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13. A Review on Root-knot Nematode (*Meloidogyne spp.*)

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Abstract:

Root-knot nematode (RKN), which is brought on by Meloidogyne species, is an obligatory parasite that lives on different species of plants that are employed as hosts. Root-knot nematode (RKN) is a necessary parasite that inhabits a variety of plants that are used as hosts and is caused by Meloidogyne species. In the tropics and subtropics, the presence of RKN in the crop becomes one of the key restrictions in vegetable crops, resulting in an estimated yield loss of 5–43%.

The primary food group in the Indian diet, vegetables are essential to guaranteeing the growing Indian population's nutritional and economic security. Root knot nematode (Meloidogyne spp.) substantially hinders vegetable output, though. Numerous scientific efforts have been done to understand the many cultural, physical, biological, pharmacological, and genetic-based strategies for the control of root-knot nematodes in vegetable crops, with a focus on India.

In contrast to individual approaches, the idea of integrated nematode management (INM) is gaining ground for managing the root-knot nematode. Integrated natural resource management (INM) is a part of integrated pest management (IPM), not a separate technique. INM is a practical method that combines chemical, physical, biological, and cultural techniques. This review included the following topics: the host range of RKN, the distribution of RKN species worldwide, the symptoms of infected plants, the interactions between Meloidogyne spp. and other soil-borne diseases, management strategies and losses resulting from Meloidogyne spp. on diverse agricultural plants.

Keywords:

Host range, Management, Losses, Meloidogyne spp., Root-knot nematode, Symptoms.

13.1 Introduction:

Root-knot nematodes (Meloidogyne species) are parasitic worms that live in the roots of affected plants. The name Meloidogyne, which comes from the Greek for an apple-shaped female, is used to describe root-knot nematodes. The root-knot nematodes of the genus Meloidogyne are among the most widespread and widespread plant parasites in nature, with over 90 recognised species (Karssen, 2002; Karssen and Moens, 2006). The four most common species, which make up to 95% of all RKN, are *Meloidogyne incognita, M. hapla, M. javanica, and M. arenaria* (Dong *et al*., 2012). The genus Meloidogyne contains 98 species, with *M. incognita*, *M. javanica*, *M. hapla*, and *M. arenaria* being the most common ones encountered by farmers (Jones *et al*. 2013). Roundworms without segments are included in the diverse phylum Nematoda, which includes nematodes. Nematodes are ubiquitous in nature and can be found in almost all ecosystems worldwide. They can survive in a variety of severe environments, from freezing to hot desert regions. Nematodes infect many herbaceous, woody, monocotyledonous, and dicotyledonous plants, decimating agricultural crops and woodland flora all over the world (Moens and Karssen, 2006).

Nematodes known as endoparasites penetrate host cells and feed from within, whereas ectoparasites feed by inserting the stylet into root cells on the root surface (as discussed by Escobar *et al*., 2015). Sedentary (sessile) end-parasites are referred to as root-knot nematodes (RKN). They were given their name, galls or knots, for the unique structure they produce in the afflicted plants' roots. They can survive anywhere in the world, in hot and cold regions. The root-knot nematode, which is a pest of almost all major crops, is one of the most destructive plant-parasitic nematodes, claim Gill and Mcsorley in their 2011 paper.

According to Sasser (1980), approximately 2,000 plant species have been identified as root-knot nematode hosts, and the majority of cultivated vegetation is attacked by at least one species of these worms. Over 3000 plant species were already present in the host range in 2003 (Abad *et al*., 2003). This suggests that there is more root-knot nematode-infected hosts. It is challenging to identify well-known crops that are not hosts because the host range of root-knot nematodes is so diverse (Olsen, 2000). Various plants, including weeds, grasses, shrubs, trees, and bedding plants, can act as hosts.

M. ardenensis, M. arenaria, M. baetica, M. hispanica, M. incognita, *M. javanica,* and *M. lusitanica* are just a few of the Meloidogyne species that can parasitize woody plants (trees and shrubs) in Europe. It has been debated for a long time where the genus Meloidogyne falls in the hierarchy of families. The classification suggested by De Ley and Blaxter (2002) is one that the writers of this work agree with. Nematode investigations in tree forests in northern Spain indicated high rates of infection of European holly feeder roots by a root-knot nematode, raising the possibility of a threat to this widespread holly's native habitat in Europe. Root-knot nematode species include Meloidogyne incognita and *Meloidogyne javanica* (Ahmad *et al*., 2010, Zia-UI-Haq *et al*., 2011). Among them *M. incognita* is the most widespread species (Wondiard and Kifle 2000).

Solomon (1987) and Tadele and Mengistu (2000) both noted the presence of *M. incognita* on tomato in the country's eastern region, especially in eastern Hararghe (Ethiopia), where numerous vegetable crops were subjected to root-knot nematode attacks.

In North Florida field tests, a significant root-knot nematode infestation unexpectedly appeared on all bottle gourd and Cucurbita rootstocks (unpublished data). When grafting to bottle gourd and Cucurbita rootstocks in China, where agricultural space is constrained and farmers are required to grow the same crop year after year, root-knot nematodes have become a significant obstacle.

To identify regional RKNS populations, several investigations were conducted in Jordan (Abu-Gharbieh and Hammou, 1970; Hashim, 1979; Abu-Gharbieh, 1982a; Abu-Gharbieh, 1982b; Karajeh, 2004). In Jordan's irrigated districts, samples of soil and galled roots allowed researchers to isolate and identify *M. javanica* and *M. incognita*. *M. javanica* made up around 84% of the RKN populations examined, followed by *M. incognita* race 1, *M. incognita* race 2, and *M. arenaria* race 2.

Three populations of *M. javanica* were identified as being particularly virulent to the Mi gene of tomato resistance among the samples, as evidenced by their capacity to infect the roots of the resistant tomato cultivar Better Boy (Karajeh *et al*., 2005).

Previous studies have listed plant estern parasitic nematodes associated with banana (Kashaija *et al.*, 1994) and root and tubercrops (Coyne *et al.*, 2003); with some species found to and be more parasitic and pathogenic causing economic losses to these crops; for example, *Meloidogyne* spp. on cassava (*Manihot ercialesculenta*) (Coyne and Talwana, 2000), of its *Radopholus similis, Pratylenchus goodeyi and StoreHelicotylenchus multicinctus* on banana (Speijer land and Kajumba, 2000), *Meloidogyne* spp. and hern *Pratylenchus sudanensis* on yams (*Dioscorea* spp.) (Mudiope *et al.*, 1998).

Therefore, it is AIF, anticipated that plant parasitic nematodes do occur on cereals and can pose a significant threateties to their production in Uganda. RKN species (*M. incognita, M. javanica*) have also been recorded to reside in Ethiopia (Stewart and Dagnachew, 1967; Seid *et al*., 2017).

The most prevalent of these species is *M. incognita* (Wondirad and Kifle, 2000). In the country's east, particularly in eastern Hararghe, where numerous vegetable crops were attacked by this RKN (Solomon, 1987; Tadele and Mengistu, 2000; Seid *et al*., 2017), *M. incognita* was discovered on tomatoes.

In the country's central and western regions, tomato growing is severely hampered by the RKN, specifically *M. incognita* (Mandefroand Mekete, 2002; Seid *et al*., 2017).

There have been reports on the impact of root-knot nematode population densities on vegetable crop growth and yield in Nigeria.*Meloidogyne* spp. caused dwarfing, wilting, browning of leaves, flower abortion and, in severe cases, early mortality in cowpea, according to Ezigbo (1973).

Enokpa *et al.* (1996) similarly found decreased development in tomato plants exposed to*Meloidogyne* spp. Pepper (Capsicum annuum) infected with*Meloidogyne* Spp. was shown to have stunted development, chlorotic leaves and early senescence (Ogbuji and Okarfor, 1984).

13.2 Distribution of *Meloidogyne* Species Around the World:

According to Trudgill and Blok (2001), M. incognita is easily found in all temperate and tropical countries and is probably the most destructive crop pathogen in the entire world. According to Olsen (2000), RKN are most prevalent in soils' top foot to a few feet deep. The most prevalent Meloidogyne species in cold climates with temperatures between 0°C and 15°C or higher is *M. hapla*. At latitude 40°S, it can be found in northern North America, northern Europe, northern Asia, southern Canada in North America, and southern South America. It can be discovered in Africa at elevations more than 1500 metres. Victoria, the most southern state in Australia, has a high prevalence of it. The two most common *Meloidogyne* species in the tropics are *Meloidogyne incognita* and *M. javanica*.

These species become more frequent the closer one approaches to the equator. *Meloidogyne javanica* is the most prevalent species in various regions of tropical Asia, Australia, and Africa. Species of meloidogyne. On the other hand, *M. arenaria* and *M. incognita* are both common and omnipresent there.

As a result, it was believed that the three main Meloidogyne species—*M. javanica*, *M. incognita*, and *M. arenaria*—lived constantly in warm countries between 35°S and 35°N latitudes (Taylor and Sasser, 1978). Due to their global distribution and commonality, the four species of Meloidogyne—*M. javanica, M. incognita, M. hapla, and M. arenaria*—probably do greater harm to agricultural crops than other Meloidogyne species (Sasser, 1977).

13.3 Symptoms in Infected Plants:

The worst-case situation for infected plants is plant death. These symptoms of nutrient deficiency include delayed or stunted development, yellowing of the leaves, wilting, and other symptoms. Elder plants that have been severely affected rapidly wilt and disappear. The nematode-induced expansion of root cells causes swellings or galls to develop on the roots of afflicted plants.

The size of galls can range from minute thickenings to tumours that are 5 to 10 cm in diameter. Outdoor-grown plants frequently have galled stems or leaves. Galls produced by Meloidogyne sp. are significantly smaller than those produced by other species. All root knot galls harm the vascular tissues of the roots, obstructing the plant's normal ability to absorb water and nutrients.

Additionally, they increase the root system's susceptibility to bacterial and fungal infections that can lead to illness (Rahman, 2003). Olsen (2000) asserts that while the galls are simple to identify, the RKN cannot be determined since they are too small and require microscopic examination. Furthermore, even when adequate levels of these nutrients are present in the soil, sick plants may show symptoms of nitrogen, potassium, or phosphorus shortages. Infected plants wilt during the high daytime temperatures and then recover at night. The roots are also shorter and bushier than on healthy plants (Tisserat, 2006).

Host range of *Meloidogyne incognita and Meloidogyne javanica.*

Table 13.1: Host plant species that were found infested with root knot nematodes (*Meloidogyne*species and races) under the field conditions.

Host plant	Scientific Name	Family	Plant type	*Meloidogyne sp.*	Researchers survey reports	Host plant
Cabbage	*Brassica oleraceavar. capitata*	*Brassicaceae*	Vegetable crop	*M. incognita* *M. javanica*	Abu-Gharbieh (1987) Hashim (1979)	Cabbage
Cucumber	*Cucumis sativus* L.	*Cucurbitaceae*	Vegetable crop	*M. incognita* race 1 *M. javanica*	Karajeh (2004)Abu-Gharbieh (1982 b	Cucumber
Egg plant	*Solanum melongena* L.	*Solanaceae*	Vegetable crop	*M. incognita* *M. javanica*	Abu-Gharbieh (1982)	Egg plant
Fig	*Ficus carica*	*Moraceae*	Fruit tree	*M. incognita* race 1	Karajeh (2004)	Fig
Garlic	*Allium sativum* L.	*Lilaceae*	Vegetable crop	*M. incognita* *M. javanica*	Abu-Gharbieh (1982 b) Karajeh (2004)	Garlic
Grapevine	*Vitis vinifera* L.	*Vitaceae*	Fruit tree	*M. incognita* race 1 *M. javanica*	Karajeh (2004)Abu-Gharbieh (1982 b)	Grapevine
Okra	*Hibiscus esculentus* L.	*Malvaceae*	Vegetable crop	*M. incognita* *M. javanica*	Abu-Gharbieh (1982) Hashim (1979)	Okra
Olive	*Olea europaea* L.	*Oleaceae*	Fruit tree	*M. incognita* *M. javanica*	Hashim (1979)	Olive
Pepper	*Capsicum annum* L.	*Solanaceae*	Vegetable crop	*M. incognita*	Abu-Gharbieh (1982 b)	Pepper
Date palm	*Phoenix dactylifera* L.	*Palmae*	Fruit tree	*M. incognita* race 1	Karajeh (2004)	Date palm
Pomegranate	*Punica granatum* L.	*Punicaceae*	Fruit tree	*M. incognita* *M. javanica*	Hashim (1983 a)	Pomegranate
Rosemary	*Rosmarinus officinalis* L.	*Lamiaceae*	Ornamental	*M. incognita* race 1	New**	Rosemary
Squash	*Cucurbita pepo* L.	*Cucurbitaceae*	Vegetable crop	*M. incognita*	Yousef and Jacob (1994)	Squash
Tomato	*Solanum lycopersicum*	*Solanaceae*	Vegetable crop	*M. incognita*	Hashim (1979)	Tomato
Cavendish	*Musa*	*Musaceae*	Fruit tree	*M. javanica*	Yousef and	Cavendish

Host plant	Scientific Name	Family	Plant type	*Meloidogyne sp.*	Researchers survey reports	Host plant
banana	*cavendishii*				Jacob (1994)	banana
Common bean	*Phaseolus vulgaris* L.	*Leguminoseae*	Field crop	*M. javanica*	Yousef and Jacob (1994)	Common bean
Cowpea	*Vigna sinensis*	*Leguminoseae*	Field crop	*M. javanica*	Abu-Gharbieh (1982 b)	Cowpea
Faba bean	*Vicia faba* L.	*Leguminoseae*	Field crop	*M. javanica*	Abu-Gharbieh (1987)	Faba bean
Guava	*Psidium guajava* L.	*Myrtaceae*	Fruit tree	*M. javanica*	Yousef and Jacob (1994)	Guava
Jew's mallow	*Corchorus olitorius* L.	*Tiliaceae*	Vegetable crop	*M. javanica*	Abu-Gharbieh (1982 b)	Jew's mallow
Jungle rice	*Echinochloa colona* L.	*Poaceae*	Weed	*M. javanica*	New	Jungle rice
Mallow	*Malva sylvestris* L.	*Malvaceae*	Weed	*M. javanica*	New	Mallow
Peach	*Prunus persica* L.	*Rosaceae*	Fruit tree	*M. javanica*	Yousef and Jacob (1994)	Peach
Peas	*Pisum sativum*		Field crop	*M. javanica*	Karajeh (2004)	Peas
Snake cucumber	*Cucumis melo var. flexuosus* L. *Naudin*	*Cucurbitaceae*	Vegetable crop	*M. javanica*	Abu-Gharbieh (1982 b)	Snake cucumber
Yellow dock	*Rumex crispus* L.	*Polygonaceae*	Weed	*M. javanica*	New	Yellow dock
Watermelon	*Citrullus lanatus* L.	*Cucurbitaceae*	Vegetable crop	*M. javanica*	Abu-Gharbieh (1982 b)	Watermelon
White mulberry	*Morus alba* L.	*Moraceae*	Fruit tree	*M. javanica*	Karajeh (2004)	White mulberry
Wild barley	*Hordeum spontaneum* L.	*Gramineae*	Weed	*M. javanica*	New	Wild barley

13.3.1 Interaction of *Meloidogyne* Spp. with Other Soil Borne Pathogens:

The parasitism of root knot nematodes on host plants is thought to be of utmost significance in providing hosts for the entry of soil-borne bacterial and fungal pathogens. Root exudates from root knot-infected plants encourage the entry of soil-borne pathogens, which aggravates the issue even more and causes the establishment of a disease complex (Table 13.2) and catastrophic losses of 40–70% in the nation's vegetable harvests. In addition, cultivars that are resistant to bacteria and fungi that are carried by the soil are also compromised by root knot nematode.

Table 13.2: Root knot nematodes association in the development of major disease complexes in vegetable crops.

Disease complexes	Initial inoculum of Nematode spp.	Inoculum of pathogenicfungi associated Pathogenic spp.	Host crops	References
Damping off	*M. incognita* (1000 J2)	*Rhizoctonia solani* (1,2,3 and 5 g mycelium)	Tomato	Arya and Saxena, (1999)
Collar rot	*M. incognita*	*Sclerotium rolfsii*	Brinjal	Goswami *et al.*, (1970)
Bacterial wilt	*M. incognita*	*Ralstonia (Pseudomonas) solanacearum*	Tomato	Haider *et al.*, (1989)
Soft rot	*M. incognita*	*Pectobacterium carotovorum subsp. Carotovorum*	Carrot	Sowmya *et al.*,(2012)
Fusarium wilt	*M. incognita*	*Fusarium oxysporum f. sp. Lycopersici*	Tomato	Akram and Khan, 2006
Fusarium wilt	*M. incognita*	*Fusarium oxysporum f. sp. Conglutinans*	Cauliflower	Rajinikanth *et al.*, 2013
Damping-off	*M. javanica*	*Pythium debaryanum*	Tomato	Ramnath *et al.*, 1984

(Referance – IIVR bulletian 2017)

Management of *Meloidogyne* spp.-

13.4 Integrated Nematode Management (INM):

13.4.1 Objectives of Integrated Nematode management (INM):

1. To minimize environmental and health hazards.
2. Utilization of several compatible measures.
3. To maximize natural environmental resistance to plant parasitic nematodes.
4. To minimize the use of drastic control measures and also to minimize the input costs.
5. To increase reliance on location specific and resource compatible management strategy.

13.4.2 Main Components of Integrated Nematode Management:

A. Cultural Methods:

a. Prevention of new area from nematode infestations i.e., prevention of infested soil, crop residues, vegetative propagules, human activities and irrigation water.

b. Reduction of secondary soil inoculum once nematode is infested.

B. Summer Ploughing:

The nematodes and impacted tissue are exposed to the sun's heat and dehydration during two or three deep summer ploughings throughout the intense months of May through June. Through this procedure, the population density of soil-borne pathogenic fungi, bacteria, weeds, and root knot nematodes is reduced. Root-knot nematodes have been successfully managed with this technique (Jain and Bhatti, 1987).

Crop Rotation:

One common and effective cultural method for reducing the number of root knot nematodes in the soil is crop rotation. It has been demonstrated that crop rotation with graminaceous poor hosts and particular antagonistic crops for one or two years can lower the inoculum level of root knot nematodes (Sundresh and Setty 1977; Patel *et al.* 1979). When cropping sequences are considered, non-preferred hosts-sesame, mustard, wheat, maize, etc.-have been demonstrated to reduce the population of root knot nematodes (Haque and Gaur 1985; Siddiqui and Saxena 1987).

a. **Antagonistic Crop:** The crops which have nematode antagonistic properties majorly from its root exudates can be utilized as rotation crop or cover crop with susceptible crop. Crops like marigold (African marigold, French marigold), mustard, sesame, asparagus (*Asparagusofficinalis*) are known to have nematode suppressive activity by releasing nematotoxic compounds (Table 3) through root exudates (Gaur 1975; Haque and Gaur 1985) of these, marigold is the most studied crop which have ability to suppress nematode activity by releasing polythienyls toxic compounds. Marigold intercropping with tomato, okra, brinjal in different season's significantly reduced root knot nematode incidence by reducing soil nematode population 36.2, 53.5 and 72.9% respectively and percent reduction of root galls 45.4, 40.1 and 86.2% respectively, over control after 90 days of transplanting/ sowing (Umashankar *et al.* 2005). Crops like asparagus (*Asparagus officinalis*), mustard and Africanmarigold as antagonistic crops in susceptible main crop helps in suppression of root knot nematode population. Growing African marigold (*Tagetes erecta* or *Tagetes patula*) with susceptible crop helps in suppressing root knot nematode population by releasing nematotoxic compounds polyterthienyl (α-terthienyl) through root exudates respectively.
b. **Trap Cropping:** Trap crops are highly susceptible crops grown in root knot nematode infested fields and allowed to grow over a time period to invade and develop but do not support for complete its life cycle. *Crotalaria spectabilis* is the most commonly used as trapcrop against root knot nematodes. In order to create a feeding site on the plant, root-knots are made to enter the host plant's root. The plant root is impassable to mature female nematodes. After then, the nematode is caught inside the root and all of the hosts are destroyed. Some examples of trap crops are carrots, beans, and tomatoes. Two weeks after planting, the crop is destroyed by tillage techniques like hoeing in order to kill all nematodes that have lodged in the soil and the crop's root system (Westerdahl, 2007). This method is less common in large-scale commercial agriculture areas and is less effective than nematicide application since not all nematodes are encouraged to

enter the roots. However, this approach helps home gardeners solve environmental issues because it does not involve the use of chemicals. However, this approach helps home gardeners solve environmental issues because it does not involve the use of chemicals.

c. **Cover Crops:** Cover crops can also be grown outside of the regular growing season for agriculture. When cover crops are present, nematodes are unable to migrate to another field since they can only travel relatively small distances on their own (Gill and Mesorley, 2011). A few types of cover crops are cowpea (*Vigna unguiculata*), sorghum-sudangrass (*Sorghum bicolor* x *S. sudanense*), sunn hemp (*Crotalaria juncea*), and marigolds (Tagetes spp.). Additionally, legumes can be planted as cover crops to provide nitrogen to upcoming crops or to make high-quality silage using fodder (Hartwig and Ammon, 2002). There are many advantages to planting cover crops. Cover crops improve soil structure, lower soil erosion, boost soil fertility, and manage weeds, insects, nematodes, and other plant diseases.

d. **Destructions of Crop Residues:** Reducing nematode inoculum densities is facilitated by burning infected plant waste. Eliminating weeds like *Chenopodium album*, *Solanum nigrum*, *Tithonia rotundifolia*, and other unidentified weeds that are linked to vegetable crops serves as a substitute host for root knot nematodes, allowing the life cycle to continue. (Khan and others, 2014).

Applications of organic amendments: Use of organic amendments is a traditional agricultural practice in Indian farming to enhance soil fertility, soil physical condition, recycling of nutrients and soil biological activity. However, several studies evidenced that; organic amendments also can be utilized for the management root knot nematodes including other plant parasitic nematodes (Alam 1976; Akhtar *et al.* 1990; Addabdo 1995).

Generally, organic amendments are polysemic (Collange *et al.* 2011) includes organic manures (animal and poultry), plant parts and their extracts, plant products, industrial wastes, green manures from cover crops, vermicomposts, etc. high nematicidal activity and even the avoidance of phytotoxicity on crops were very acceptable characteristics of organic amendments with C: N ratios between 12 and 20. Neem (leaf, seed kernel, seed powders, seed extracts, oil, sawdust, and oilcake) is a plant product that has been widely utilized to combat root knot nematodes as well as other significant plant parasitic nematodes. Neem releases chemical substances like salanin, azadirachtin, nimbin, thionemone, and other flavonoids that have nematocidal effects.

C. Biological Control:

Biological management of Root knot nematodes main aims to manipulatethe pathogens of nematodes in the rhizosphere in order to control the plant parasitic nematodes.

Fungal Antagonists:

Nematode antagonistic fungal bio-agents generally belong to soil borne fungi group. These fungal bio-agents can be grouped into nematode trapping or predacious fungi, egg and cysts parasitic fungi, endoparasitic fungi and fungi that produce toxic metabolites against nematodes.

a. Nematode trapping fungi: *Arthrobotrys* spp. and *Monacrosporium* spp. are the two fungal antagonists which trap nematodes in constricting rings and adhesive nets respectively (Thakur and Devi, 2007). Their predation mechanism involves the association between a lectin secreted by the fungus and a carbohydrate secreted by the nematode cuticle.

b. Egg parasite: Effective bionematicides include *Paecilomyces lilacinus* 1% W. P. and *Pochonia chlamydosporia* 1% W. P. *P. lilacinus* and *P. chlamydosporia* are prospective fungal antagonists that have been effectively controlled by parasitizing root knot nematode eggs and females. (IIHR, Bengaluru)

c. Toxin producing fungi: The filamentous fungi *Trichoderma* spp. (*Trichoderma viride, T. harzianum*), strains commercially used for the management of root knot nematodes infecting vegetable crops (Rao *et al.* 1998; Goswami and Mittal 2004; Haseeb and Khan 2012). Trichoderma spp.'s mode of action comprises two processes a) direct parasitism on eggs through increasing extracellular chitinase activity; b) induce systemic resistance in plants (Sahebani and Hadavi 2008).

Bacterial Antagonist:

a. Spore forming bacteria: *Pasteuria penetrans* (Thorne) Sayre and Starris the most studied bacterial antagonists of plant parasitic nematodes. *Pasteuria penetrans* is gram positive endospore-forming, obligate parasitic bacteria widely distributed in agriculturalsoils throughout the world (Sayre and Starr 1988; Hewlett *et al.* 1994). Many studies proved their potentiality against root-knot nematodes infecting different vegetable crops (Walia and Dalal 1994; Swarnakumari and Sivakumar 2012; Swarnakumari 2017).

b. Plant growth promoting rhizobacteria (PGPR): Plant growth promoting rhizobacteria are potentially exploited as nematode antagonists against plant parasitic nematodes including root knot nematodes. Generally, plant growth promoting rhizobacteria are mostabundant in rhizosphere region of plant.

D. Physical Methods:

a. Steam sterilization: Generally used in Protected cultivation. Steam sterilization is an effective curative physical measure that can be used to mitigate the severe incidence of rootknot nematode under protected cultivation. However, this method is expensive to practicein open field condition. (IIVR Bulletian 2017)

b. Soil solarization: Utilizing a method known as soil solarization is another option to lessen RKN damage (Tisserat, 2006). To maximize the effects of oil heating, solarization is typically done in the middle of the summer. The soil was covered with plastic film for at least two weeks, which killed the nematode's egg and decreased the number of RKN. In order to reduce the incidence of root knot nematodes, damp soil is heated by being covered with 100-gauge linear low-density polyethylene (LLDPE) clear films.

Soil solarization is a technique of heating damp soil via way of means of protecting it with obvious plastic sheets to trap sun electricity at some point of the summer time season season. This is thermal deinfestation technique.

E. Chemical Control:

Judicious or need based application of nematicides is recommended as in case of highly susceptible crops and high value cash crops or for early protection of tender stages of the plantsuch as seed or seedling treatments in nursery bed applications. Carbofuran 3G and Carbosulfan 25 EC are the two carbamate group chemicals are utilized as nematicides.

- Application of Carbofuran 3G @ 0.3 g a.i. /m2 area of nursery bed.
- Bare root treatment of seedlings with carbosulfan 25 EC @ 2 ml/litre during transplantingcrops.
- Seed dressing of directly-seeded crop like okra and cucurbits with carbosulfan 25 DS @ 3% a.i. (w/w) effectively manage root knot nematode incidence in vegetable crops.
- Seed treatment with carbosulfan (25 EC) at 0.1% for overnight or root dipping 0.05% for 6hours in cucurbitaceous crops.
- Application of Carbofuran 3G @ 1 kg a.i/ha is recommended to nematode infested vegetablecrops under field condition. (IIVR bulletian 2017).
- Root gall population was found reduced in treatment containing *Metarhizium anisopliae* +*Meloidogyne graminicola* and *Metarhizium anisopliae* + *Rhizoctonia solani* +*Meloidogyne graminicola* as compared to control plots (Nair *et al.*, 2021).
- The root gall population of *Meloidogyne incognita* was significantly reduced in treatment of neem leaves, Neem + FYM as compared with other treatments including control (Krishna *et al.*, 2021).
- The root gall population of *Meloidogyne incognita* was significantly reduced in Marigold, Neem leaves amended pots as compared to other treatments. (Pranitha *et al.* 2019).
- A reduction of gall formation of soil nematodes density and improvement of plants by amendments with cake of neem, mustard, nemola, Carbfuran (3G) and FYM (Wasmi *et al.*,2014).
- Plants treated with combinations of specific rhizobacteria and Mycorrhizal fungus had a significantly lower number of galls per root system, second stage juveniles J2 and improved plant growth compared to the control, single treatments of rhizobacteria, Mycorrhizal fungus and Carbofuran 3G (chemical check). When administered in combination, P. *fluorescens*, B. subtilis and G. *fasciculatum* shown moderate impacts on both nematode reproduction and plant development, while Azotobacter sp. was determined to be the least effective. (Hasan *et al.*,2014)
- The interactive effect of *M. incognita* with *R. solani* and *P. aphanidarmatum* significantly reduced the root weight and shoot weight of tomato from other treatments. (Jasim *et al.*2013)

13.5 Losses due to *Meloidogyne* spp.:

Vegetable crops are seriously harmed by root knot nematodes. Plant-parasitic nematodes cause annual agricultural losses from different crops of 21.3 percent, or Rs. 102,039.79 million (1.58 billion USD). Nematodes cause a yield loss of 23.03 percent in horticulture crops in India, costing the country Rs. 50,224.98 million years (Kumar et al., 2020). Vegetable crops suffered yield losses of 19.6% and financial losses of Rs. 14461.22 million as a result of plant parasitic nematodes. The average annual output loss from worms in significant horticultural crops under protected culture may exceed 60% (Kumar et al., 2020). Root knot nematodes cause an average yearly production loss of 10% in vegetables worldwide. However, even higher percentage losses have been recorded, depending on the nematode species, region, crop variety, and soil population level (Collange et al. 2011). In tomato, aubergine, and melons, Sikora and Fernandez (2005) found yield decreases of up to 30%. According to Jain et al. (2007), the annual financial loss suffered by India as a result of root knot nematode infestation in major vegetable crops was estimated to be 5131.80 million rupees. In addition to causing direct damage, root knot nematodes act as a catalyst for the entry of soil-borne bacterial and fungal pathogens, aggravating the issue even more and resulting in the development of disease complexes and severe yield losses of 40–70% in vegetable crops grown throughout the nation (Rao *et al*. 2015a). The root knot nematode species *M. incognita, M. javanica*, and reniform nematode (*Rotylenchulus reniformis*) severely infest a number of crops, including tomato, chilli, gherkins, okra, muskmelon, watermelon, and flower crops such as carnations, roses, gerbera, and anthuriums, which are grown under protected cultivation.

Table 13.3: Estimated yearly output and monetary loss in various vegetable crops due to root knot nematode infestation.

Sr. No	Vegetable crops	Yield loss (%)	Monetary loss (Million rupees)
1	Tomato	27.21	2204.00
2	Brinjal	16.67	1400.30
3	Chilli	12.85	210.00
4	Okra	14.10	480.00
5	Cucurbit	18.20	547.50
6	Carrots	10	290.00
		Total	**5131.80**

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