Biocide plants as a sustainable tool for the control of pests and pathogens in vegetable cropping systems

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Abstract

Synthetic pesticides have played a major role in crop protection related to the intensification of agricultural systems. In the recent years, environmental side effects and health concerns raised by an indiscriminate use have led the EU to the ban of many synthetic pesticides. As a result of this drastic revision, currently there is a strong need for new and alternative pest control methods. An interesting source of biorational pesticides may be represented by the biocidal compounds naturally occurring in plants as products of the secondary metabolism. Groups of plant secondary metabolites most promising for the development of pesticidal formulations are glucosinolates, saponins, and more generally terpenoid phytoconstituents, such as essential oil and their constituents. Glucosinolates are thioglucosidic secondary metabolites occurring mainly in the Brassicaceae and, at a less extent, in Capparidaceae families. The incorporation of glucosinolate-containing plant material into the soil results in degradation products highly toxic to soilborne pest, pathogens and weeds. This practice, known as biofumigation, may be considered as an ecological alternative to soil toxic fumigants. Plant-derived saponins are triterpene glycosides present in top and root tissues of plant species of the families Leguminoseae, Alliaceae, Asteraceae, Polygalaceae and Agavaceae. Saponins and saponin-rich plant materials have been also reported for a biocidal activity on phytoparasites and soilborne plant pathogens. Essential oils are volatile, natural, heterogeneous mixtures of single substances, mainly terpenes and phenolics, formed as secondary metabolites by aromatic plants belonging to several botanical families. Among terpenes, limonoid triterpenes have been demonstrated to possess interesting insecticidal, nematicidal and antifungal properties. Occurrence of these compounds is mainly limited to Meliaceae and Rutaceae. Alkaloids, phenolics, cyanogenic glucosides, polyacetylenes and polythienyls are further groups of secondary metabolites also known for their biocidal activity and susceptible for the production of natural pesticides. Alkaloids are derived from various botanical families, amongst which the Solanaceae, and include a number of molecules, such as nicotine, veratrine, cevatinne and ryanodine, used as insecticides. Phenolics were found also toxic to insects, fungi, bacteria, nematodes and weeds. Cyanogenic glucosides are amino acid-derived secondary metabolites releasing, upon tissue disruption, hydrogen cyanide that suppress insects, fungus, nematodes and weeds. Finally, polyacetylenes and polythienyls, substances mainly present in Tagetes species, are also well known for their insecticidal and nematicidal properties.

Introduction

Plant-parasitic nematodes are among the most known crop pests, as worldwide distributed and responsible for substantial damages to horticultural crops of economic importance (Figure 1).

During the past decades, the control of these phytoparasites largely relied on treatments with chemical nematicides, mainly fumigants, most of which have been withdrawn after the drastic revision of synthetic pesticides operated at EC level (Directive 91/414, Regulation 2009/1107/EC and Directive 2009/128/EC; European Commission, 1991, 2009a, 2009b). Withdrawal of most available chemical nematicides and widespread public concern for long-term health and environmental effects of pesticides have generated a growing interest in alternative pest control tools (Ghorbani et al., 2008).

Plants are a huge source of nematicidal compounds, mainly constituents of the secondary metabolism involved in plant defence mechanisms against abiotic and biotic agents. These nematicidal compounds may be directly exploited as plant extracts, phytochemical formulations or organic amendments, or used as model compounds for the development of chemically synthesised derivatives. Plant-derived nematicides could fit well to the principles of Integrated Pest Management, thanks to their safety to environment, humans and animals, selective mode of action and absence of pest resistance (Chitwood, 2002). A further advantage of plant-based nematode management strategies is represented by their large flexibility, as the large
Mechanisms of action and modes of use of nematicidal plants

Nematode suppressiveness of phytochemicals can be the result of various and often-concomitant mechanisms, such as repellence, disorientation, nematode trapping, hatching stimulation or inhibition. Active principles present in plant tissues or released as root exudates may also have a direct toxicity to nematodes, causing mortality or only a temporary immobilization. Other plant metabolites may act as antifeedants, i.e. to cause a permanent or temporary interruption of nematode feeding. This is the case of absinthin, a dimeric sesquiterpene produced by Artemisia absinthium and responsible of an antifeedant activity on insects and nematodes. Some species, such as Raphanus sativus, can work as trapping plants, i.e. attracting the nematode inside the roots but blocking its reproduction and the completion of life cycle (Guesmi et al., 2013). Further suggested mechanisms have hypothesised an induction of morphological and physiological changes or a repellent activity on nematodes, such as for amines and pyridines (Feldmesser et al., 1976).

Modes of exploitation of the nematicidal properties of a plant species should be specifically adapted to the mechanisms of action. Agronomical practices, such as the incorporation into the soil of plant biomass, or rotation and intercropping with plants releasing nematotoxic allelochemicals in the soil, have been often demonstrated for an effective nematode suppression (Widmer and Abawi, 2000; D’Addabbo et al., 2009; Avato et al., 2013). Besides agronomical uses, an industrial production of commercial formulations based on extracts, oils, purified components or biomasses of nematicidal plants has also frequently occurred (Giannakou, 2011; D’Addabbo et al., 2011b; D’Addabbo et al., 2009; Ntalli et al., 2009; Colombo et al., 2012).

Main chemical groups of nematicidal plant compounds

Glucosinolates

Glucosinolates (GLSs) are thiogluicosidic secondary metabolites, mainly present in the Brassicaceae and Capparidaceae families, which coexist in vivo with the myrosinase enzyme. Myrosinase-catalysed hydrolysis of glucosinolates, upon tissue damage by harvesting, processing or mastication, results in the release of a variety of isothiocyanate derivatives with nematotoxic action (Table 1).

Some species, such as Daucus carota, Meloidogyne species, or to the potato (Solanum tuberosum L.) cyst nematode Globodera rostochiensis Woll., though data were extended also to the GLSs’ in vitro activity against the grapevine (Vitis vinifera L.) virus-vector nematode Xiphinema index Thorne et Allen and the carrot (Daucus carota L.) cyst nematode Heterodera carotaet Jones (Figure 3) (Avato et al., 2013).

The volatility of most isothiocyanates and other GLS hydrolysis products led to coin the term biofumigation to describe the suppression of soil-borne pests and pathogens by biocidal volatiles released by brassicaceous rotation and green manure crops or by seed meal amendments incorporated into the soil (Angus et al., 1994; Smolinska et al., 1997; Matthiessen and Kirkegaard, 2006) (Figure 4). The negative impact of soil amendments with brassicaceous plant material on phytoparasitic
nematodes was documented since the early 90s (Mojtahedi et al., 1991, 1993b) and largely exploited during the following years (Potter et al., 1998; Zasada and Ferris, 2004; Monfort et al., 2007; Gimsing and Kirkegaard, 2009).

Content and chemical profile of glucosinolates and their degradation products depend on plant species/genotype, environment, phenological stage and tissue and, therefore, an appropriate management of these parameters is needed to select plant material with enhanced nematicidal potential to target organisms.

In addition to the species of genus Brassica spp., nematicidal potential of other Brassicaceae plants has been also investigated. Radish (Raphanus sativus L. ssp. oleiformis) or white mustard (Sinapis alba L.) were satisfactorily applied as intercrop plants for the control of the sugarbeet cyst nematode, Heterodera schachtii Schmidt, though the same species resulted differently suppressive on the root-knot nematode Meloidogyne incognita Kofoid et White (Chitw.) (Figure 5) (Guesmi et al., 2013). Rocket, Eruca sativa L., provided a remarkable biocidal effect against root-knot nematodes in field (Curto, 2008). Meadowfoam, Limnanthes alba Benth., is another promising GLS containing plant with a potential for the management of nematode pests (Zasada et al., 2012).

Saponins

Saponins are a large group of glycosidic secondary metabolites produced by many plant species, including major food crops, belonging to three major chemical classes: steroid glycosides; steroid alkaloid glycosides and triterpene glycosides, which include the largest number of structures.

Due to their chemical, physical and physiological characteristics, naturally occurring saponins display a broad spectrum of biological and pharmacological effects, also including fungicidal, molluscicidal, antibacterial and antiviral activities (Tava and Avato, 2006). Biological effects of saponins are normally ascribed to their specific interaction with the cell membranes, as causing changes in cell permeability (Sprag et al., 2004; Tava and Avato, 2006).

Table 1. Percentage mortality of adult specimens of the virus vector nematode Xiphinema after 2, 4 or 8 h of exposure to 0.05, 0.30, 1.0 or 2.0 mg mL⁻¹ solutions of different isothiocyanates.

<table>
<thead>
<tr>
<th>Isothiocyanate</th>
<th>Rate (mg mL⁻¹)</th>
<th>2 h</th>
<th>4 h</th>
<th>8 h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allil-isothiocyanate</td>
<td>0.05</td>
<td>33.3b</td>
<td>33.3b</td>
<td>100c</td>
</tr>
<tr>
<td></td>
<td>0.30</td>
<td>33.3b</td>
<td>40.0b</td>
<td>100c</td>
</tr>
<tr>
<td></td>
<td>1.00</td>
<td>60c</td>
<td>100d</td>
<td>100c</td>
</tr>
<tr>
<td></td>
<td>2.00</td>
<td>100c</td>
<td>100d</td>
<td>100c</td>
</tr>
<tr>
<td>Feniletil-isothiocyanate</td>
<td>0.05</td>
<td>16.7d</td>
<td>66.7d</td>
<td>100c</td>
</tr>
<tr>
<td></td>
<td>0.30</td>
<td>28.7d</td>
<td>100d</td>
<td>100c</td>
</tr>
<tr>
<td></td>
<td>1.00</td>
<td>56.7e</td>
<td>100d</td>
<td>100c</td>
</tr>
<tr>
<td></td>
<td>2.00</td>
<td>96.7cde</td>
<td>100d</td>
<td>100c</td>
</tr>
<tr>
<td>Benzil-isothiocyanate</td>
<td>0.05</td>
<td>16.7d</td>
<td>40b</td>
<td>73.3c</td>
</tr>
<tr>
<td></td>
<td>0.30</td>
<td>66.7d</td>
<td>63.3d</td>
<td>96.7c</td>
</tr>
<tr>
<td></td>
<td>1.00</td>
<td>73.3d</td>
<td>100d</td>
<td>100c</td>
</tr>
<tr>
<td></td>
<td>2.00</td>
<td>76.7cde</td>
<td>100d</td>
<td>100c</td>
</tr>
<tr>
<td>Butil-isothiocyanate</td>
<td>0.05</td>
<td>33.3b</td>
<td>93.3d</td>
<td>83.3d</td>
</tr>
<tr>
<td></td>
<td>0.30</td>
<td>86.7bde</td>
<td>96.7d</td>
<td>100c</td>
</tr>
<tr>
<td></td>
<td>1.00</td>
<td>100c</td>
<td>100d</td>
<td>100c</td>
</tr>
<tr>
<td></td>
<td>2.00</td>
<td>100c</td>
<td>100d</td>
<td>100c</td>
</tr>
<tr>
<td>Water control</td>
<td>-</td>
<td>0.0a</td>
<td>0.0a</td>
<td>0a</td>
</tr>
</tbody>
</table>

Modified from Avato et al., 2013. *Values with the same letters are not significantly different at P=0.05 according to Fisher’s least significant difference test.
Literature on the nematicidal activity of saponins is quite limited. The in vitro and pot experiments of Omar et al. (1994) showed that 260–280 ppm solutions of saponins reduced total populations, number of egg masses and viable juveniles of the root-knot nematode *Meloidogyne javanica* Treub. Motility of *M. incognita* juveniles was reported as significantly reduced by the exposure to eight different steroidal and triterpenoid saponins from *Asparagus* spp. (Chitwood, 2002). A formulation of saponins from the bark of quillay (*Quillaja saponaria* Molina) resulted in a satisfactorily nematode control also at low dosage (San Martin and Magnunacelaya, 2005). Moreover, field trials with aqueous extracts of *Q. saponaria* significantly reduced the density of *M. incognita* in the soil and increased tomato or melon crop yield (D’Addabbo et al., 2005) (Figure 6). Adversely, Argentieri et al. (2008) documented a poor nematicidal effect of an almost pure formulation of quillay saponins in an in vitro experiment on *X. index*. In the same experiment, pure saponins from different *Medicago* species were nematicidal on *X. index*, as inducing 100% mortality at 500 g mL⁻¹ rate between 8 and 48 h exposures (Table 2).

Saponins found in the genus *Medicago* are triterpene glycosides and include different structural types, distinguished by their aglycones and...
sugars, which have some chemotaxonomic relevance to discriminate among the various species within the genus (Tava and Avato, 2006; Tava et al., 2009).

Although the exact function of saponins in *Medicago* plants is not fully understood, they are regarded as constitutive resistance factors involved in defence mechanisms especially against pathogens.

Saponins from *Medicago sativa* L., as showing a well characterised chemical composition and well established biological activities, seem to represent good candidates for phytoneemtode control. The *in vitro* investigation of the biocidal effects of saponin mixtures from alfalfa top and root tissues on *X. index*, *M. incognita* and *G. rostochiensis* showed that saponins from both plant parts were nematotoxic to the three phytoparasite species and their activity was dependent on the concentration and nematode incubation time (Argentieri et al., 2008; D’Addabbo et al., 2011a).

Bioactivity data from these *in vitro* experiments suggested exploring also the efficacy of *Medicago* plant material to suppress plant parasitic nematode populations through soil amendments (D’Addabbo et al., 2009). Soil amendments with leaf and root dry biomass of *M. sativa* were found to reduce root and soil population densities of *M. incognita* and *G. rostochiensis* compared to a non-treated control, according to a dose-related relationship (Figure 7). Further field experiments evidenced the high suppressiveness of a pelleted formulation of *M. sativa* dry biomass on *M. incognita* on tomato and on the cyst nematode *H. carotae* on carrot (D’Addabbo et al., 2010) (Table 3). However, results suggest that phytoneemtode suppression in amended soil could be only partially attributed to the saponin content of *M. sativa* tissues, as the presence of active

![Figure 7. Tomato roots from soil uninfested (A), treated with 2% *Medicago sativa* dry leaves (B), treated with fenamiphos (C) and untreated (D).]

Table 3. Effect of soil amendments with alfalfa pellets on yield tomato and soil population density of the root-knot nematode *Meloidogyne incognita* on carrot and of the cyst nematode *Heterodera carotae* on carrot.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Rate</th>
<th>Crop yield (T ha⁻¹)</th>
<th>Nematode population (eggs and J2 mL⁻¹ soil)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Tomato</td>
<td>Carrot</td>
</tr>
<tr>
<td>Alfalfa pellet</td>
<td>20 t ha⁻¹</td>
<td>68.6b</td>
<td>75.6b</td>
</tr>
<tr>
<td>Alfalfa pellet</td>
<td>40 t ha⁻¹</td>
<td>71.6b</td>
<td>76.0bc</td>
</tr>
<tr>
<td>Quillay extract</td>
<td>30 L ha⁻¹</td>
<td>55.5b</td>
<td>59.6b</td>
</tr>
<tr>
<td>Fenamiphos</td>
<td>30 L ha⁻¹</td>
<td>58.3b</td>
<td>107.2d</td>
</tr>
<tr>
<td>Control</td>
<td>-</td>
<td>46.0a</td>
<td>58.2a</td>
</tr>
<tr>
<td>Quillay</td>
<td>20 L ha⁻¹</td>
<td>Before sowing</td>
<td>38b</td>
</tr>
<tr>
<td>Quillay</td>
<td>30 L ha⁻¹</td>
<td>Before sowing</td>
<td>34b</td>
</tr>
<tr>
<td>Quillay</td>
<td>40 L ha⁻¹</td>
<td>Before sowing</td>
<td>35ab</td>
</tr>
<tr>
<td>Azadirachtin (2.5%)</td>
<td>3+3</td>
<td>Before sowing + emergence</td>
<td>31ab</td>
</tr>
<tr>
<td>Azadirachtin (1.6%)</td>
<td>7+7</td>
<td>Before sowing + emergence</td>
<td>26b</td>
</tr>
<tr>
<td>Phosthiazate</td>
<td>4*</td>
<td>Before sowing</td>
<td>144c</td>
</tr>
<tr>
<td>Non treated soil</td>
<td>-</td>
<td>Before sowing</td>
<td>20b</td>
</tr>
</tbody>
</table>

**Values with the same letters are not significantly different at P=0.05 according to Fisher’s least significant difference test.**

Table 4. Effect of treatments with quillay and azadirachtin formulations on carrot yield and soil population density of *Heterodera carotae* in Sicilia.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Dose (L ha⁻¹)</th>
<th>Time of application</th>
<th>Crop yield (T ha⁻¹)</th>
<th>Nematode population (eggs and J2 g⁻¹ soil)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quillay</td>
<td>20</td>
<td>Before sowing</td>
<td>38b</td>
<td>15b</td>
</tr>
<tr>
<td>Quillay</td>
<td>30</td>
<td>Before sowing</td>
<td>34ab</td>
<td>16b</td>
</tr>
<tr>
<td>Quillay</td>
<td>40</td>
<td>Before sowing</td>
<td>35ab</td>
<td>20b</td>
</tr>
<tr>
<td>Azadirachtin (2.5%)</td>
<td>3+3</td>
<td>Before sowing + emergence</td>
<td>31ab</td>
<td>18b</td>
</tr>
<tr>
<td>Azadirachtin (1.6%)</td>
<td>7+7</td>
<td>Before sowing + emergence</td>
<td>26b</td>
<td>32c</td>
</tr>
<tr>
<td>Azadirachtin (1.0%)</td>
<td>4</td>
<td>Before sowing</td>
<td>20b</td>
<td>34b</td>
</tr>
<tr>
<td>Phosthiazate</td>
<td>4*</td>
<td>Before sowing</td>
<td>144c</td>
<td>10b</td>
</tr>
<tr>
<td>Non treated soil</td>
<td>-</td>
<td>Before sowing</td>
<td>20b</td>
<td>18b</td>
</tr>
</tbody>
</table>

**Values with the same letters are not significantly different at P=0.05 according to Fisher’s least significant difference test.**
metabolites other than saponins, such as phenolics and canavanine, or the release of nematotoxic ammoniacal nitrogen should be also considered (Natelson, 1985; Bailey and Lazarovits, 2003).

**Limonoid triterpenes**

Limonoids are a group of metabolically altered triterpenes occurring in species belonging to Rutaceae and mainly Meliaceae families, though limonoids from the neem tree (Azadirachta indica A. Juss.) are the most widely investigated for their biological activities (Akhtar, 2000). Neem contains more than 100 limonoid compounds, including azadirachtin, salannin, and nimbin, mainly working as repellents, feeding deterrents and insect growth inhibitors (Schmutterer, 1990). Azadirachtin is the most known neem limonoid, due to its activity against insects and phytoparasitic nematodes (Akhtar, 2000; Oka et al., 2007) (Table 4). Soil treatments with azadiractin formulations, either alone or combined with other nonchemical techniques, such as soil solarisation, demonstrated to be effective mainly for reducing root-knot nematode infestation and increasing crop yield in several field and greenhouse experiments in Central and Southern Italy (Caroppo et al., 2005; Colombo et al., 2005). However, the nematicidal effect of neem formulations was also demonstrated on cyst-nematode species, such as Heterodera cajani Koshy and Heterodera glycines Ichinoe (Mojumder and Raman, 1999; Rodrigues et al., 2001).

**Essential oils**

Essential oils (EOs) are secondary metabolites produced by aromatic plant species from many botanical families, such as Myrtaceae, Lauraceae, Lamiaceae, Asteraceae. EOs are mixtures of volatile compounds, including low molecular weight terpenes and phenolics constituents, that play a major role in plant chemical defence against insects, fungal pathogens and also nematodes (Bakkali et al., 2008). Chemical composition, toxicity and bioactivity of EOs are largely affected by climate and agronomical and technical factors, as the plant phenological stage and the method of extraction (Lahlou, 2004). Due to a low mammalian toxicity and persistence in the environment, as well as to a low induction of resistance in target organisms, EOs are more and more considered as good candidates for the development of new sustainable nematicidal formulations.

As exhaustively reviewed by Andrés et al. (2012), a large number of EOs from different botanical families has been analysed in vitro for their nematicidal activity, mainly against root-knot nematodes and the pinewood nematode Bursaphelenchus xylophilus Nickle. In particular, a high toxicity to root-knot nematodes has been reported for the EOs from Cymbopogon spp., Mentha spp., Eucalyptus spp., Pelargonium graveolens L’Hér. and Ocimum basilicum L. (Sangwan et al., 1990; Leela and timing |
<table>
<thead>
<tr>
<th>Yield (T ha⁻¹)</th>
<th>Root gall index (0-5)</th>
<th>Final nematode population (eggs and J2 mL⁻¹ soil)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q. saponaria 30 at transplant</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q. saponaria 20+10 at transplant and 15 dd after transplant</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q. saponaria 10+10+10 at transplant and 15 and 30 dd after transplant</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T. erecta 40 at transplant</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T. erecta 30+10 at transplant and 15 dd after transplant</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T. erecta 20+10+10 at transplant and 15 and 30 dd after transplant</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fenamiphos 36 7 dd before transplant</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non treated</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Non treated

**Table 5. Effect of treatments with formulates of Quillaja saponaria and Tagetes erecta on field tomato yield and infestation of the root-knot nematode Meloidogyne incognita in Southern Italy.**

Values with the same letters are not significantly different at P=0.05 according to Fisher’s least significant difference test.
Eucalyptus globulus (Laquale et al., 2013a). Toxicity of a large number of EOs to B. xylophilus has been reported mainly by studies from Korea and Portugal, as these countries are severely affected by the presence of this nematode (Kong et al., 2006; Barbosa et al., 2010).

Much fewer data are available on the in vivo effect of EOs on phytonematodes. A consistent suppression of M. incognita on tomato roots after soil drench treatments with water emulsions of EOs from Schinus molle L., Cinnamomum camphora (L.) J. Presl, Eugenia caryophyllata Thunb., Cinnamomum zeylanicum Blume and Citrus aurantium L. has been recently reported by Laquale et al. (2013b) (Figure 8). The same authors also documented the nematicidal effect of soil treatments with EOs of Eucalyptus citrirodor Hook. and Eucalyptus globulus Labill. on the same nematode species (Laquale et al., 2013a).

Polyethylenyls

Polyethylenyls are substances with insecticidal and nematicidal properties, present in species of the Asteraceae family and mainly in the genus Tagetes (Chitwood, 2002). The most known polyethylenyls are surely those responsible for the nematicidal activity of Tagetes erecta L. (Uhlenbroek and Bijloo, 1958) (Figure 9). The nematicidal effect of Tagetes species, used either as a source of nematode-antagonistic formulations or as cover, green manure or rotation crops, has been reported by a large number of studies (Wang et al., 2007; Hooks et al., 2010). In field and greenhouse experiments, a commercial formulation of the aqueous extract of T. erecta effectively controlled the infestation of M. incognita on tomato (Solanum lycopersicum L.) both in Southern and Northern Italy, resulting also in a stimulating effect on crop growth and yield (Curto et al., 2006; D'Addabbo et al., 2008) (Table 5).

Alkaloids

Alkaloids are nitrogen-containing natural secondary metabolites from several botanical families, amongst which also the Solanaceae, though the highest activity against phytonematodes was reported for pyrrolizidine alkaloids from Fabaceae species, but also from Liliaceae, Apocynaceae and Papaveraceae (Thoden et al., 2009). A nematicidal activity has been documented also for steroidal alkaloids, such as α-tomatine and α-chaconine and solanine (Chitwood, 2002).

Phenolics, flavonoids and tannins

Phenolics are known as toxic to insects, fungi, bacteria, weeds and also nematodes (Ohi and Panno, 2010). Among phenolics, a consistent nematicidal activity was often reported for flavonoids (Ntalli and Caboni, 2012), a large group of secondary metabolites with a key role in plant defence against insects, fungal and bacterial pathogens and viral diseases.

A role in plant protection from predators and parasites is also played by tannins, polyphenolic compounds widely present in many plant species and documented for their activity on phytoparasitic nematodes (Hewlett et al., 1999). Soil treatments with tannic acid were found to effectively control the infestation of the root-knot nematode Meloidogyne arenaria Chitow. on squash (Cucurbita pepo L.) (Mian and Rodriguez-Kabana, 1982). Application to the soil of a commercial formulation of the tannins from chestnut (Castanea sativa Mill.) significantly reduced the population of M. javanica on potted tomato (Maistrello et al., 2010).

Cyanogenic glycosides

Cyanogenic glycosides are cyanide-releasing aminoacid-derived glycosides, involved in the defense of more than 2500 plant species against predators and parasites. Cyanide is one of the decomposition products of the β-glucosidase-hydrolysis of glycoside molecule, occurring upon plant tissue disruption by predators or by mechanical incorporation of plant materials into the soil. Green manure of sudangrass, Sorghum sudanense (Piper) Stapf. Poaceae, is widely reported for its suppressiveness on root-knot nematodes (Mojatiedi et al., 1993a; Widmer and Abawi, 2000) due to the soil fumigating effect of the cyanide released by the hydrolysis of dhurrin, a cyanogenic glucoside largely present in sudangrass.

Conclusions

This short review confirms once more that nematicidal plants and their phytochemicals can play a relevant role in the sustainable management of phytoparasitic nematodes, either in organic and conventional vegetable cropping systems. In organic systems, nematicidal plant-based techniques can represent a fundamental nematode management tool, due to the poor availability of admitted control methods. In conventional agriculture, plant-derived nematicidal formulations can be applied as stand-alone treatments in short-cycle crops, in which risk of residues in the final products does not allow treatments with synthetic nematicides. Combination of plant formulations with synthetic nematicides is recommended for long-cycle crops and, more generally, in the presence of high initial nematode densities. Use of nematicidal plant-based agronomical techniques, such as green manures, rotations or intercropping, is more suitable to extensive crop systems, whereas liquid, meal and pelleted industrial formulations should be the first choice in the intensive systems, where the strict crop successions do not allow the application of agronomical methods.

Finally, a careful cost-benefit evaluation is needed before the application of any nematode control strategies based on biocidal plants, as plant commercial formulations are expensive and agronomical techniques are cheaper but time and labour consuming.

References


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