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Nematicidal Weeds in the Control of Plant Parasitic Nematodes

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ABSTRACT

Weeds are one of the important pests of agricultural production that affect the yield of cultivated plants. These unwanted plants pose a problem, especially in vegetable fields. Synthetic chemicals are used against weeds, but their use is limited due to the uncontrolled application of these substances threatening animal and environmental health, the risk of residues in air, soil and food products, the emergence of poor-quality products by causing phytotoxicity in plants, and the formation of resistance in the targeted pests. The use of plant secretions provides eco-friendly nematode control. In this review, the allelochemicals secreted by plants were discussed and the information on weed species with nematocidal potential was given.

Keywords: Nematode, weed, suppression, allelopathy, secondary metabolites.

Introduction

Regular growth in world population increases the demand for agricultural land and products. The inability to supply food will lead to the emergence of hunger in the future. In parallel with the population increase, the production areas are decreasing day by day due to the opening of agricultural lands for zoning in order to solve the housing problem. For this reason, agriculture is carried out in many countries with the aim of obtaining the highest yield in limited areas. Agricultural production encounters various abiotic and biotic factors that negatively affect crop yield. Causing significant yield loss, weeds, soil-born pathogens and plant parasitic nematodes gain importance within biotic factors. Ontime management of these harmful organisms is recommended to achieve production with higher yield [32].

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Plant parasitic nematodes are important soil born pests of agricultural production that significantly affect crop yield. Many species were identified all around the world and these threaten especially vegetable production. There are 4,100 species of herbivorous nematodes identified and these species are the leading species that cause yield and quality losses in cultivated plants [61]. Among plant parasitic nematodes, 250 species belonging to 43 genera are considered harmful pests in agricultural production in many countries in the world, and 126 species belonging to 33 genera are included in the quarantine pests list [62]. Plant parasitic nematodes feed on parts of the plant such as roots, stems, leaves and flowers. Plant feeders are divided into three groups as endoparasites, ectoparasites and semi-endoparasites according to their feeding patterns in the plant. Ectoparasitic nematodes including genera such as *Longidorus, Criconema* and *Xiphinem*a feed by sinking their stylets from the outer surface of the plant root, while *Meloidogyne* sp. and *Pratylenchus* sp. endoparasitic nematodes enter the root and feed inside the cell. Semiecto andendoparasitic nematodes usually immerse the head of the body into the tissue [63]. While nematodes feeds on their stylets in the plant, they cause death by emptying the cell contents. Some nematodes do not cause cell death but stimulate elongation and growth, and as a result, giant cells with richer nutrient content are formed [64]. In addition to these harmful effects, nematodes lead important pathogens to enter the plant and cause disease [65].

Various methods have been proposed for the control of nematodes but cannot be applied due to inefficient results. In Europe, there were 520 licensed pesticides with active substances in 2019, of which 64% are synthetic chemicals, 9% are organics, 7% are inorganic substances and pheromones, 5% planted extracts and oils, 2% are fatty acids, 1% plant hormones, 1% paraffin and 4% others. Only 110 of these active substances were in the low risk group in terms of harmful effects, and the majority of them planted extracts and pheromones. In chemical control, broad-spectrum fumigants such as methyl bromide and specific pesticides are used. However, a big portion of pesticides is banned in some European countries and some states of the USA due to their harm to human and environmental health and residues that reach dangerous levels in groundwater [66]. Despite the significant increases in the application of synthetic chemicals, their use is limited by harmful effect to the environment and animal health as a result of their uncontrolled use, residual risks on air, soil and food resources, decrease in product quality due to phytotoxicity in plants, and the emergence of resistance in target organisms.

Based on these disadvantages, researches on eco-friendly alternative management methods have become one of the most studied issues in recent years. Until now the efficiency of several methods including allelopathy, crop rotation, mulching, was approved in many studies and nonharmful, environmentally friendly and low-cost management was achieved with the use of plants and their secretions with nematode suppressive potential.

Allelochemicals

Many plants can secrete chemicals that will affect the growth of other organisms around them, and the phenomenon of affecting other living things in this way is called allelopathy. Allelopathic interaction can occur between different plants, between plants and other organisms (fungi, viruses and microorganisms), or between different kinds of organisms (fungi, virus and microorganisms) [58]. This phenomenon has been observed for 2000 years, and the first serious studies began in the 1900s. The term allelopathy was first defined by the German scientist Molisch in 1973. In later years, Rice [54] from the University of Oklahoma explained allelopathy in all its aspects.

Chemical secretions with an allelopathic effect are called allelochemicals [11]. The suppressive effect of many allelochemicals from different organisms hase been studied for years and plant derived allelochemicals gave the most promising result in the control of several weed species, nematodes and plant pathogens. Plant derived allelochemicals are found in all plant parts, including leaves, flowers, fruits, stems, roots, rhizomes, seeds and pollen and their release to the environment occurs by root exudation, plant residue decomposition, leaching from plants and volatilization [67]. Allelochemicals are grouped inro several categories including organic acids, fatty acids, lactones, coumarins, flavonoids, quinones, phenols, aliphatic aldehydes, terpenoids and steroids, alkaloids, amino acids and peptides, nucleosides and tannins, sulfides and glucosinolates, nucleosides and purines ([54]; [11]). The number of 10.000 different allelochemicals with the varying modes of action are It has been estimated that higher plants can produce over 10,000 different allelochemicals, which vary in their activity and mode of action in receptor plants. A single plant may contain and secrete more than one allelochemical and these components together increase the plant's allelopathic potential. The plants with this feature increase the success in pest and disease management [30].

The allelochemicals are applied in crop protection in four different ways; 1) Using allelopathic plant residues as mulch or manure material; 2) Growing allelopathic plants in crop rotation or intercropping; 3) Cultivation of crop plants with allelopathic potential as a cover crop; 4) Applying the aqueous extracts of the plants with allelopathic potential ([8]).

Weeds are harmful plants that also secrete many allelochemicals that affect the growth of plants and many organisms. Weed can be defined as unwanted plants competing with crops for water, light and nutrients, causing yield and quality losses [68]. Weeds are very dense and common in areas with suitable temperature and moisture conditions. Depending on various abiotic and biotic factors such as temperature and crop system, weed density varies, but weeds continue to cause damage in infested areas every year. Among 250.000 identified plants in the world 8000 have been recognized as weeds and of these 250 were included in the list of most harmful pests [20], [21]. Unless there is no interference by humans, animals, microorganisms and other plants weeds have high adaptation potential to newly introduced environments [69]. Furthermore, some pests and pathogens overwinter and survive on weed plants. A dense weed population complicates agriculture and increases production expenditures [43]. Weeds also may interfere with the harvested product and endanger human and animal health.

Weeds produce toxic derivatives like phenolic acids, glycosides, terpenoids, alkaloids, terpenes and flavonoids may have detrimental effect on soil microorganisms and crop plants [48]. Allelochemicals play four different roles in increasing or decreasing nematode density; 1) Release of nematicidal secretions from roots that kill nematodes, inhibit nematode movement, affect physiological and biological parameters like egg hatching; 2) Release of nematode suppressing substance after decomposition of weed residues in the soil; 3) Increase of microorganisms antagonistic to nematodes due to improvement of soil organic matter through weed residues and secretions; 4) Alteration of host plant defense system due to promotion or inhibition of plant growth by allelochemicals [8].

Nematicidal Allelochemicals

Nematicidal weeds mostly belonged to Asteraceae, Compositae, Fabaceae and Brassicaceae families. Glucosinolates, saponins, limonoid triterpenes, essential oils, polyphenols, alkaloids, phenolics, flavonoids, tannins, cyanogenic glycosides are the main groups of nematicidal compounds produced by weeds.

- **Glucosinolates**

The order Brassica includes 3000 plant species belonging to 350 genera. Species in this order produce glucosinolate secondary metabolites that enable plants to protect themselves from biotic and abiotic stress conditions. Furthermore, glucosinolates were found in about 500 dicotyledonous species which are not belonged to Brassica [25]. These are accumulated in the leaf, root, seed and stems of plants from Caricaceae, Resedaceae, Akaniaceae, Brassicaceae, Bataceae, Capparidaceae, Gyrostemonaceae, Moringaceae, Limnanthaceae, Tropaeolaceae

Pentadiplandraceae, Salvadoraceae, Tovariaceae, Koeberliniaceae, Cleomaceae, Emblingiaceae, and Setchellanthaceae families [37]. The number of glucosinolates is higher in Brassicales which contain more than 80% [22]. Glucosinolates (GSL) are secondary metabolites containing S and N. These metabolites are composed of sulfonated oxime and β-thioglucose [70]. It is an organic anion (Figure 1). When glucosinolates are hydrolized by the myrosinase enzyme in plants, chemicals such as isothiocyanate, thiocyanate and nitrile are released. Hydrolysis occurs after cell disruption due to severe plant damage. All these compound have biopesticidal impacts on nematodes, pathogens and harmful organisms. Because of these properties, these plants are also called biofumigants ([39]; [66]; [71]).

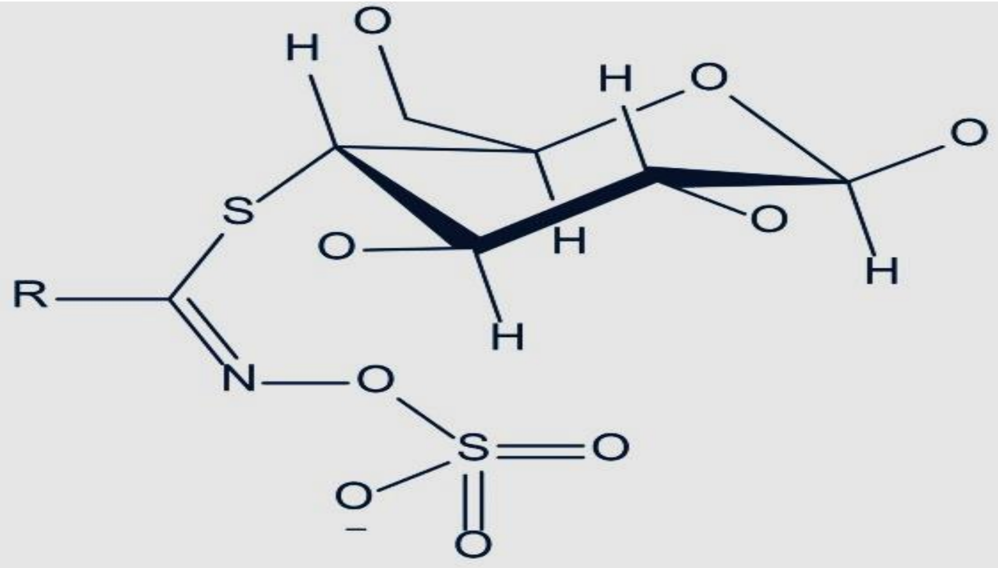

Figure 1. Structure of glucosinolates [9]

GSL, has a function in the defense against fungi and pests, regulation of growth, regulation of nitrogen and sulfur metabolism. It also plays a role in plant defense against heat-related stress effects More than 130 different compounds were identified belonging to the group of glucosinolates and they are divided into three groups as aliphatic, indole, and aromatic glucosinolates. The nematode suppressive substances called isothiocyanates are released by aliphatic and aromatic glucosinolates. Indole glucosinolates have no ability to produce isothiocyanates ([72]; [2]).

The suppressive effect of *Brassicales* crops (*Brassica napus*, *Brassica hirta, Raphanus sativus* L. ssp. *oleiformis*, *Eruca sativa* L.) species has been investigated for years and experiments with these plants have yielded promising results regarding their use as an alternative bionematicide to synthetic chemicals. The sigificant nematode reduction was observed in *Xiphinema index, X. americanum, Gobodera rostochiensis, G. pallida, Melidogyne incognita, M. hapla, M. javanica, M. chitwoodi, Tylenchus semipenetrans, Pratylenchus penetrans, P. neglectus, Heterodera carotae* ([40]; [51]; [59]; [33]; [56]; [7]; [24]). Common glucosinolates with nematicidal potential include gluconapin, progoitrin, sinigrin, glucoraphanin, glucocapparin, gluconasturtin, glucolepdiin, grucin, glucoiberin, glucotropeolin, sinalbin, epi-progoitrin, ([59]; [7]). In many studies, it has been revealed that many weeds from the brassica order, as well as cultivated plants, have nematidal potential.

- **Saponins**

Saponins are secondary metabolites divided to two groups based on steroid or triterpenoid aglycone content. In saponins steroids or triterpenoids are attached via three carbone of sapogenin (Figure 2). More than 50.000 plants have been reported to possess saponins in their seeds, flowers, leaves, stems and fruit. The highest level of these compounds was measured in legume crops [18].

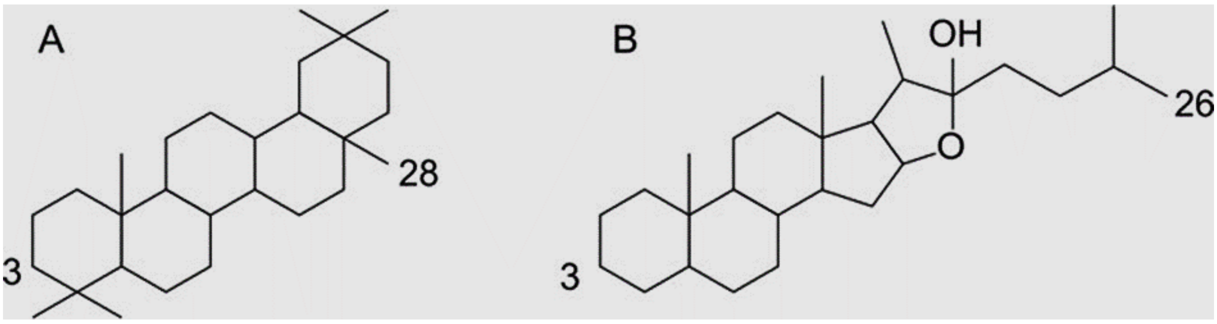

Figure 2. Structure of saponins A: Tripenoid B: Steroidal saponins (Kreigel et al., 2017).

Until now 150 different natural saponins were revealed in plants and they were grouped into 11 classes including tirucallanes, cycloartanes, cucurbitanes, dammaranes, lupanes, oleananes, hopanes, ursanes, taraxasteranes, lanostanes and steroids [35]. Saponins have been isolated from some plants belonging to families like Leguminosae, Agavaceae, Caryophyllaceae, Amarathaceae, Apiaceae, Araliaceae, Chenopodiaceae, Euphorbiaceae, Rosaceae, Prumulaceae, Poaceae, Liliaceae, Convolvulaceae, Fabaceae, Scrophulariaceae and Solanaceae The distribution of saponins vary among different plants. In some plants, saponins accumulate in the root phloem, while in some in the epidermal cell membrane or the periderm and outer cambium tissue of the root [17]. Species from the *Medicago* genus have higher saponin content and contain 95 saponin species which belonged to triterpene glycosides, steroid alkaloid glycosides, and steroid glycosides groups [57]. The nematicidal potential of *Medicago* *arborea*, *M. heyniana* Greuter, *M. lupulina* L. and *M. truncatula* Gaertn., *M. arabica*, *M. hybrida* (Pourr.) Trautv., *M. murex* Willd and *M. sativa* against *Meloidogyne incognita*, *Xiphinema index*, H. Carotae and *Gobodera rostochiensis* were demonstrated in several studies. These secondary metabolites are found to affect cell permeability of mature or juvenile nematodes and decrease cholesterol levels of eggs [6]; [23].

- **Limonoid triterpenes**

Limonoids are formed after an alteration of triterpenes. Families belonging to Cneoraceae Rutaceae, Cucurbitaceae, Simaroubaceae and Meliceae contain a higher amount of limonoids (Figure 3). The number of limonoids identified across the world reached 227 and these belonged to plants from 21 families [49]. *Azadrachta indica* A. Juss neem tree was the most studied plant that carried more than 100 limonoids such as salannin, mahmoudin, gedunin, nimbolide, azadirachtin, nimbidin, sodium nimbidate and nimbin ([73]; [31]). These compounds are accumulated in leaves, seeds, stem, bark and fruits of plants [14].

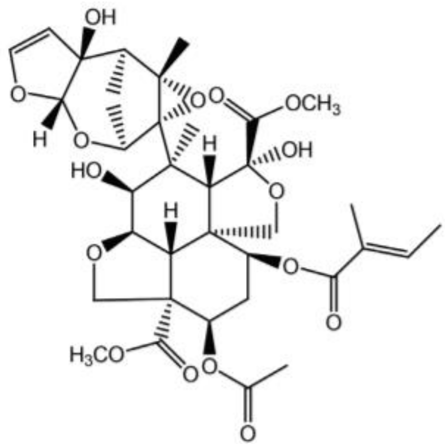

Figure 3. Structure of azadrachtin [42].

The nematicidal effect of azadrachtin from neem was revealed in several studies. The suppressive impact was determined on *Heterodera jacani*, *Heterodera glycines*, *Meloidogyne incognita* and some other nematode species ([41]; [55]; [34]).

- **Essential oils**

Essential oils (EOs) are secondary metabolites produced by plants belinging to families such as Myrtaceae, Apiaceae, Burseraceae, Asteraceae, Laurenceae, Lamiaceae, Zingiberaceae, Poacea and Pinaceae. The plants from genera Thymus, Mentha, Artemisia, Cympogon, Ocimum, Lavandula, Oreganum, Rosmarinus, Melaleuca, Citrus, Eucalyptus and Eugenia contain higher amount of essential oils. Essential oils contain non-polar and polar compounds (Figure 4).

These secondary metabolites are classified into four groups like Phenylpropanoids, terpenes, sulphur or nitrogen containing compounds, straight chain compounds.

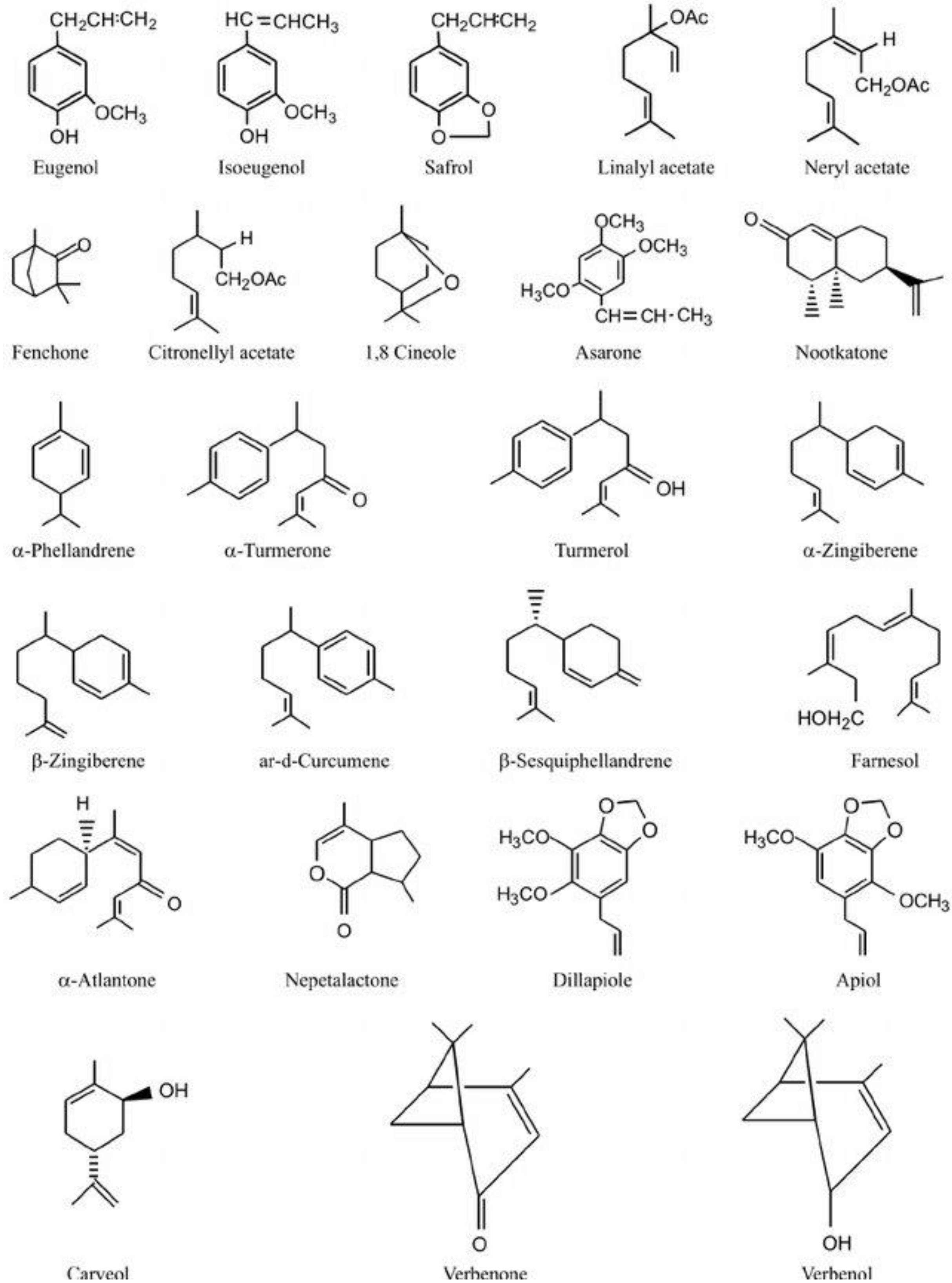

Figure 4. Structure of essential oils [29].

The impact of these compounds on nematodes was investigated and results indicated the nematicidal potential of several plants. Root-knotnematode *Meloidogyne* spp. was successfully suppressed by oils from *Mentha rotundifolia, Carum carvi, Foeniculum vulgare* and *Mentha spicata* plants [46]. More than 310 plant species like *Artemisia arborescencs, Boswellia carterii, Cymbopogon citrates, Cinnamomum zeylanicum, Coriandrum sativum, Zingiber officinalis, Origanum vulgare, Pimenta dioica, Thymus vulgaris, Allium cepa, Paeonia moutan, Perilla frutescens, Schizonepeta tenuifolia, Pelargonium inquinans, Syzygium aromaticum, Coriandrum sativum, Liquidambar orientalis* and *Pimpinella anisum* decreased *Bursaphelenchus xyllophilus* nematode populations in in-vitro studies [5].

- **Polythienyls**

Polythienyls are compounds accumulated in plant parts of Asteraceae family [12]. *Tagetes* spp. is the genus that accumulate polythienlys and contains plant species with nematicidal potential. *Tagetes petula* and *T.erecta* caused significant death of *Meloidogyne incognita, M. javanica, M. hapla, Pratylenchus penetrans, Globodera rostochiensis, Ditylenchus dipsaci, Narcissus tazetta* nematode individuals [12].

- **Alkaloids**

Alkaloids are secondary metabolites containing nitrogen (Figure 5). Alkaloids group constitutes approximately 15.000 secondary metabolites [36]. Plants from families like Solanaceae, Liliaceae, Fabaceae, Apocynaceae and Papaveraceae have alkaloids. The nematicidal potential of pyrrolizidine alkaloids and steroidal alkaloids [12].

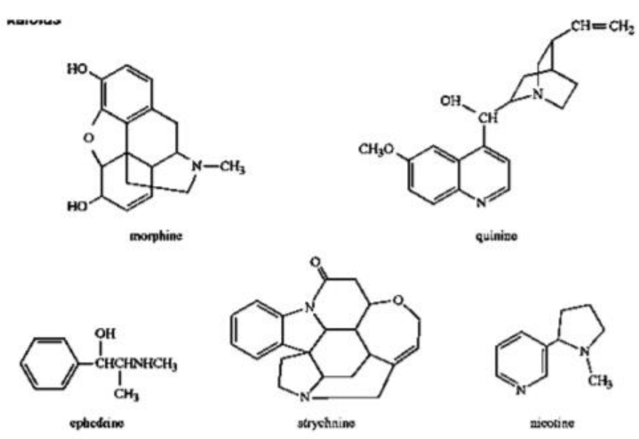

Figure 5. Structure of alkaloids [36].

- **Phenolics, flavonoids, tannins, cyanogenix glycosides**

Phenolics are compounds that are present in several plant species (Figure 6). Especially phenolics from this group have nematicidal potential on several nematode species [45]. Compounds like tannic acid derived from plants like Chesnut showed nematicidal activity on *Meloidogyne* species [12].

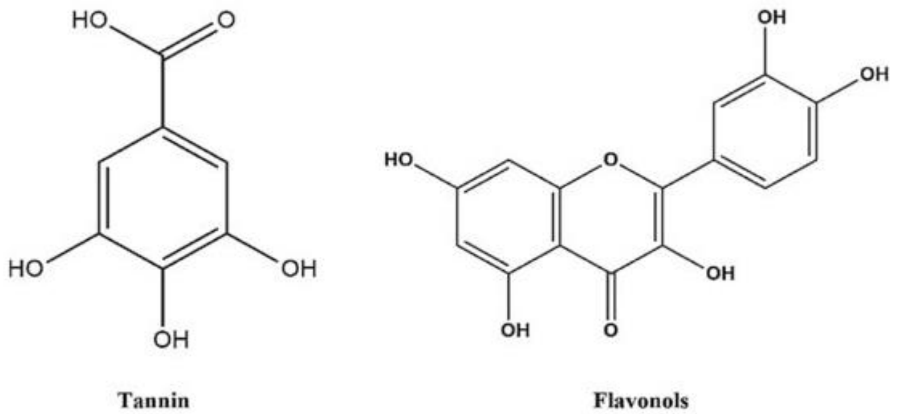

Figure 6. Structure of tannins and flavonoids [26].

Cyanogenic glucosides are aminoacids that release cyanids (Figure 7). Plants like *Sorghum sudanense* contai cyanogenic glucosides and suppress mant nematode species [12].

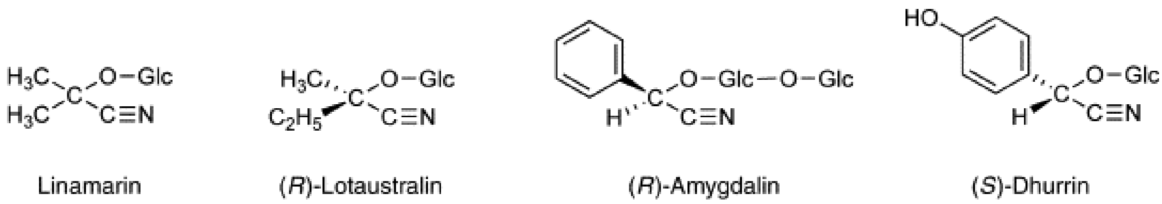

Figure 7. Structure of cyanogenic glucosides [74].

All secondary metabolite groups described in the previous part of this manuscript are present in several weed species and these weeds were found to have nematode inhibitory potential. The list of weeds with nematicidal potential were given in Table 1.

Conclussion

Plant derivatives secondary metabolites provides ecofriendly and low cost nematode suppression. In addition the use of plant secretions have potential to improve soil structure and plant growth. In this review major groups of secondary metabolites are discussed and nematode suppressive potentials are explained with samples.

Table 1. Some weeds with nematidical potential

Weed latin name	Common name	Target nematode species	Literature
Acalypha indica L.	Indian copperleaf	*Meloidogyne incognita*	[27]
Acanthospermum hispidum DC	Bristly starbur	*Meloidogyne incognita*	[10]
Achyranthes aspera L.	Chaff flower	*Meloidogyne incognita*	[27]
Aerva persica (Burm.fil.) Merr	-	*Meloidogyne incognita*	[10]
Argemone mexicana L.	Mexican poppy	*Meloidogyne incognita*	[27]
Armoracia rusticana P.Gaertn.,Mey and Sherb.	Horse radish	*Meloidogyne incognita*	[4]
Artemisia judaica L.	Judean wormwood	*Meloidogyne javanica*	[46]
Artemisia dracunculus L.	Tarragon	*Meloidogyne javanica*	[28]
Asparagus spp.	Sparagus fern	*Meloidogyne incognita*	[12]
Barbarea verna (Mill)Asch	Early yellow-rocket	*Meloidogyne incognita*	[15]
Bidens pillosa L.	blackjack	*Meloidogyne incognita*	[10]
Brassica juncea L.	Wild mustard	*Meloidogyne incognita, Melodogyne javanica Globodera pallida, Pratylenchus neglectus,*	[53]; [47]; [44]
Brassica tournefortii Gouan	African mustard	*Pratylenchus penetrans, Meloidogyne chitwoodi*	[51]; [13]
Brassica oxyrrhina Cos (Wilk)	Smooth-stemmed turnip	*Pratylenchus penetrans, Meloidogyne chitwoodi, Pratylenchus neglectus*	[51]; [13]
Calotropis procera (Aiton) W. T. Aiton	Calotrope	*Tylenchulus semipenetrans*	[3]
Capparis spinosa L.	Caper bush	*Meloidogyne incognita*	[75]
Chenopodium ambrosioides L.	Mexican tea	*Meloidogyne incognita*	[76]
Cleome viscosa L.	Asian spiderflower	*Meloidogyne incognita*	[77]
Cymbopogon martinii (Roxb.) J.F.Watson	Palmarosa	*Meloidogyne incognita*	[77]
Chrysanthemum coronarium L.	Crown daisy	*Meloidogyne artiellia*	[50]
Datura alba	Angel's trumpet	*Tylenchulus semipenetrans*	[3]
Datura stramonium W.	Jimson weed	*Globodera rostochiensis Meloidogyne incognita*	[10]
Descurainia sophia (L.) Webb ex Prantl	Flixweed	*Meloidogyne javanica*	[78]

Flaveria trinervia (Spren.) Mohr.	Gaika weed	*Meloidogyne incognita*	[10]
Glycyrrhiza glabra	Licorice	*Meloidogyne* spp.	[19]
Heliotropium indicum L.	Indian heliotrope	*Meloidogyne incognita*	[10]
Lepidium draba L.	Hoary cress	*Tylenchulus semipenetrans*	[38]
Lippia juneliana L.	-	*Meloidogyne spp*	[79]
Lippia turbinata Griseb.	-	*Meloidogyne spp*	[79]
Mentha pulegium	Pennroyal	*Meloidogyne incognita*	[45]
Melissa officinalis L.	Common balm	*Meloidogyne incognita*	[45]
Nasturtium officinale R. Br.	Watercress	*Meloidogyne hapla*	[60]
Ononis natrix L.	Yellow Restharrow	*Meloidogyne* spp.	[16]
Peganum harmala L.	Syrian rue	*Meloidogyne* spp.	[16]
Raphanus raphanistrum L.	Wild radish	*Meloidogyne incognita*	[80]
Ricinis communis	Castor bean	*Meloidogyne incognita*	[51]; [13]
Ruta chalepensis L.	-	*Meloidogyne incognita, Meloidogyne javanica*	[45]
Senna tora	Sickle senna	*Meloidogyne incognita*	[10]
Sinapis arvensis subsp. *arvensis*	Wild mustard	*Xiphinema index, Pratylenchus penetrans, Meloidogyne chitwoodi Rotylenchulus reniformis Meloidogyne incognita*	[1]; [80]
Sinapis alba	White mustard	*Pratylenchus penetrans, Meloidogyne chitwoodi*	[13]
Sisymbrium irio	London rocket	*Rotylennchulus reniformis, Meloidogyne incognita*	[52]
Xanthium strumarium L.	Cocklebur	*Meloidogyne incognita*	[10]

DECLARATION OF COMPETING INTEREST

The authors declare that there are no conflict of interest.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Lerzan Öztürk: carried out reviewing and final edition of the manuscript

Bahadır ŞİN: carried out literature review writing and editing of manuscript.

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