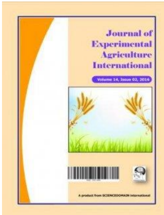

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Current Status of the Occurrence and Reaction Root-knot Nematodes in the Main Botanical Families of Medicinal Plants

Cristina dos Santos Ribeiro Costa[1*], Antonio Elton da Silva Costa[1], Ana Maria Maciel dos Santos[1], Jacqueline Wanessa de Lima Pereira[1], Rejane Rodrigues da Costa e Carvalho[1] and José Luiz Sandes de Carvalho Filho[1]

[1]*Rural Federal University of Pernambuco (UFRPE), Recife, PE, Brazil.*

Authors' contributions

This work was carried out in collaboration among all authors. Authors CSRC, AESC and AMMS designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors JWLP and RRCC managed the analyses of the study. Author JLSCF managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Medicinal plants are described such as those produce substances capable of provoking reactions in the human body leading to the cure of diseases. Like as cultivated species, medicinal plants can be attacked by various pests and diseases, affecting the qualitative and quantitative characteristics of their curative properties, as well as productivity. Phytonematodes are one of the main factors limiting the productivity of cultivated plants. In medicinal species this pathogens group has caused damage in the sanity of the plants interfering in the quality of the compounds produced. Among them, due to the high parasitism degree, the species of the genus *Meloidogyne*, popularly known as root-knot nematodes. Among the management strategies of these phytopathogens, biological and cultural controls have low efficiency reports. Likewise, chemical control is not indicated due to

**Corresponding author: E-mail: crisriibeiro@hotmail.com;*

its high cost, besides, its high toxicity and risk of environmental pollution. Therefore, the most effective control method is the use of resistant plant species or cultivars. Once these species are identified, they can be used as antagonists or incorporated into the soil, aiming to decrease the nematode population in infested areas. The use of resistant medicinal species allows little or no reproduction of *Meloidogyne* spp., providing effective control in the field. Other advantages are the reduction of production costs, and the protection of the environment against pollution caused by chemical waste.

Keywords: Meloidogyne incognita; Meloidogyne javanica; Meloidogyne enterolobii; phytonematodes; parasitism; resistance sources; gall; traditional medicine; herbal medicines.

1. INTRODUCTION

Plants have been used as medicines for thousands of years in the form of raw drugs such as tinctures, teas, poultices, and other herbal formulations. Medicinal plants can be described as any plant which has in one or more organs substances that can be used for therapeutic purposes or that are precursors of semisynthetic drugs [1]. Knowledge about the use of medicinal plants has been passed down through generations among traditional populations. Over the years, the use of plants as a drug began to be carried out from the isolation of active compounds, starting with the isolation of morphine and opium in the early 19th century [2]. The isolation and pharmacological characterization of the active compounds of medicinal plants to be continue carried until the present day.

The consumption demand of medicinal plants and herbal medicines has increased worldwide. The World Health Organization (WHO) reported that about 80% of the world population makes use of some type of medicinal herb for the treatment of the most diverse diseases [3]. The use of medicinal plants has even received incentives from WHO itself. It is estimated that the market for natural products has increase of approximately 22% per year [4]. Among the factors contributed to this increase are the high cost of synthetic drugs and the resistance of pathogens to synthetic drugs. This growing increase in the use demand for medicinal plants meant that the production of some species was not made on extractivism form anymore, but now it is carried out in the form of a large-scale cultivation.

Like other cultivated species, medicinal plants can be attacked by pests and diseases which, in addition to causing damage, can affect both qualitatively and quantitatively the production of their active ingredients. Among the pathogens that may affect medicinal plants are phytonematods, [5], such as those of the genus *Meloidogyne*. Species of this genus are popularly known as root-knot nematodes, they are highly polyphagous sedentary microorganisms penetrate the plant roots and when they set up their feeding cycle, they cause the plants to form galls at their roots, once installed, their feeding cycle pass to parasitize the host plant. The damage severity caused will depend on the susceptibility of the parasitized species / variety, on the environmental conditions, on the presence of other pathogens and on the population density of these pathogens in the soil [6].

In general, the root-knot nematodes weaken the parasitized plants as a result of the decrease of their nutrients in cell sap. In addition, wounds, lesions and the formation of feeding sites near vascular tissues reduce the roots ability to absorb water and nutrients. As a result, the aerial part does not develop normally, causing reduction in the production and, in some cases, culminating in the plant death. The medicinal species, jaborandi (*Pilocarpus microphyllus*) produces the alkaloid pilocarpine, which is synthesized in the roots and translocated to the leaves, from where it is extracted and marketed as eye drops for the glaucoma treatment. According to [7], commercial plantations of jaborandi, in the state of Maranhão - Brazil, under conditions of high temperature, sandy soil and irrigation, were severely impaired by *M. javanica*. The attack symptoms were the low development of the plants and the decrease in the pilocarpine content of the collected leaves, compromising the drug production.

The control of *Meloidogyne* spp. is essential for the success of plant species cultivation, since the root-knot nematodes can cause losses of up to 100% in the production, depending on their infestation intensity of the area and the planted cultivars. Different control methods can be used against the root-knot nematodes, among them the chemical, cultural and biological, but some of them stand out as inefficient and others can cause environmental damage, compromising the sanity of the people who manipulate them such as pollution of the agricultural environment. In view of the difficulty of nematode control by the previously mentioned methods, the use of resistant cultivars is a widely accepted alternative, due to its low cost and high efficiency [8]. Medicinal plants produce substances in their secondary metabolism that may decrease or even inhibit the reproduction of field nematodes by decreasing the population of these pathogens. In this sense, it is necessary to identify plant species having these properties, aiming to make them a viable alternative to the meloidogynosis management.

2. GENERAL ASPECTS OF MEDICINAL PLANTS

Medicinal plants are characterized as those have active principles capable of restoring the homeostasis of the organism affected by diseases [9]. The natural properties of medicinal plants are exploited by humans to meet their needs, especially those with therapeutic actions and effects, and are often the only resources available for the treatment of diseases in underdeveloped communities, rural communities and people living in isolated groups [10]. Traditional medicine involves the use of plant extracts or their active principles, research and scientific proof of the effectiveness of these species used, can serve as a source of raw material for modern medicines. In developing countries, the use of medicinal plants contributes by replacing imported drugs, thus, increasing the economic self-sufficiency of these countries [11].

Traditional medicine has a long history of serving people throughout the world, it is believed the use of plants in the treatment of diseases has been carried out since the emergence of early civilizations [12]. Fossil records indicate the use of plants as medicines since the Paleolithic period. Evidence of this initial association was found in the tomb of a Neanderthal man buried 60,000 years ago, where pollen analysis indicated that all plants buried with the corpse had medicinal value [13].

The Sumerian Clay Table is the earliest known medical document with 4,000 years old, and in that document are records of plant remedies for various diseases. At the time of the ancient Egyptian civilization, there was already information about the great wealth of medicinal plants. Among the many remedies prescribed were man's drake for pain relief and garlic for the treatment of circulatory and cardiac disorders. This information, along with hundreds of other remedies, has been preserved in the Ebers papyrus written about 3,500 years ago [13]. In ancient China, there is also information about the first medicinal uses of plants.

In Brazil, the history of the use of plants in the treatment of diseases has strong influences from African, indigenous and European cultures [14]. The contribution of the African peoples to the tradition of the use of medicinal plants in Brazil came from the plants that the slaves brought with them for use in religious rituals and also for their use of the pharmacological properties, empirically discovered. The Brazilian Indian people who lived in countless tribes used a great quantity of medicinal plants and, through the shamans, this knowledge of the local herbs and their uses was transmitted and improved with each generation.

Medicinal plants, herbal remedies and isolated natural products represent a market that moves billions of dollars in both developed and developing countries [16]. According to the Organization for Economic Cooperation and Development [17], drug use in general is increasing, and part of this increase is due to the growing need for medicines for the treatment of chronic diseases and those related to aging.

In the group of drug products highlighted in the above survey, the following categories of drugs have the highest growth rates, antihypertensive, antidepressant, antidiabetic and antitumor drugs. In the survey conducted between 2000 and 2015 in the OECD countries, consumption almost doubled for drugs was used as antihypertensives, antidiabetics and antidepressants, and almost quadrupled for drugs was used to control cholesterol.

These data demonstrate how the pharmaceutical market is consolidated among the existing pharmaceutical formulations, most of them are derived from plants or synthetic analogs derived from plants. Based on the known curative capacity present in several plant species, a large part of the world population, mainly from developing countries, still makes use of medicinal plants for their daily health care needs and depend on plants for use as medicines [16].
The World Health Organization also stated that the consumption of medicinal plants has

increased considerably over the last few years, as well as the number of species used, [3]. Datas of the United Nations indicate the world market for natural products is growing by 7% a year. Involving more than 32 thousand species, of which 900 are cultivated or are in the process of domestication, and moves around 400 thousand tons of plants per year. In Brazil, it is estimated that sales of pharmaceutical products derived from plants reach US $ 550 million [18]. According to Coutinho [19], only the Amazon, in 2050, will be able to produce 500 billion dollars in medicines and cosmetics, from medicinal and aromatic plants.

The World Health Organization also affirmed that the consumption of medicinal plants has increased considerably over the last years, as well as the number of species used [3]. The world market for natural products presents an increasing demand of 7% per year, involving more than 32,000 species, of which 900 are cultivated or are in the process of domestication and moving around 400,000 tons of plants per year. In Brazil, it is estimated sales of pharmaceutical products derived from plants reached US $ 550 million [18]. According to Coutinho [19], only the brazilian amazonia, in 2050, will be able to produce 500 billion dollars in medicines and cosmetics, from medicinal and aromatic plants.

Brazil has one of the most interesting, important and diverse floras of the planet, distributed in their limits in six bioactive phytogeographical domains: Amazon, Cerrado, Caatinga, Atlantic Forest, Pampa and Pantanal [20]. There is a growing interest in scientifically studying and documenting this diversity, including new technologies for study involving both academy and pharmaceutical companies that promote studies for commercial exorcination of plant resources for the development of new medicines [21].

Due to the growing interest in the use of medicinal plants, there is a notable growth in the field of research involving these species, in addition to the adoption by health systems in developed countries of traditional medicine as a medical practice integrating their culture. Historically, all drugs were derived from plants, either in the simple form, through raw vegetable materials or in the refined form of crude extracts, mixtures, oils, etc., which demonstrate the important role of research and development of new drugs. Since 2002, the World Health Organization (WHO) has encouraged the rescue of data on plants used in the practice of ancient medicine, since they are considered potentially useful in the development of new drugs [22] Recent estimates suggested that thousands of plants are known with medicinal applications in various cultures [23], and are still used today to treat diseases [24].

Several studies about the chemical composition of medicinal plants allowing an association between different species and their respective biological activities based on observation, description and experimental research. Such studies have largely contributed to the discovery of bioactive natural products [25]. Medicinal plants produce a broad spectrum of chemical compounds, apparently without direct contribution to their growth and development, termed secondary metabolites [26]. Such as those outlined below, divided into three main classes of compounds of interest in plants: flavonoid, terpenes and phenolic compounds. Terpenes are found in families such as Rhamnaceae, have several curative actions, such as purgative, energetic, and antifebrile action, being widely used because of its effectiveness and its low cost [27]. Flavonoids are present in families such as Passifloraceae that represent a chemical class of ubiquity in the group of phenolic substances of plant origin [28], presenting a wide range of biological activities, such as antitumor, anti-inflammatory, antioxidant, antibacterial action, antiparasitic, antiviral, among others [29]. And, the phenolic compounds found easily in plants of the family Lamiaceae and Asteraceae may exhibit antimicrobial and anti-inflammatory effects [30].

For the plants, these compounds have different biological properties and in phytotherapy are used in the treatment of a wide variety of diseases, including cancers [31], neurological disorders [26], chronic inflammations and lesions [32], diabetes [33], atherosclerosis [34], cardiovascular diseases and skin diseases [35]. Many botanical families have in their compounds healing properties, derived from substances produced by their secondary metabolism.

2.1 Acanthaceae

Acanthaceae is a family of dicotyledonous plants, of the order Lamiales, which contains 250 genera and about 2,500 species, mostly composed of tropical herbs, shrubs, creepers or epiphytes, mainly distributed in Indonesia, Malaysia, Africa, Brazil and Central America [36]. In Brazil, the family is represented by 41 genera and 432 species [37], of wich *Justicia gendarussa* (black adusa) and *Justicia pectoralis* var. *stenophylla* (freshcut) are some examples of medicinal plants of this family. Some species are used as ornamental and forage, and are commonly found in both wet and semi-arid forests [38]. Phytochemical studies indicate some species of this family have potential for pharmacological use.

The medicinal plants of this family are used for the treatment of fever, rheumatism, headache, abdominal cramps, lung inflammations, cough, and also as expectorant, sudorific, anti-inflammatory and aphrodisiac [15]. The main constituents present in these plants responsible for these curative effects are coumarins, umbelliferae, dihydroxycoumarin, acetylated orthohydroxy-transcinnamic acid, betasitosterol, C-glycosylphoflavones-0-methoxylated eswertisin, 2 "-0-ramnosilesterthylaponine, betaine and lignan justicidina B [39].

2.2 Amaranthaceae

The Amaranthaceae family is composed of 169 genera and about 2,360 species, being the largest genera being *Atriplex* (300 spp.), *Gomphrena* (120 spp.), *Salsola* (120 spp.), *Alternanthera* (100 spp.), *Chenopodium* (100 spp.), *Ptilotus* (100 spp.), *Suaeda* (100 spp.), *Iresine* (80 spp.), *Amaranthus* (60 spp.), *Corispermum* (60 spp.) e *Celosia* (50 spp.), mainly distributed by *Ptilotu*s (100 spp.), *Suaeda* (100 spp.), distributed in regions of tropical climate and temperate regions. In Brazil, there are 145 species belonging to 19 genera, being 71 endemic species from different regions and Brazilian biomes [40]. The plants of the Amaranthaceae family are predominantly herbaceous and sub-shrub.

About 20 species have food and / or medicinal uses, mainly species of the genus *Alternanthera, Amaranthus* and *Gomphrena*. Among the medicinal properties of these plants are the antitumor, diuretic, digestive, depurative, vermifuge, emmenagogue, tonic, bitter, immunostimulating, astringent, antidiarrheal, antitussive, laxative and antiblenorrhagic activities [15]. These medicinal properties are derived from the presence of flavonic compounds, palmitic, oleic and linoleic acids, as well as carotenoids, saponins, ecdysterone, spinasterol and ascaridiol.

The species of the family Amaranthaceae are able to tolerate highly arid habitats and very saline soils due to a series of specific adaptations. These include extremely high seed production, varying between 13,000 and 50,000 seeds per plant, depending on soil richness and an efficient seed dispersal mechanism [41]. Both mechanisms are intended to ensure the survival of plants during arid periods and in hostile environments. Some species may accumulate high concentrations of arsenic in different parts of their organism, without showing decrease of the growth, contributing to their use as fixatives in highly polluted soils [41].

2.3 Apiaceae

The family Apiaceae (formerly known as the Umbelliferae family), is one of the great families among dicotyledons, comprising approximately 450 genera and 3,700 species [42]. This family has great economic value, because it has edible species, spices, as well as used in perfumery or as essences in alcoholic beverages. Besides the gastronomic importance, these plants are sources of gums and resins of great medicinal use as sedatives, antispasmodics, stimulants, and even poisons, being possible to emphasize *Anethum graveolens* (dill), *Anthriscus cerefolium* (garden chervil), *Angélica* spp. (*Angelica*), *Carum carvi* (caraway), *Coriandrum sativum* (Coriander), *Cuminum cyminum* (cumin), *Foeniculum vulgare* (sweet fennel), *Ferula gummosa* (galbanum) and *Pimpinella anisum* (anise) [15].

The plants of this family usually have the pungent odor due to the presence of essential oil or oleoresin and several other compounds with many biological activities [43]. Some of the main properties are the ability to induce apoptosis, antibacterial action, anti-inflammatory, excitatory, depurative, depurative, expectorant, febrile, aphrodisiac, hepatoprotective, vaso-relaxing, diuretic effects, cyclooxygenase inhibitor and antitumor activities [44]. The essential oils of Apiaceae are employed in different fields such as food and beverages, cosmetics and pharmaceuticals, [45]. In addition to the essential oil, these plants may contain alkaloids, saponins, flavonoids, quercetin, amino acids, minerals, pectins, tannins, mucilage, acetic and oxalic acids, coryandrol, limonene, linalool, terpinene and sugars. They are also considered promising candidates for biocides to control parasites and vectors [46].

2.4 Apocynaceae

The family Apocynaceae is composed of species usually characterized by the presence of latex, about 5,000 species distributed in 550 genera [47]. They are found predominantly in the tropics and subtropics [48]. In Brazil, there are more than 400 species in 41 genera, of which 32 are found only in the Amazon [49].

Many of the tree species of this family present high quality in their woods [50]; in addition, their bark is commonly used in the infusions form for the treatment of a number of diseases due to their low toxicity and the absence of contraindications [50]. As examples, the species *Aspidosperma ramiflorum* (guatambu amarillo) is employed in the treatment of leishmaniasis; *Aspidosperma nitidum* (brasilian name: "carapanaúba") is used as a contraceptive, in the inflammation treatment of the uterus and ovary, in diabetes, in stomach problems, against cancer, fever and rheumatism; *Catharanthus roseus* (madagascar periwinkle) is used as vasodilator, sudorific, diuretic, hypoglycemic, antileukemic and febrifuge and; *Calotropis procera* (roostertree) that has analgesic, antirheumatic, proteolytic, anti-inflammatory, odontogenic and tranquilizing properties [15].

Phytochemical studies pointed to the frequent occurrence of alkaloid structures, biologically they act on the opiate, GABAergic, cholinergic, muscarinic, serotonergic and dopaminergic neurotransmitter systems [50]. They were widely used as arterial hypotension, sympatholytic, diuretic, peripheral vasoconstrictor, respiratory stimulant, anesthetic, adrenergic blocking agent, intestinal spasmogen, sedative and skeletal muscle relaxant [51]. Besides, these substances, methyl ether, coumarins, sugars, triterpenoids, betulinic acid, cardioactive glycosides and lactose iridoids can also be found [15].

2.5 Asteraceae

The Asteraceae family is predominantly composed of herbaceous individuals, but includes some woody species and arboreal types. This botanical family has approximately 25,000 species distributed in more than 1,100 genera [52], being characterized as the second largest family of the vegetable kingdom. The family members have a remarkable ecological and economic importance, including ethnobotanical, phytochemical, and medicinal purposes [52].

Several plants of this family are edible and are used in traditional medicine. The species of this family are generally a source of many biologically active compounds such as essential oils, organic compounds [53], flavonoids [54], terpenoids [55], lignans [54], alkaloids, saponins, stilbenes and sterols [56], polysaccharides [57], antioxidants, lapatin, fuquinone, glycosides, mucilages, antibiotic principle and B-complex vitamins conferring anesthetic, bactericidal, anti-inflammatory, antimycotic, contraceptive, cancerous and ulcer inhibitory action, antipyretic, hepatoprotective and immunostimulatory activity [15].

2.6 Brassicaceae

The Brassicaceae family (syn. Cruciferae) has relevant importance economic and scientific,because it includes a large number of cultivated plants, mainly olive, medicinal and ornamental species, weeds and some model organisms, such as *Arabidopsis thaliana* [58]. The family has 338 genera containing 3,709 species [59], among the main medicinal plants belonging to this family, it is possible to highlight *Brassica rapa* (mustard), *Coronopus didymus* (lesser swinecress) and *Nasturtium officinale* (watercress).

In traditional medicine, plants belonging to the family Brassicaceae are used as a revulsive or rubefacient drug, blood depurative, diuretic, expectorant, febrifuge, stomachic, tonic and as a stimulant of the digestive organs. Externally, they can be used in the treatment of rheumatic pain and injury [15]. These medicinal properties are due to the presence of essential oils, glycosides, carotenes, thioglucosides, minerals, vitamins, triglycerides, proteins, sinapine and phenylpropanoide [60].

2.7 Costaceae

The Costaceae family belongs to about 110 to 115 species, distributed in the genera *Costus*, *Monocostus*, *Dimerocostuse* and *Tapeinocheilas*, being generally found in tropical and subtropical areas, tropical forests and other humid environments. *Costus*, the largest genus, has a pantropical distribution, with its greatest diversity in the neotropical region (about 40 spp.), The species of this family present great variability in terms of leaf and flower morphology [61].

Economically, the family still has little importance, being cultivated mainly for ornamental and medicinal purposes [62].

Phytochemical studies in plants of the Costaceae family show mainly the presence of flavonoids, quercetin, tamarixetine, steroids, alkaloids, saponins, inulin, tannins, sistosterol, mucilages, sapogenins, pectins and calcium oxalate [63]. In addition to these compounds, diosgenin has also been isolated from rhizomes, which has attracted the attention of many researchers as a new precursor source of steroidal hormones [64]. These compounds confer depurative, astringent, diuretic, antimicrobial, antioxidant, anti-inflammatory and cardiovascular protective properties [65].

2.8 Crassulaceae

Crassulaceae is a family of dicotyledonous plants, consisting of 35 genera with approximately 1,400 species, usually herbaceous and succulent plants, occasionally sub-shrub or shrub, mainly distributed in the Northern Hemisphere and Southern Africa [66]. Several species of this family are used in the landscaping as forraces, creating borders or massifs in the sunny spaces, being ideal for compositions of rocky gardens, some plants are cultivated in pots, including in hanging pots, making use of pending plants or prostrate habits. They are also ideal for the constitution of minijardins, according to the species [66].

Among the species belonging to the family Crassulaceae, the species *Bryophyllum pinnatum* (airplant) presents a wide use in folk medicine for the treatment of arthritis and dyspepsia [66,15]. The mentioned species also has anti-inflammatory, antitumor, antiviral, antimicrobial, emollient and healing properties and can be used for the relief of pertussis, bronchitis, asthma and various respiratory tract infections; external use for the treatment of burns, dermatoses, bruises, cuts, dermatitis and boils; acnes, pimples, calluses and chicken pox; itching for no apparent reason; heartburn, gastritis, ulcer and stomach or abdominal discomfort; headaches and migraines; dysentery and diarrhea; cramps and menstrual disorders; balance diabetes; eliminate or reduce kidney stones [67]. Regarding chemical composition, the literature reported the presence of polysaccharides, anthocyanidins, flavonoids, bufadienolides, aglycone, patuletin, quercitrin and isoquercitrin [68].

2.9 Lamiaceae

The Lamiaceae family is one of the most diversified in terms of use in traditional medicine, having its medicinal value based on the high concentration of volatile oils [69]. It is one of the largest families among dicotyledons, being composed of more than 240 genera, many species belonging to this family are highly aromatic, due to the presence of glandular structures producing volatile oils [70]. These oils are important in the composition of pesticides, pharmaceuticals, flavorings, perfumes, fragrances and cosmetics [71].

Species of Lamiaceae family have a wide range of biological and pharmacological activities, including essential oils, linalool, limonene, citral, citronellol, flavonoids, mucilages, esters, coumarins, tannins, saponins, diterpenes, stachyhyd, glycosides, fatty acids, edridiol, resins and bitter substances [15].

These compounds are present in the species of this family with antimicrobial, spasmolytic, carminative, anticancer, antivomitive, anti-infective, anti-dyspeptic and other properties [15, 70]. Some medicinal herbs of this family such as *Mentha arvensis* (wild mint), *Mentha piperita* (peppermint) *Thymus vulgaris* (garden thyme) and *Salvia officinalis* (kitchen sage), have expressive amounts of phenolic acids and are therefore considered promising sources of natural antioxidants [72].

2.10 Moraceae

The Moraceae family comprises 37 genera and more than 1,100 species worldwide, distributed in tropical forests of Central and South America [73]. In general, the plants in this family are trees and shrubs adapted to a wide range of tropical rainforest habitats, including terra firme forests, seasonal and flooded forests [74]. Species of the family Moraceae have important economic value, producing quality wood for use in the civil construction, naval and furniture industries, in addition to its recognized medicinal value. These species are widely recognized as sources of bioactive secondary metabolites, among them flavonoids, stilbenes, triterpenoids and xanthones [75].

Among the medicinal plants of the family Moraceae stand out: *Brosimum gaudichaudii* (mamica-de-cadela) was used in the treatment of vitiligo and other skin patches, rheumatic diseases, cold flu and bronchitis) [76]; *Dorstenia cayapia* (Dorstenia) for treatment of typhoid fever and other infections of the digestive tract, of respiratory airways and respiratory atony [76]; *Ficus carica* (edible fig) are widely used in traditional medicine as a pectoral and laxative emollient, for treatment of constipation, bronchitis, coughs, flu, colds, mouth and throat inflammations [77] and; *Ficus insipida* (chalate) that has purgative, aphrodisiac and memory-stimulating action [76]. The literature reported that these medicinal properties are due to the presence of alkaloids, sterols, triterpenes, coumarins, flavonoids, furanocoumarins, organic acids, mucilages, pectin, sugars, dorstenin, bergapten and psoralen.

2.11 Phytolaccaceae

The family Phytolaccaceae comprises about 17 genera and 120 species pantropical, widely distributed throughout the American territory [78]. Among the species of Phytolaccaceae, the most popular is *Petiveria alliacea* (guinea henweed), a perennial shrub with a rigid and straight stem, reaching a height of up to 150 cm [79]. The medicinal use of *P. alliacea* occurs in several regions of the world, mainly in the American continent. The same has curative and mystical purposes, is used in religious ceremonies in Brazil, with reports from the time of slavery, where slaves used *P. alliacea* for its toxic and sedative effects [80]. According to indigenous medicine, the root and leaf powders of *P. alliacea* have several therapeutic properties, such as diuretic, antispasmodic, emenagogic, analgesic, anti-inflammatory, antileukemic, antirheumatic, anthelmintic, antimicrobial and depurative properties.

In addition, different preparations of *P. alliacea* are used for their activities in the central nervous system (CNS) as anticonvulsants, anxiolytics, mnemonics, anesthetics and sedatives [81]. In the chemical composition of *P. alliaceae* are found coumarins, saponins, flavonoids, tannins and organic sulfides [82].

2.12 Rutaceae

About 180 genera and 1300-1600 species belong to the Rutaceae family. Plants of this family have great economic value and some of them have highly fragrant flowers and are used in the commercial production of essential oils. Some constituents of essential oils, such as citronella and bergamot, are obtained by distillation of plants of this family [83]. Genres like *Citrus*, *Poncirus* and *Fortunella* produce fruits with high commercial value; *Citrus* has aromatic plants; *Murraya*, *Atalantia* and *Citrus* have ornamental plants; and *Zanthoxylum*, *Citrus*, *Phellodendron*, and *Evodia* have species used for medicinal purposes [84].

Among the medicinal plants belonging to the Rutaceae family, it is possible to emphasize *Citrus aurantium* (bigarade) being considered aromatic, bitter, digestive, expectorant, diuretic and hypotensive [85]; *Ertela trifolia* has emmenagogue, diuretic, tonic, sudorific and stimulant properties [86]; *Pilocarpus microphyllus* used in the treatment of bronchitis, dry skin, and as hair tonic, in addition to possessing sweat, febrifuge and stimulant properties [15]; and *Ruta graveolens* is used in the treatment of menstrual disorders, skin inflammations, ear pain, toothache, cramps, liver diseases and verminoses [87]. In the phytochemical composition of Rutaceae, pectin, hesperidin, bitter substances, narigenin, sugars, limonene, linalool, linalyl acetate, saponin, lignan, alkaloids and flavonic glycosides stand out [15].

2.13 Solanaceae

The Solanaceae family has 3,000 species, distributed in 84 genera [88]. They are species of cosmopolitan distribution. In Brazil there are 32 genera and 350 species, among herbaceous, shrub and arboreal plants [15]. This family has several species of economic importance such as potato (*Solanum tuberosum*), eggplant (*S. melongela*), tomato (*S. lycopersicum*), cucumber (*S. muricatum*) and peppers in general (*Capsicum* spp.). Some plants of the family Solanaceae have been studied for use in the pharmaceutical industry because they possess chemicals of the class of alkaloids in general, emphasizing tropical alkaloids and ale-steroids [89]. Many species are widely used for medicinal, hallucinogenic and for steroid synthesis, used in the pharmaceutical industry [15].

This family has a wide range of medicinal plants, among them *Datura inoxia* (prickly burr) used to cure cough and asthma [90], treatment of swollen limbs, use as repellent and vermicide [91]. *Solanum nigrum* (black nightshade) is an antispasmodic, diuretic, analgesic, sedative, narcotic, expectorant, anaphrodisiac and laxative plant [92]; *Solanum surattense* (yellow-fruit nightshade) is used in the treatment of phlegmatic cough, asthma, chest pain and fever [93]; and *Withania somnifera* (withania) is useful in fighting chronic fatigue, weakness, dehydration, brittle bones, impotence, premature aging, weight loss, weakness, muscle tension, tumors, inflammation, psoriasis, bronchitis, asthma, ulcers, scabies and insomnia [94]. The main active constituents responsible for the healing properties of the Solanaceae family are fatty acids, alkaloids, triterpenoids, saponins, steroids, essential oils and quassinoids [15].

2.14 Verbenaceae

The Verbenaceae family consists of trees, shrubs and herbs found mainly in the tropical regions of the world [95]. The family includes about 1,200 species distributed in 35 genera. Plants of the Verbenaceae family are well known for their uses in traditional medicinal systems in several countries [95]. A large number of plants in this family has bioactive phytochemicals with important pharmacological effects, among them the diterpenoids, having antimicrobial and antiparasitic properties [96], tannins, mucilages and alkaloids [97,15].

One species of medicinal plants of this family, *Lippia alba* (bushy lippia) is commonly used throughout Brazil, has high concentrations of citral, myrcene, limonene and carvina, these constituents give it calming, analgesic, anxiolytic, sedative and mucolytic [98]; *Lippia gracilis* (brasilian name: “alecrim de chapada”) is a species of the semi-arid region of the Northeastern region. Its chemical composition contains thymol, carvacrol, flavonoids and quinones, which give it antimicrobial, fungicidal and molluscicidal activities, as well as being used in the treatment of acne, scabies, white cloth, impingens, dandruff and bad smell in the armpits, feet and groin [15]; and *Stachytarpheta cayennensi*s (cayenne porterweed) is a plant widely used in traditional Brazilian medicine for the treatment of fevers, dyspepsia, hepatitis, constipation, colds, flu, bronchitis, wounds, bruises and skin conditions.

3. ROOT-KNOT NEMATODES

Nematodes probably arose early in the Cambrian Period [99], although some researchers have suggested that their origin dates back to a billion years ago [100]. Free-living nematodes, present in terrestrial and aquatic environments, have developed parasitic relationships with other eukaryotes on several independent occasions [101]. Molecular and palaeontologic evidence suggests land plants originated from 425 to 490 million years [102], indicating that land plants and nematodes coexisted in the earth soil for an extended period of time, developing morphological and physiological characteristics specific to feed from the roots of plants in the rhizosphere [103].

The productive and economic losses caused by nematodes on cultivated species are difficult to establish accurately. It is estimated that global averages of income loss are around 10%, with this figure reaching 20% for some crops; in monetary terms, world losses exceed US $ 175 billion annually [6]. Most of the damage is caused by a relatively small number of nematode genera that attack the crops, especially the sedentary root-knot nematodes (*Meloidogyne* spp.), the cyst nematode (*Globodera* and *Heterodera* spp.) and some migratory nematodes (including *Pratylenchus* and *Radopholus* spp.) [3].

The species with the greatest agricultural importance are those that infect the roots, this because many of the control strategies, such as chemical control, are inefficient [104]. Root-knot nematodes (*Meloidogyne* spp.) are one of the most polyphagous and damaging genera among plant parasitic nematodes. The species of this genus are biotrophic endoparasites capable of infecting a large number of higher plant species and have an almost cosmopolitan distribution [103]. Several genera of nematodes exploit all parts of plants, but the economically most important species are those that infect the roots. In part because many of the control strategies, such as chemical control, are inefficient [104]. Root-knot nematodes (*Meloidogyne* spp.) are one of the most polyphagous and damaging genera of plant parasitic nematodes. The species of the genus *Meloidogyne* are biotrophic endoparasites capable of infecting a large number of higher plant species and have an almost cosmopolitan distribution [103].

The soil texture strongly influences the distribution of *Meloidogyne* spp., since they occur predominantly in sandy soils, besides the texture, the presence and development of *M. incognita* is associated to neutral pH soils, where they may persist in dormancy for a certain period of time [105]. [106] stated that in the absence of host plants, the eggs of this nematode are resistant to environmental and nematicidal stresses and hatch occures only under the stimulation of plant root emanations. During this period of dormancy, the eggs can withstand soil water deficiency and only hatch occures under favorable conditions to the development of the pathogen, making it difficult to control.

The species of the genus *Meloidogyne* are highly diversified, showing diversity in terms of cytogenetics, mode of reproduction, specialization in parasitism, and range of hosts [107]. In general, this high level of diversity contributes to a complex pathogen-host interaction leading to highly successful parasitism. For example, the three main species of the genus *Meloidogyne* (*M. incognita*, *M. javanica* and *M. arenaria*) are highly polyphagous, infecting more than 3,000 plant species [107].

Meloidogyne spp. have a sedentary endoparasitic lifestyle with second-stage infectious-mobile juveniles (J2) that invade the plant through the roots and migrate intercellularly through tissues to developing vascular cells [106], reproduced by mitotic parthenogenesis [108]. These nematodes establish an intimate relationship with their hosts, inducing the formation of gall, the main visible symptom of root-knot nematode infection [106].

Infection occurs when the second stage mobile juvenile (J2) is attracted to the host plant root system. J2 migrates intercellularly toward the vascular cylinder, where it injects secretions through its stylet into approximately six cells of the parenchyma [109]. The affected plant cells undergo a transformation, becoming giant and multinucleate in which the nematode nourishes non-destructively during the rest of its life cycle. During their biological cycle, the nematodes feed on nutrients and water from the host plant. This impairs the plants growth, causing wilt and increasing the susceptibility of the plant to other pathogens and, in some cases leading to death of plant [110].

According to [111], the secretions originating from the esophageal glands of the nematode play important roles in the penetration of the host and in the formation of giant cells. The root-knot nematodes have three esophageal glandular cells, one dorsal and two subventral gland cells. Each gland is a single enlarged cell that is specialized to export secretions to the esophagus of the nematode [112]. Once in the lumen, the secretions of the glands are exported out of the nematode through the stylet. Some studies reported that the subventral glands produce pectinases and cellulases that help the nematode to penetrate the host root [104]. This hypothesis was confirmed by the identification of several genes encoding cellulases and pectate lyases that are expressed in the subventral glands of the root-knot nematodes [104].

After the feeding cycle, the *Meloidogyne* spp. will cause reduction in the translocation of water and nutrients from the roots to the leaves causing symptoms, in the aerial part, identical to those of nutritional deficiency. The increase in the metabolic activity of giant cells induced by nematode parasitism will stimulate the mobilization of photoassimilates from shoot to roots and, in particular, to the giant cells themselves, which are used to feed the nematode [111]. The intensity in reducing the size and production of the plant varies according to the population of nematodes, the association with other pathogens (*Fusarium* spp., *Rhizoctonia solani*, etc.) and with other factors, such as the degree of susceptibility of the cultivated variety and soil fertility.

Another way to consider the impact of nematodes on crops is through the management strategies used in their control. In 2010, about US $ 7.3 billion in chemical products were sold in Brazil for the treatment of pests and diseases of plants, corresponding to about 7% of total sales of agricultural products in the country. [113] However, issues such as groundwater contamination, mammalian and avian toxicity, and residues in food have caused much more severe restrictions on the use of chemicals, and in many countries the use of effective but highly toxic nematicides, were and are still prohibited [6]. The literature is also replete with studies on organic media, such as green manures, to control nematodes, but these strategies are ineffective [114].

Even if environmentally safe nematicides are developed, or if biocontrol agents are identified, host resistance will continue to be the safest and most efficient form of nematode control [104]. Resistance to nematodes is yet to be identified for many cultivated plants, although several resistance genes have been identified [115]. [116] reports that in peppers (*Capsicum annum*) there are ten genes for dominant resistance to *Meloidogyne* spp. (*Me1*, *Me2*, *Me3*, *Me4*, *Me5*, *Me6*, *Me7*, *Mech1*, *Mech2* and *N*). According to the aforementioned author, four of the ten genes (*Me1*, *Me3*, *Me7* and *N*) confer resistance to a wide range of species of the genus *Meloidogyne*, serving as important resources for the development of peptide cultivars resistant to meloidogynosis.

Although about 100 species of *Meloidogyne* are known so far [117], historically, species of the genus *Meloidogyne* were divided into main and secondary species [118]. According to [108] *M. arenaria*, *M. incognita*, *M. javanica* (occurring in tropical regions) and *M. hapla* (occurring in temperate regions) are considered the four main species of *Meloidogyne*. However, these authors consider five more species as secondary species. They are: *Meloidogyne chitwoodi, M. fallax*, *M. enterolobii*, *M. minor* and *M. paranaensis*.

The vast majority of research focused on only four species: *M. arenaria*, *M. hapla*, *M. incognita* and *M. javanica*. The reason for the high status of these four species is in part due to the fact that they are extremely widespread and infect a wide range of hosts, but to a certain extent, it is also historical and can be attributed to a study of [108]. In this study, the authors reported that *M. arenaria*, *M. hapla*, *M. incognita* and *M. javanica* made up 99% of all species identified in more than 660 isolates from 65 countries.

Sasser et al. [119] formulated a study to list the most harmful nematodes for agriculture, for which the authors interviewed 371 nematologists worldwide. More recently, another survey was carried out with the same purpose and was attended by 225 nematologists [120]. In both cases, the votes were grouped, resulting in a list of the 10 most important nematodes for agriculture (Table 1). In general, the lists are similar, mainly in the first five positions, and in both stands out importance of the genus *Meloidogyne* was classified as the most important in both studies.

3.1 *Meloidogyne enterolobii*

Meloidogyne enterolobii was initially reported causing severe damage to a pacara-earpod tree (*Enterolobium contortisiliquum*) population on the island of Hainan in China [121]. Since this report, *M. enterolobii* has been the topic of few published studies, which seemed to be of little importance [121], which is in opposition to the fact that the species is considered a polyphase with a range of hosts similar to *M. incognita* [122]. Most registered hosts often include vegetables such as tomato, pepper and watermelon [122], fruit trees such as guava [123], ornamental plants [124], weeds and medicinal plants [125]. Despite being less frequently reported in the literature, *M. enterolobii* is a highly aggressive species with a high rate of root infestation that induces more severe symptoms than other species of gall nematodes [126].

In heavily infested areas, cultivation may become unfeasible, as for guava in Brazil [127]. Another interesting fact is the ability of *M. enterolobii* to develop in genotypes of crops resistant to the main species of *Meloidogyne*, including cotton, sweet potato, tomato (*Mi-1* gene), potato (*Mh* gene), soybean (*Mir1* gene), chili (*N* gene), sweet pepper (*Tabasco* gene) and cowpea (*Rk* gene) [128,129,130]. Few cultures are recorded as resistant to *M. enterolobii*, including grapefruit, sour orange, garlic and peanut [131].

Table 1. Ranking of the main phytonematoids according to economic importance in a survey carried out by Sasser and Freckman (1987) and Jones et al. (2013)

Classification of Sasser and Freckman (1987)		Classification of Jones et al. (2013)	
1º	*Meloidogyne*	1º	*Meloidogyne* spp.
2º	*Pratylenchus*	2º	*Heterodera* spp. e *Globodera* spp.
3º	*Heterodera*	3º	*Pratylenchus* spp.
4º	*Ditylenchus*	4º	*Radopholus similis*
5º	*Globodera*	5º	*Ditylenchus dipsaci*
6º	*Tylenchulus*	6º	*Bursaphelenchus xylophilus*
7º	*Xiphinema*	7º	*Rotylenchulus reniformis*
8º	*Radopholus*	8º	*Xiphinema index*
9º	*Rotylenchulus*	9º	*Nacobbus aberrans*
10º	*Helicotylenchus*	10º	*Aphelenchoides besseyi*

Until recently, it was assumed that the distribution of *M. enterolobii* was restricted to regions with typically tropical climatic conditions, such as Africa, South and Central America, the Caribbean and Asia. In 2004, during the regulatory sampling in ornamental nurseries, this nematode was detected in Florida [131]. In addition, the presence of *M. enterolobii* was reported in greenhouses in France and Switzerland [132]. There is the possibility that its distribution has been underestimated due to misidentification in different regions of the world, including Europe. As *M. enterolobii* is also likely to survive in the hottest parts of Europe and in greenhouses throughout the region, the risk of its establishment and dissemination in this area is very likely [133]. In 2010, *M. enterolobii* was added to the alert list of the European Organization for the Protection of Mediterranean Plants (EPPO) [134], with a recommendation by that organization that its member countries define this nematode as a quarantine pest.

In Brazil, the first report of this nematode causing damages in cultivated plants was carried out by [135] in the municipalities of Petrolina in Pernambuco, and of Curaçá and Juazeiro in Bahia in commercial plantations of guava (*Psidium guajava* L.). The main symptoms described were the presence of large galls associated with necrosis of the root system, resulting in drastic reduction of radicels, important in plant nutrition. Subsequently, *M. enterolobi*i was recorded in several regions of the country such as: Rio de Janeiro [136] Ceará [137], Piauí [138], Paraná [139], Mato Grosso do Sul [140], Espírito Santo [141] and Maranhão [142]. causing severe damage in commercial guava orchards.

3.2 *Meloidogyne incognita*

Meloidogyne incognita is a pathogen that causes deformation in the root system of parasitized hosts, causing gall formation and occurrence of cracks in the cortex. The most frequent symptoms as a consequence of the presence of the pathogen are wilt, chlorosis and nutritional deficiency symptoms [143]. It is a highly polyphagous species, causing significant economic losses [144], being harmful to cotton (*Gossypium hirsutum*), sugar beet (*Beta vulgaris*), tomato (*Solanum lycopersicum*), pepper (*Capsicum annuum*), watermelon (*Citrullus lanatus*), melon (*Cucumis melo*), okra (*Abelmoschus esculentus*), and soybean (*Glycine max*) among other cultivated species [23]. *Meloidogyne incognita* is a control species more difficult than any other species of the genus *Meloidogyne* due to its high variability within the species, with four species known for this genus [143].

It is a parasite that has the ability to develop rapidly under appropriate conditions. This rapid population growth is mainly due to the rapidity of its biological cycle (about 28 days), combined with the high female fecundity. The exact number of eggs produced varies depending on environmental conditions. Under favorable conditions, a single female can produce 500 to 2000 eggs [143]. The eggs have shells containing chitin as protection and are deposited by the female in a gelatinous matrix secreted by the female resistant to desiccation. Although males occur, reproduction occurs exclusively via mitotic parthenogenesis (apomixis) [143].

3.3 *Meloidogyne javanica*

Meloidogyne javanica is one of the most important species among the group of gnats nematodes, has a wide range of hosts among crop cultivars, pastures and grasses, and horticultural and ornamental crops. This species is highly adapted to the most diverse environmental conditions. [124]. *M. javanica* is distributed throughout the world, developing at temperatures ranging from 3°C up to a maximum of 36°C, and can tolerate up to 4 or 5 months without rainfall, and has a preference for clay-poor soils [108].

The embryogenesis of *M. javanica* has been studied for over 40 years, since it has been reported that the stages of development of the embryo are easily identifiable, with eight stages in egg formation [144]. There are several cell divisions leading to the additional elongation stage, resulting in the juvenile first stage, the J1 stage of *M. javanica* has approximately 500 cells, the eggshell has three layers, the yolk layer being very peripheral, on a chitinous layer and a more internal layer of lipids, the *M. javanica* egg can withstand long periods of drought and only hatch under conditions favorable to the development of the pathogen [144].

4. REACTION OF MEDICINAL PLANTS TO *Meloidogyne* spp.

Among the diseases can compromise the qualitative and quantitative characteristics of the pharmacological and productive properties of medicinal plants, nematode diseases can be highlighted [8], especially the species of the genus *Meloidogyne* [8]. Some studies have been developed with the purpose of evaluating the reproduction of *Meloidogyne* spp. in medicinal species. From these studies, resistant species can be identified and used as resistance source genes, as well as their use in crop rotation systems aiming to decrease the nematode population in infested areas.

Maciel et al. [145] evaluated the reproductive rates of *Meloidogyne incognita* race 2 and *Meloidogyne javanica* in eight species of medicinal plants. Evaluations were performed based on egg mass indices and nematode reproduction factors. In relation to the results, *Achillea millefolium* (millefolium), *Arctium lappa* (burdock), *Bryophyllum calycinum* (brasilian name: "folha-da-fortuna") and *Crassula portulacea* (balm) were non-efficient hosts or unfavorable to both species. *Plectranthus barbatus* (forskohlii) and *Polygonum hydropiperoides* (swamp smartweed) were efficient to the two species to reproduce. *Achyrocline satureoides* (marcela) and *Tropaeolum majus* (nasturtium) were efficient for *M. javanica* and not for *M. incognita*.

Karl et al. [146] tested the pathogenicity of *Meloidogyne javanica* in sweet basil (*Ocimum basilicum*), holy basil (*Ocimum sanctum*), common balm (*Melissa officinalis*), and tropical White weed (*Ageratum conyzoides*). The level of infection by the nematode was quantified by the number of galls and eggs per root system, expressed on a scale of 0 to 5. The four species evaluated were highly susceptible, with all the inoculated plants receiving a grade 5 in relation to the gall index and to the number of eggs. However, only sweet basil was resistant to infection by *M. javanica*, presenting a significant reduction in shoot fresh and dry weights.

Dias et al. [147] evaluated four species of medicinal plants, in protected cultivation, regarding hostability to *Meloidogyne incognita*. The reaction of the medicinal plants was done by counting the eggs and juveniles of the roots, estimating the Host Susceptibility Index (ISH). *Achillea millefolium* (bloodwort), *Arctium lappa* (greater burdock) and *Bryophyllum calycinum* (brasilian name: "folha-da-fortuna"), were resistant, while *Ageratum conyzoides* were susceptible.

In a study published in 2004 [148], 22 species of medicinal plants were evaluated for hostability to *M. hapla* in greenhouse. The evaluations were performed based on the gall index and the reproduction factor. Twelve of these species [*Angelica dahurica* (angelica), *Arctium lappa* (greater burdock), *Astragalus membranaceous* (astragalus), *Carthamus tinctorius* (safflower), *Codonopsis lanceolata* (deodeok), *C. pilosula* (dang shen), *Coriandrum sativum* (coriander), *Glycyrrhiza uralensis* (chinese liquorice), *Leonurus sibiricus* (honey weed), *Ligusticum tenuissimum* (vinum), *Ostericum koreanum* (tyosen-nodake) and *Peucedanum japonicum* (coastal hog fennel)] were registered as susceptible to *M. hapla*. *Cassia tora* (foetid cassia), *Coix lacryma-jobi* (adlay) and *Perilla frutescens* (beefsteak plant) were immune, neither galls nor nematodes were found in these plants. *Achyranthes japonica* (japanese chaff flower), *Atractylodes japonica* (japanese Atractylodes), *Hibiscus manihot* (aibika), *Ricinus communis* (castor bean) and *Sophora flavescens* (shrubby sophora) were considered resistant. *Doellingeria scabra* (korean aster) and *Agastache rugosa* (korean mint) were susceptible and hypersensitive, respectively.

In the study of the reaction of 14 species of medicinal plants to *Meloidogyne paranaensis*, [8] evaluated the multiplication of the nematodes in the roots by counting eggs and J2 in the root systems, calculating the reproductive factors (RF). Plants with FR <1, susceptible with FR ≥ 1 and immune with FR = 0 were considered resistant. The species that showed resistance to *M. paranaensis* were *Taraxacum officinale* (common dandelion), *Matricaria recutita* (German chamomile), *Melissa officinalis* (common balm), *Hyssopus officinalis* (hyssop), *Lippia alba* (bushy lippia), *Kalanchoe pinnata* (cathedral bells) and *Sedum praealtum* (green cockscomb); and the susceptible ones were: *Ocimum basilicum* (sweet basil), and *Plectranthus barbatus* (forskohli).

When evaluating 15 species of medicinal plants for hostability to *M. javanica* and *M. incognita*, [149], they counted the number of galls and eggs, as well as the determination of the reproduction factor. In this study with inoculation of *M. incognita*, chamomile was susceptible, with RF = 1.64, being considered a good host, the other plants were considered resistant, with RF <1. For *M. javanica*, all plants behaved as resistant, with FR <1, with immunity to myrrh, rue and balm, which had RF = 0.

The reaction of seven species of medicinal plants to *M. paranaenses* was studied by [150] with evaluations through determinations of gall index and reproduction factor. The accessions of *Pfaffia glomerata* (Brazilian ginseng), *Hypericum perforatum* (eola-weed) and *Melissa officinalis* were highly susceptible to *M. paranaensis*. *Pogostemon cablin* (patchouly) had an intermediate reaction and was classified as susceptible. *Artemisia annua* (sweet sagewort) and *Catharanthus roseus* (madagascar periwinkle) were highly resistant, and *Cordia verbenacea* (Brasilian name: “erva-baleeira”) was classified as resistant. *Catharanthus roseus* was distinguished because it had a high gall index but did not allow the multiplication of the nematode.

Moreira et al. [6] evaluated the susceptibility of 30 species, being 20 ornamental and 10 medicinal [*Peumus boldus* (boldo), *Ocimum gratissimum* (african basil), *Mentha arvensis* (wild mint), *Mentha villosa* (mojito mint)., *Plectranthus amboinicus* (mexican mint), *O. basilicum* (sweet basil), *Rosmarinus officinalis* (rosemary), *Cymbopogon citratus* (lemon grass), *Lippia alba* (bushy lippia), *C. winterianus* (cymbopogon grass)) to *M. incognita*. The evaluation of the plants was performed by measuring the number of galls and eggs, egg mass index, reproduction factor and reproduction factor reduction. From these variables, the reaction of the plants to the nematode was classified. With regard to medicinal plants, the species, *M. villosa*, *L. alba* and *C. citratus*, *C. winterianus* and *P. boldus* did not have galls in their root systems, the other species behaved as moderately susceptible, with few galls and, or females isolated at their roots.

5. CONCLUSION

The identification of resistance sources among medicinal species is an important alternative in the management of cultivated areas infested with nematodes. In cultivation systems, these species can be used in consortium or rotation with other cultivated species aiming at reducing the inoculum concentration in the field, reducing agricultural losses. In addition, the knowledge of these possible resistance sources, in the medium and long term, can be used as a subsidy for breeding programs in order to select materials for nematode resistance of the genus *Meloidogyne*. The literature indicates that resistance attributed to medicinal plants comes from substances derived from the secondary metabolism of these species, such as phenolic compounds, steroids, triterpenes, anthraquinones, flavonoid glycosides, saponin glycosides, condensed tannins, hydrolysable tannins and sugars. Knowing which of these substances are involved in resistance to root-knot nematodes, it is possible to isolate these compounds for later use in the formulation of products capable of controlling this pathogen.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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