moriyasu M, Kariya K (2002) Effects of kojic acid on thyroidal functions in rats by single-dose administration and in cultured rat thyroid cells (FRTL-5 cells). *J Toxicol Sci* 27:423–431.
- Holgador R, Magnusson C (2012) Quarantine nematodes – European legislation, current status and perspectives. Data sheet of quarantine pests for European and Mediterranean plant protection organization. Bioforsk, Belgrade. https://www.eppo.int/RESOURCES/eppo_publications
- Jain RK, Dabur KR, Gupta DS (1994) Assessment of available losses in field due to root knot nematodes *Meloidogyne incognita* in a few vegetable crops. *Indian J Nematol* 24:81–184
- Jalal GE, Reed SK (1986) Materials and methods for controlling nematodes. *Plant and Soil* 85:112–118
- Jang JY, Le Dang Q, Choi YH, Choi GJ, Jang KS, Cha B, Luu NH, Kim J-C (2015) Nematicidal activities of 4-quinolone alkaloids isolated from the aerial part of *Triumfetta grandidens* against *Meloidogyne incognita*. *J Agric Food Chem* 63(1):68–74
- Julio LF, Barrero AF, Herrador Del Pino MM, Arteaga JF, Burillo J, Andres MF, Díaz CE, González-Coloma A (2016) Phytotoxic and nematocidal components of *Lavandula luisieri*. *J Nat Prod* 79(2):261–266
- Kashaja IN, Fogain R, Speijer PR (1999) Habitat management for control of banana nematodes. In: Frison EA, Gold CS, Karamura EB, Sikora (eds) Mobilizing IPM for sustainable banana production in Africa, p 108. <https://cgspace.cgiar.org/handle/10568/105389>
- Klaschka U (2016) Are natural compounds used in personal care products toxic for the aquatic environment? *Sustain Chem Pharm* 4(2016):13–20
- Kottogoda MB (1985) Safety in use of pesticides and medical treatment. *Chem Ind*:623–625
- Kratochvil RJ, Sardanelli S, Everts K, E. (2004) Gallagher evaluation of crop rotation and other cultural practices for management of root-knot and lesion nematodes. *Agron J* 96:1419–1428
- Lambert K, Bekal S (2002) Introduction to plant-parasitic nematodes. *Plant Health Instr*. <https://doi.org/10.1094/PHI-I-2002-1218-01>
- Leela NK, Khan RM, Reddy PP, Nidiry ESJ (1992) Nematicidal activity of essential oil of *Pelargonium graveolens* against the root-knot nematode *Meloidogyne incognita*. *Nematol Mediterr* 20:57–58
- Li W, Sun Y, Yan X, Yang S, Lee S, Byun H, Moon CS, Han BS, Kim Y (2013) Isolation of nematocidal triterpenoid saponins from *Pulsatilla koreana* root and their activities against *Meloidogyne incognita*. *Molecules* 18(5):5306–5316
- Loveridge R, Ryan GE, Sum P, Grey-Read O (2019) Poisoning causing the decline in South-East Asia's largest vulture population. *Bird Conserv Int* 29(1):41–54
- Mahajan R, Singh P, Bajaj KL, Kalsi PS (1986) Nematicidal activity of some sesquiterpenoids against root-knot nematode (*M. incognita*). *Nematologia* 32:119–123
- Maistrello L, Vaccari G, Sasanelli N (2010) Effect of chestnut tannins on the root-knot nematode *Meloidogyne javanica*. *Helminthologia* 47:48–57
- Maurice M, Perry RN, Starr JL (2009) *Meloidogyne* species: a diverse group of novel and important plant parasites. In: Perry RN, Moens M, Starr JL (eds) Root-knot Nematodes. CABI Publishing, Wallingford, pp 1–17
- McSorley R (2003) Adaptations of nematodes to environmental extremes. *Florida Entomologist* 86 (2):138–142
- Moosavi MR (2012) Nematicidal effect of some herbal powders and their aqueous extracts against *Meloidogyne javanica*. *Nematropica* 42:48–56

- Mori M, Hyeon S, Kimura Y, Susuki A (1982) The nematicidal activity of acetylene compounds. *Agric Biol Chem* 46:309–311
- Mukhtar T, Kayani MZ, Hussain MA (2013) Nematicidal activities of *Cannabis sativa* L. and *Zanthoxylum alatum* Roxb. against *Meloidogyne incognita*. *Ind Crop Prod* 42:447–453. <https://doi.org/10.1016/j.indcrop.2012.06.027>
- Narayana YD, Reddy DR (1980) Penetration, development and histopathology of root-knot nematodes in tomato 'NTDR-1'. *Nematol Mediterr* 8:43–49
- Nguyen D-M-C, Seo D-J, Kim K-Y, Park R-D, Kim D-H, Han Y-S, Kim TH, Jung W-J (2013) Nematicidal activity of 3,4-dihydroxybenzoic acid purified from *Terminalia nigrovenulosa* bark against *Meloidogyne incognita*. *Microb Pathog* 59–60:52–59
- Nguyen LTT, Jang JY, Kim TY, Yu NH, Park AR, Lee S, Bae CH, Yeo JH, Hur JS, Park HW, Kim JC (2018) Nematicidal activity of verrucarins A and roridin A isolated from *Myrothecium verrucaria* against *Meloidogyne incognita*. *Pestic Biochem Phys* 148:133–143
- Novtoný L, Misík L, Honzlová A, Ondracek P, Kuca K et al (2011) Incidental poisoning of animals by carbamates in the Czech Republic. *J Appl Biomed* 9:157–161
- Oka Y (2001) Nematicidal activity of essential oil components against the root-knot nematode *Meloidogyne javanica*. *Nematology* 3:159–164
- Oka Y, Nacar S, Putievsky E, Ravid U, Yaniv Z, Spiegel Y (2000) Nematicidal activity of essential oils and their components against the root-knot nematode. *Phytopathology* 90:710–715
- Onifade AK, Fawole B (1996) Effect of some plant extracts on the pathogenicity of *M. incognita* on cowpea. *Global J Pure Appl Sci* 2(1):9–15
- Ota Y, Imai T, Onose J, Takami S, Cho YM, Hirose M, Nishikawa A (2009) A 55-week chronic toxicity study of dietary administered kojic acid (KA) in male F344 rats. *J Toxicol Sci* 34:305–313.
- Perez MP, Navas-Cortes JA, Pascual-Villalobos MJ, Castillo P (2003) Nematicidal activity of essential oils and organic amendments from Asteraceae against root-knot nematodes. *Plant Pathol* 52(3):395–401
- Perry L, Dickau R, Zarrillo S, Holst I, Pearsall DM, Piperno DR et al (2007) Starch fossils and the domestication and dispersal of chili peppers (*Capsicum* spp. L.) in the Americas. *Science* 315:986–988
- Phillips AK, Appel AG, Sims SR (2010) Topical toxicity of essential oils to the German cockroach (Dictyoptera: Blattellidae). *J Econ Entomol* 103(2):448–459
- Pinkerton CB, Kitner DR (2006) Effects of biologically derived products on motility and reproduction of the root-lesion nematode, *Pratylenchus penetrans* on strawberry. *Nematropica* 36:181–196
- Rao MS, Reddy PP (1991) Studies on the comparative efficacy of certain plant leaves and carbofuran in the management of *Meloidogyne incognita* on tomato. *Curr Nematol* 3(1):5–6
- Renčo M, Sasanelli N, Maistrello L (2014) Plants as natural sources of nematicides. Nova Science Publishers, Inc, New York, pp 115–142
- Ripamonti E, Alliffranchini E, Todeschi S, Bocchietto E (2018) Endocrine disruption by mixtures in topical consumer products. *Cosmetics* 2018(5):61
- Seth B, Yadav A, Tandon A, Shankar J, Kumar Chaturvedi R (2019) Carbofuran hampers oligodendrocytes development leading to impaired myelination in the hippocampus of rat brain. *Neurotoxicology* 70:161–179
- Sharom MS, Miles JRW, Harris CR, McEwen FL (1980) Behaviour of 12 insecticides in soil and aqueous suspensions of soil and sediment. *Water Res* 14:1095–1100
- Sikora RA, Coyne DL, Hallman J, Timper P (2018) Reflections on nematology in subtropical and tropical agriculture, vol 125. CABI, Wallingford, pp 1–19
- Stapleton JJ, DeVay JE (1983) Response of phytoparasitic and free-living nematodes to soil solarization and 1,3-dichloropropene in California. *Phytopathology* 73:1429
- Starr JL, Jeger MJ (1985) Dynamics of winter survival of eggs and juveniles of *Meloidogyne incognita* and *M. arenaria*. *J Nematol* 17(3):252–256
- Steiner G, Albin FM (1946) Resuscitation of the nematode *Tylenchus polyhyphus*, n. sp., after almost 39 years dormancy. *J Wash Acad Sci* 36:97–99

- Stirlin GR (1991) Antagonists of nematodes. In: Stirling GR (ed) Biological control of plant parasitic nematodes. CAB International, Wallingford, Oxford, pp 50–98
- Stirlin G, Stanton J (1997) Nematode diseases and their control. In: Brown JF, Ogle HJ (eds) Plant pathogens and plant diseases. Rockvale Publications, Armidale, Australia, pp 505–517
- Stoll G (2000) Natural Crop protection in the tropics: letting information come to life. Margraf Verlag Publication, Weikersheim, Germany, p 376
- Subramaniyan S (1985) Effect of *Eupatorium odoratum* extracts on *Meloidogyne incognita*. Indian J Nematol 15:247
- Sultana N, Akhter M, Khan RA, Afza N, Tareen RB, Malik A (2010) Nematicidal natural products from the aerial parts of *Buddleja crispa*. Nat Prod Res 24(9):783–788
- Sweelam ME (1989) The potential use of some ornamental plants for nematode control in Egypt. Bull Facul Agric Univ Cairo 40(2):391–393
- Talwana H, Sibanda Z, Wanjohi W, Kimenju W, Luambano-Nyoni N et al (2016) Agricultural nematology in East and Southern Africa: problems, management strategies and stakeholder linkages. Pest Manag Sci 72:226–245
- Uhlenbroek JH, Bijloo JD (1958) Investigations on nematicides. Isolation and structure of a nematicidal principle occurring in Tagetes roots. Recueil des Travaux Chimiques des Pays-Bas 77:1004–1008
- United State Environmental Protection Agency (USEPA) (1990) Drinking water criteria document on carbofuran. Prepared under Program No. 1524 for contract 68-C8-0033 by ICAIR, Life Systems, Inc. Cleveland, Ohio for the U.S. Environmental Protection Agency
- United State Environmental Protection Agency (USEPA) (2009) Bans carbofuran pesticide residues on food. Environmental News Service
- United States Environmental Protection Agency (USEPA) (2019) Hazard summary. [EPA.gov. https://www3.epa.gov/ttn/atw/hlthef/dibromo-.html](https://www3.epa.gov/ttn/atw/hlthef/dibromo-.html). Accessed 10 May 2019
- Varma J, Dubey NK (1999) Prospectives of botanical and microbial products as pesticides of tomorrow. Curr Sci 76:172–179. <http://www.ias.ac.in/currensci/jan25/articles22.html>
- Viaene N, Coyne DL, Davies K (2013a) Biological and cultural control. In: Perry RA, Moens M (eds) Plant nematology, 2nd edn. CABI, Wallingford, pp 383–410
- Viaene N, Coyne D, Davies K, Perry R, Moens M (2013b) Biological and cultural management. In: Perry RN, Moens M (eds) Plant nematology. CABI, Wallingford, pp 383–410
- Vrain C (1980) Fatty acids and their derivatives for nematode control. J Nematol 12(4):240
- Waele DD, Romulo GD (1998) The root-knot nematodes of banana, *Musa* pest factsheet no. 3. CGIAR, France. <https://cgspace.cgiar.org/bitstream/handle/10568/105398/697.pdf?sequence=7&isAllowed=y>
- Wesemael WML, Moens M (2008) Quality damage on carrots (*Daucus carota* L.) caused by the root-knot nematode *Meloidogyne chitwoodi*. Nematology 10:261–270
- Wesemael WML, Perry RN, Moens M (2006) The influence of root diffusate and host age on hatching of the root-knot nematodes, *Meloidogyne chitwoodi* and *M. fallax*. Nematology 8:895–902
- WHO (2009) The World Health Organization (WHO) recommended classification of pesticides by hazard and guidelines to classification. http://www.who.int/ipcs/publications/pesticides_hazard/en/
- Wiratno W, Taniwiryono D, Berg HV, Riksen JAG, Rietjens IMCM, Djiwanti SR, Kammenga JE, Murk AJ (2009) Nematicidal activity of plant extracts against the root-knot nematode, *Meloidogyne incognita*. Open Nat Prod J 2:77–85
- Zeinsteger P, Oliver C, Ledri D, Danielle M, Mestorino N (2014) Presence of pesticide carbofuran (carbamato) in bait samples and gastric content of caninos of the city of Urdinarrain, Entre Ríos.
- Zin SRM, Omar SZ, Khan NLA, Musameh NI, Das S, Kassim NM (2013) Effects of the phytoestrogen genistein on the development of the reproductive system of Sprague Dawley rats. Clinics 68:253–262
- Zin SRM, Omar SZ, Khan NLA, Musameh NI, Das S, Kassim NM (2014) Effects of genistein on male Sprague Dawley rats reproductive development. Biomed Res 25:391–400