

Review Article

Plant Parasitic Nematodes and their management in crop production: a review

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ABSTRACT

Plant Parasitic Nematodes are small worm like transparent, bilateral symmetry, pseudocoelomate, multicellular, free living or parasitic microorganism which are predatory, aquatic, terrestrial, entopathogenic, ectoparasite, endoparasite, semi-endoparasite or sedentary. They cause substantial problems to major crops throughout the world, including vegetables, fruits, and grain crops. The root knot and cyst nematodes are economically important pests in numerous crops. Crop damage from nematodes is not readily apparent in most cases, and it often remains hidden by the many other factors limiting plant growth. In the past, the control of the nematodes has been based on the synthetic nematicides, the number of which has been drastically restricted in the EU because of their environmental side effects and subsequent restriction in European Union (EU) rules and regulations. Many other methods like cultural control, biological control, use of biotechnological tools and methods, use of resistant cultivars are tested and proven successful in controlling different species of nematodes all over the world. Alternatively, combinations of the different methods are proven to be highly effective both economically and environmentally.

Keywords: Agriculture, *Meloidogyne*, metabolic function, Plant Parasitic Nematodes

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INTRODUCTION

In taxonomy of nematode, Bastian made a description of 100 species under 22 new and 7 known genera. Schneider and Butschli gave comprehensive survey on free living nematodes including 202 species belonging to 27 genera. Filipjev made significant changes in the classification of nematodes whereas Micoletzky reported 142 genera and 931 species. The recent classification of nematode is based on the hypothesis of paramonov and filipjev (Shah & Mahamood, 2017). About 50 million nematodes are found in a square meter of moderately fertile soil to 30 cm depth. Nathan Augustus Cobb, father of nematology provided a good mental picture of the importance and diversity of nematode when he started that, "if all matter in the universe except nematode were swept away, our worldwide still be dimly recognisable.

We should find its mountains, hills, valley, rivers, lake, oceans represented by a fil of nematodes” (Jilie & Stirling, 1997). Nematodes fit in the category of Ecdysozoa that constitute animals which can moult their cuticle. More than 30,000 species of roundworm are found in nematode generally in the range of 0.2 mm to 6 m. An agriculturally important species of plant parasite nematode called Root knot nematodes were recognized by Barkeley in galls on cucumber roots (Bernard *et al.*, 2017). Nematodes are familiar in all types of soil and environment worldwide which are found in the maze of interconnected through called pores which are formed by soil formation process (Guerena, 2006). Plant Parasitic Nematodes (PPN) are small worm like transparent, bilateral symmetry, pseudocoelomate, multicellular, free living or parasitic microorganism which are predatory, aquatic, terrestrial, entopathogenic, ectoparasite, endoparasite, semi-endoparasite i.e. (e.g. *Tylenchulus semipenetrans*) or sedentary (Shah & Mahamood, 2017). PPN are prolonged, slender organism that has glistening smooth surfaces and Young one has body tapering to a point towards both ends but adults are swollen and no longer resemble to worms (Kumar & Yadav, 2020) and (Goss, 2008). Plant parasite nematode are identified by stylet and sub-ventral and dorsal esophagous glands which plays significant role in evolutionary adaptations for plant parasitism. Due to the numerous annulations, they look like segmented on the cuticle that allow bending without kinking but are unsegmented. Their body have identified organs for feeding, digestive, nervous and excretory systems and have well developed reproductive system which lack circulatory and respiratory organs (Goss, 2008). Most of the species are called “farmers best friend because many species cause death to insects” (Shah & Mahamood, 2017). Crop damage from nematodes is not readily apparent in most cases, and it often remains hidden by the many other factors limiting plant growth (Schmitt & Sipes, 2000). Nematode management should be multifaceted. Since eliminating nematodes is not possible, the goal is to manage their population, reducing their numbers below damaging levels (Schmitt & Sipes, 2000). Common management methods used include planting resistant crop varieties, rotating crops, incorporating soil amendments, and applying pesticides. In some cases, soil solarization also may be practical (Schmitt & Sipes, 2000).

Characteristics of some important Plant Parasite Nematode

The characteristics of different Plant Parasitic Nematode (PPNs) are listed below:

Cyst nematode

Heterodera spp.

- Distribution: The occurrence of cyst nematode species such as *H. filipjevi* and *H. latipons* has been reported in North Africa, Algeria, European countries and Mediterrean countries (Smaha *et al.*, 2019).
- Host range: Altogether there are 70 species of cyst nematode genus *Heterodera*. There are 12 devoted species causing economic loss of *H. avenae* group. The major host range of these species are potato, soybean, oats, wheat, barley etc. (Bohlmann & Sobczak, 2014).
- Symptoms: In severe case cyst nematode causes stunting, wilting and chlorosis and causes yield loss. After many weeks of parasitism, adult female present or attached to host roots (Mitiku, 2018) (Lilly *et al.*, 2005).
- Duration of Life cycle: The duration of lifecycle is upto 55 days and reproduction is through amphimictic process (Singh *et al.*, 2013).
- Feeding habit: Migratory endoparasite juvenile enters into the root region of the vascular tissue and feed their content (Mitiku, 2018).

Root Rot Nematode

Hrischmanniella spp.

- Distribution: Among the different species of *Hrischmanniella*, *H. miticausa* has been reported in Papua New Guinea and Solomon island (CABI, 2019). They fall under group sedentary. They got their names from the galls of knot like structure which they form in roots of the plants they have infected (Subedi *et al.*, 2020).
- Host Range: Altogether there are 24 species of Root rot nematodes of genus *Hrischmanniella*. Out of 24 species, 12 species of *Hrischmanniella* are parasitic to rice. Major host range of these species are rice, cotton, sugarcane and maize (Regmi, *et al.*, 2016).
- Symptoms: There is no any clear symptoms above the ground but chlorosis and growth retardation appear when *H. oryzae* enters through lateral root on root tips. Then, it migrates towards the aerenchyma region of root causes the necrotic trace. After that the secondary invasion microorganism along with necrosis causes browning of rice roots (Bauters *et al.*, 2014).
- Duration of Life cycle: Under favourable condition the cycle extends up to 30 days. Mode of reproduction is sexual. It is migratory endoparasitic in habit (Regmi *et al.*, 2016).

Sting Nematode

Belonolaimus spp.

- Distribution: *Belonolaimus longicaudatus* has been reported firstly in south eastern United States. In the Gulf of Mexico and Atlantic coasts from Texas to Virginia , it is found commonly. Four lateral lines of *Belonolaimus spp* have been found in Australia, Venezuela and Brazil (Gozel *et al.*, 2006).
- Host range: The host range of *Belonolaimus longicaudatus* are corn, turfgrasses, peanuts, citrus, strawberry and root vegetables (Abu-Gharbieh & Perry, 1970).
- Symptoms: Due to a greater number of populations of *B. longicaudatus* nematode causes the root region damaged, water and nutrient uptake capacity gets eliminate, poor growth, wilting, leaf chlorosis etc. In severe case, it causes death of the plant (Stirling, *et al.*, 2013).
- Duration of Life cycle: This parasite feed the root region ectoparasitically. The duration of lifecycle may extend upto 28 days. Reproduction is through amphimictic process. (Singh *et al.*, 2013)

Citrus Nematode

Tylenchulus spp.

- Distribution: It is distributed throughout the world. In citrus groups this plant parasite nematode is commonly found. The host range of these species is mostly citrus relatives (Rutaceae family) and *Poncirus trifoliata* and its hybrids can also be parasitized. It can also infect grapes, olive and persimmon (Inserraet *et al.*, 1994).
- Symptoms: According to the level of infection the economic yield loss of *T. semipenetrans* is about 10 to 30%. *T. semipenetrans* symptoms above the ground are slow growth of the plant, yellowing of the foliage, reduction in the number of fruit and yield. Moreover, the root region is severely infected with citrus nematode and is thicker than healthier root. Hence, causes slow decline in the citrus (Verdejo-Lucas & McKenry, 2004).

- Duration of Life cycle: Its feeding habit is semi endoparasitic in nature. Duration of lifecycle ranges from 4 to 8 weeks. The mode of reproduction is amphimictic, meiotic and parthenogenesis process (Singh *et al.*, 2013).

Seed gall Nematode/Ear Cockle Nematode

Anguina spp.

- Distribution: The distribution pattern of seed gall nematode has been reported in West Africa, North Africa, Australia, Brazil, China, India, Turkey, France, Italy, Iraq, USA (Tulek *et al.*, 2015). According to latest classification altogether there are 11 species of *Anguina* (Powers *et al.*, 2001).
- Host range: Main host of these species are wheat, rye and barley. It has been reported that (52-100) % losses in wheat can be incurred, 50% and 65% losses in wheat and rye respectively (Mukhtar *et al.*, 2018).
- Symptoms: In the moist soil the second stage of juvenile penetrate the wheat seedling and feed their content ectoparasitically (Ozberk *et al.*, 2011). Later, it enters into the floral primordia endoparasitically (Mukhtar *et al.*, 2018). Also, there is rolling, curling of leaf, small blisters on leaf and distortion of stem (Ami & Taher, 2013).

Lesion Nematode

Pratylenchus spp.

Root lesion nematodes (RLNs) are distributed throughout the world. They belong to genus *Pratylenchus* constituting of about 97 valid species.

- Host range: Major host ranges are cereals legumes vegetables, fruits, ornamentals, coffee, peanuts etc. In temperate region 12 species of root lesion nematode causes severe damage. It is estimated that 8 species of root lesion nematode cause devastating damage in cereals crop (Yu *et al.*, 2012).
- Symptoms: Specific symptoms associated with the vegetables crop such as potato plant is that it causes yellowing of foliage, reduction in growth and necrosis in the root and tuber of potato (Esteves *et al.*, 2015).
- Duration of Life cycle: They are migratory endoparasitic in habit. The life cycle last longer than 3-9 weeks depending on species and environment condition. For example, in Red clover the life cycle duration of *P. penetrans* is 9 weeks. The modes of reproduction are parthenogenesis and anhydrobiosis. Anhydrobiosis occur when *Pratylenchus spp.* in soil live for many years (Jones & Fosu-Nyarko, 2014).

Root Knot Nematode

Meloidogyne spp.

- Distribution: They are distributed throughout the world. Altogether there are 98 known *Meloidogyne spp.* which causes the economic losses of about 5% throughout the world (Khanal *et al.*, 2016).
- Host range: Major host ranges are cover crop, fruit tree, weeds, ornamental and agronomic plants (Khanal *et al.*, 2016).
- Symptoms: Formation of galls or knot due to expansion of root cells. The secondary symptoms are wilting, yellowing of leaves, nutrient deficiency, slow or stunted growth (Ralmi *et al.*, 2016).
- Duration of Life cycle: They are migratory or sedentary endoparasitic in nature as they enter into the root region and feed their content (Das *et al.*, 2015). The total length of life cycle in most of the species is about 3-4 weeks under the suitable

temperature of 27-30°C. Mode of reproduction is parthenogenesis and sometimes occur by amphimixis (Singh *et al.*, 2019).

Life of Nematode

Nematodes complete its life cycle within 6 stages i.e., egg, 4 juvenile stage and adult stage. The first 4 stage are immature so called it as a juvenile stage and it undergoes direct and uncomplicated life cycle. Generally, the female lays eggs in the soil or in plant tissues in single or in groups which are oval in shape. Eggs are covered by the external portion layer, inner lipid, and true shell secreted. The first moult occurs within the egg shell and second stage juvenile comes out by rupturing the egg shell as J2. The larvae may spend their whole life within the host or may either leave the feeding sites. The larvae are similar in adults in appearance. Adults also spend most of time in the soil to feed upon new roots (Maggenti & Allen, 1959). The life cycle of a nematode is given in Figure 1.

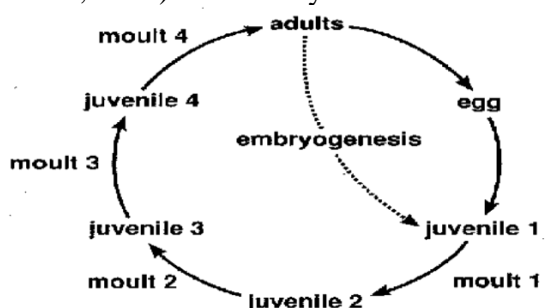


Figure 1: Generalized life cycle of a nematode (Stirling *et al.*, 2013)

Effects of Plant Parasitic Nematodes in major agricultural crops

Generally, in most of the place in the world farmers cultivate mainly Rice, Wheat, Maize, Potato, Soyabean, Oat, Barley, Cauliflower, Cabbage, etc. as a major Cereals and vegetables crops but in yet more or less than \$80 billion has been estimated losses due to the nematodes annually worldwide. In subterranean ecosystem, nematode plays important role in food chain (Bernard *et al.*, 2017). Some of the impact of Nematode on Rice, Wheat, Maize and Potato are listed below:

Rice (*Oryza sativa*)

PPNs are one of the most important soil borne pests of rice with annual losses of 10-25% worldwide. Rice production is affected by more than 100 species of nematodes. In a temperate and tropical areas *Meloidogyne spp.* are important pathogens of rice. Symptoms of infected rice are hook shaped galls, stunting, decreased tiller number and poor growth and reproduction (Pokhrel *et al.*, 2007). Rice root nematode is mostly found in irrigated rice production system (Kyndt *et al.*, 2014).

Wheat (*Triticum aestivum*)

Wheat yields are decreased by cereal cyst nematodes (*Heterodera spp.*) of *Heterodera avenae* group. They also damage barley and oat. Root lesion nematode *Pratylenchus neglectus* and *Pratylenchus theories* and also seed gall or ear cockle nematode (*Anguina tritici*) also causes losses in wheat production.

Maize (*Zea mays*)

In the world more than 50 species of parasitic nematodes are found in maize. The most devastating genera are root knot nematode, (*Meloidogyne spp.*) and the cyst nematode (Nicol *et al.*, 2011). The symptoms caused by corn cyst nematodes are poor development of plant, leaf chlorosis with minor galling.

Potato (*Solanum tuberosum*)

Cyst nematodes are abundant pathogen causing more losses in the yields. Root knot nematode and stem nematode are major plant parasite pathogen of potato.

Management Practice of Plant Parasitic Nematodes

Cultural method

Common management methods for PPNs used include planting resistant crop varieties, rotating crops, incorporating soil amendments, and applying pesticides. In some cases, soil solarization also may be practical (Schmitt & Sipes, 2000). Crop rotation and cover crop plays a vital role in the integrated pest management as it helps to decrease the density of plant parasitic nematode. Cover crops like *Mucuna pruriens*, *Crotalaria spectabilis*, show the resistant against three species of PPNs viz. *Meloidogyne anenaria*, *Meloidogyne javinica*, *Meloidogyne incognita* (Bernard *et al.*, 2017). Rotational crops like garlic, onion, asparagus, corn, cahaba white vetch, nova white vetch helps to reduce the infestation of *Meloidogyne spp.* as well as helps to prevent the plant from diseases and insect pest. Resistant crop like crotalaria, velvet bean and grasses like rye are resistant to Root knot Nematode (RKN). Allelo chemical like Dhurrin are produced from sudan grass and sorghum which further converted to hydrogen cyanide and used as powerful nematicide (ATTRA, 2003). Antagonistic crop like marigold alone can infest or decrease the population density of 14 genera of Plant parasite nematodes including *Meloidogyne spp.* by showing antagonistic affect (Kafle, 2013).

Biological control

It is defined as the involvement of the useful organism genes or their different forms of product which helps to decrease the negative effects on the plants and promotes positive effects. It is also called as Biopesticides. Biopesticides are defined as, "the products aimed at protecting the plants made from living organism or natural substance from species co-evolution, not produced by chemistry and use of which is recommended for control of pests or bio-aggressor for a better response of the bio-cenosis and environment" (Trainer *et al.*, 2014). The main biocontrol agents used to control different nematode species is given in Table 1.

Also, by the participation of soil microbes of the damaging phase of complicated organic materials and nitrogenous compounds which are available in the cow dung, green manure, crop residue etc helps to reduce the infestation of PPNs. Application of these substances in the soil helps to increase fertility and micro fauna of soil (Agbenin, 2011).

Table 1. Main biocontrol agents used to control different nematodes species

Bio control agents	Pathogens
<i>Paecilomyces lilacinus</i>	Severe attack on the egg of different Plant Parasite Nematodes species
<i>Pasteuria penetrans</i>	Reduce infection as well as fecundity of the Plant Parasite Nematode species
Rhizosphere bacteria (<i>Bacillus subtilis</i>)	Have effect on nematode multiplication
Green manure/ crop residue	Plant Parasitic Nematode (PPN)
Cow dung/ poultry manure	Plant Parasitic Nematode (PPN)
Neem seed powder	Plant Parasitic Nematode (PPN)

(FAO, 2020; Agbenin, 2011)

Biotechnology Method

Biotechnological research of plant parasite nematode species helps to show up the crop species resistance present in their gene pool. In order to show up their synthetic form of resistance, they destroy their feeding cells and insert the toxic compound in the nematode invading cells (Nyarko & Jones, 2015). The tools that have been used for the identification and management of Plant Parasitic Nematodes:

- Isozyme electrophoresis and antibodies
Sometimes it is difficult to identify different species of nematodes such as root knot nematode, cyst nematode based on their morphology. But now it is easy to guess the single adult female *M. javanica*, *M. arenaria*, *M. incognita* through isoenzyme differences in esterase and maltase dehydrogenase (Caswell-Chen *et al.*, 1993).
- Polymerase chain reaction (PCR)
In this technique two oligonucleotide primers hybridize opposite strands of DNA by making proper sequence to the target DNA. The amplification process can be controlled by heating and cooling cycles. It can produce the exact copy $10^6 - 10^9$ of the target DNA sequence. It can be also done with little sample (Caswell-Chen *et al.*, 1993)
- RAPD (Randomly amplified polymorphic DNA)
In nematode control it has been used for the identification of genetic diversity of different species of nematode. Through RAPD markers, the inter and intra variation of most of nematode can be known. In this process by comparing the RAPD profile of single female genomic stability of nematode species can be known (Shah & Mir, 2015).
- RFLP (Restriction fragment length polymerase)
Major step in this process is listed below:
 1. Primer design
 2. Selection of restriction endonuclease.
 3. Amplification of PCR (polymerase chain reaction).
 4. Restriction endonuclease treatment
 5. Electrophoresis

It helps to know the evolutionary relationship, characterization and development of nematode species (Shah & Mir, 2015).

Host plant resistance method

The researcher and scientist distinguished the different types of natural genes which are used for developing plant resistance to nematode. In case of traditional breeding nematode resistance plant have little success. For mitigating nematodes RNA interference (RNAi) technology consider as reliable process (Tamilarasan & Rajam, 2014). Mainly two types of resistance i.e. passive and active resistance works in the relationship between host plant and

nematode resistance. In passive resistance anatomical, physiological and chemical barrier affect the infestation of nematode. Active resistance causes histological change which forms the necroses around the nematode and leads the nematode to die (Giebel, 1982). Sugarbeet cyst nematode can be resisted by HS1pro1 gene, Mi-1.2 gene in tomato (*Solanum lycopersicum*) provide resistant against root knot nematodes. It has been concluded that in isogenic nematode pressure of 200,000 eggs/ plants. Moreover, GPa2 gene shows resistance against potato cyst nematode (*Globodera pallida*) (Briar *et al.*, 2016) and (Ralmi *et al.*, 2016). Metabolites like methyl salicylate, 2-isopropyl-3-methoxypyrazine tridecane, limonene etc. affects the movements of nematodes to find their suitable host (Sikder & Vestergard, 2020).

Chemical method

The ultimate aim of using the chemical pesticide is to create the toxic barrier between the host and pathogen. The nematicides based on their movement in the soil can be categorized into two categories. They are fumigants and non fumigants. Liquid formulations which are vapourized after contact with air are considered to be as fumigants. In the vapourized form their molecules get detached, start moving in the soil and decompose into product that penetrate cuticle of nematodes, affect in metabolic function. Organophosphate and carbamates are categorized into non fumigants which directly have the systematic action on phytonematodes and are more effective at low doses (Ebene *et al.*, 2019). Also, many nematicides are toxic and volatile in nature which affects the human, animal health and environment causing the severe problem such as ozone layer depletion and ground water contamination (Hussain *et al.*, 2017).

Pesticide category for the effective control of nematodes (Ebene *et al.*, 2019).

Organophosphates (ops):

- Cadusafos: potato, cotton, sugarcane,
- Ethoproph: potato
- Fenamiphos: Banana, cotton, coffee, tomato
- Phorate: corn, tomatoes, wheat
- Fosthiazate: potato, banana, carrot
- Thiodicarb: cotton, oats, peanuts, barley, beans

Iso thiocyanates

- Metam sodium: potato, carrot, tobacco, strawberry and tomato
- Abamectin: cotton, garlic, corn and soyabean
- Fluensulfone: cotton, potato, coffee, sugarcane, citrus, guava, chilli, pepper

CONCLUSION

Plant parasite nematode affects several crops like rice, wheat, potato and maize. It declines the productivity and causes crop disease. Infestation of these plant parasite nematodes on plants can take place endoparasitically and ectoparasitically. Furthermore, they can migrate towards the vascular system of plants resulting in damaging of roots and affect the nutrient uptake and transportation mechanism. Nematode management should be multifaceted. Since eliminating nematodes is not possible, the goal is to manage their population, reducing their numbers below damaging levels. For effective management of nematodes, first step is to make an accurate diagnosis, and then proper selection of the most effective and environmentally control method. Crop rotation and cover crops can be done in integrated way in a cultural method. Chemicals, which are less aggressive to human animals and

environment and more specific to phytonematodes, can be applied. The use of bio controls agents and nematode resistant varieties can be used to control nematode species. The integration of traditional and molecular methods can be used as sustainable pest management practices for control of plant parasitic nematodes.

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Authors' Contributions

H.R. Mandal, S. Katel, J. Shrestha and S. Subedi wrote this review paper.

Conflict of Interest

The authors declare no conflict of interest regarding publication of this manuscript.

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