Nematode Pests
of
Horticultural Crops
and
Their Management

Course No.: H/ENTO-365
Credits : 2 (1+1)

College of Horticulture, Pune-411 005

Syllabus

Course Title: Nematode Pests of Horticultural Crops and their Management

Credits : 2 (1+1)

Theory:

- ✓ History and development of Nematology, Definition, Economic Importance, General Characters of plant parasitic nematodes, their morphology and biology, Symptomatology and management of important plant parasitic nematodes of fruits (tropical, subtropical and temperate), vegetables, tubers, ornamentals, spice and plantation crops.
- ✓ Role of nematodes in plant disease complex.

Practical:

- ✓ Methods of sampling and extraction of nematodes from soil and plant parts.
- ✓ Killing, fixing and preparation of temporary and permanent mounts. Nematicides and their use.
- ✓ Collection and preservation of nematode infested plant specimens.

History of Nematology: Pre-1850

- Vedas are the earliest religious scriptures in the human history. There are occasional references to nematode parasites of human beings by the name **Krmin** or **Krmi** in Sanskrit (meaning worms) in Rig, Yajur and Atharva vedas written 6000-4000 BC. The vedic people were aware about the krimis, their symptoms, vectors, and their cure. Later,when indigenous medical science Ayurveda developed following Atharv veda (3000 BC and later), Charak recognized 20 different organsims as krimis in his Samhita, which included nematodes besides arthropods and leeches.
- The earliest written account of a nematode "sighting," as it were, may be found in the Old Testament in the Bible: "And the Lord sent fiery serpents among the people, and they bit the people; and much people of Israel died". Many nematologists assume and the circumstantial evidence suggests the "**fiery serpents"** to be the Guinea worm, ***Dracunculus medinensis,*** as this nematode is known to inhabit the region near the Red Sea.
- Before 1750, a large number of nematode observations were recorded; many by the notable great minds of ancient civilization. Hippocrates (ca. 420 B.C.), Aristotle (ca. 350 B.C.), Celsus (ca 10 B.C.), Galen (ca. 180 A.D.) and Redi (1684) described nematodes parasitizing humans, other large animals and birds.
- Petrus Borellus (1656) was the first to describe the **first free- living nematode,** which he dubbed the "vinegar eel;" scientifically referred as ***Turbatrix aceti.***
- Being less conspicuous, plant parasitic nematodes didn't receive as much or as early attention as did animal parasites.
- The earliest information to a plant parasitic nematode is, however, preserved in famous writ. "Sowed cockle, reaped no corn," a line by William Shakespeare penned in 1594 in "Love's Labour Lost', Act IV, Scene 3, most certainly has reference to blighted wheat caused by the plant parasitic nematode, *Anguina tritici*
- Turbevil Needham (1743) accidently recorded **first plant parasitic nematode** when he crushed one of the shrunken and blackened wheat grains and observed "Aquatic worms, Eels, or Serpents, which they very much resemble." He named it ***Vibrio tritici.*** Later this nematode was rightly named as ***Anguina tritici*** by Steinbuch.
- From 1750 to the early 1900's, Nematology research continued to be descriptive and taxonomic, focusing primarily on free-living nematodes, and plant and animal parasites.

19th century History of Nematology (Events of significance):

- Berkley (1855) discovered **first root-knot nematode** from galled roots of green-house cucumbers in England.
- Schacht (1859) ascribed the decline in sugar beet to a cyst nematode later named as ***Heterodera schachtii*** by Schmidt in 1871.
- Kuhn (1871) was the **first to use soil fumigation** to control *Heterodera schachtii,* applying **carbon disulfide (CS_2)** treatments in sugar beet fields in Germany.
- Goeldi (1887) described *Meloidogyne exigua* causing gallson the roots of coffee in Brazil.
- Ritzema-Bos (1891) discovered for the first time a foliar nematode when he discovered ***Aphelenchoides fragariae***on strawberry.
- Atkinson (1892) described **for the first time the interactive role of nematodes** in producing disease complexes. He reported that the cotton wilt caused by ***Fusarium oxysporum*** increased mani fold in presence of **root-knot nematode.**
- Leibscher(1892) reported pea cyst nematode ***Heterodera goettingiana*** on pea.

Modern History

Although 18th and 19th century scientists yielded a considerable amount of important fundamental and applied knowledge about nematode biology, real qualitative and quantitative research in nematology began only near the turn of the 20th century.

- In 1907, **Nathan Augustus Cobb,** an extremely productive scientist, a keen observer, an artist and a prolific writer **later called The Father of Nematology,** joined Sugar Plant Research Centre in Hawaii (USA). His important contributions are:

Nathan Augustus Cobb (1859-1932)

- He described detailed **morphology of plant parasitic nematodes** and described **minute sensory organs** of nematodes like amphids, deirids, cephalids, papillae and phasmids.
- Devised **nematode extraction techniques** from soil, **methods for sampling, nematode sectioning** and **mounting.** Many of his techniques are still unsurpassed.
- He devised **"Cobb's slides"** in which nematode specimens are mounted between two coverslips. The slides allow observation of the specimen from both sides and minimize refractive interference of the image. Even now, important nematode specimens are mounted on Cobb's slides.
- Invented a new **camera lucida device** for drawing and measurements of nematodes.
- Discovered many **new species** of plant parasitic nematodes.

- Published his first paper on nematology in the United States (1913).
- He separated free living nematodes and plant parasitic nematodes. He advised to shift plant parasitic nematodes. from Helminthology to Nematology and coined the term **Nema** (1914).
- Cobb (1918) published "**Contributions to a Science of Nematology"** and his lab manual "**Estimating the Nema Population of Soil"** for the benefit of new workers in this field.
- There are 568 publications to his credit.

- In 1933 Tom Goodey published his book named "**Plant Parasitic Nematodes and the Diseases they cause".**
- In 1934 I N Filipjev in Russia produced his book "**Nematodes that are of Importance for Agriculture".**
- In 1937 B G Chitwood and M B Chitwood wrote a

  book "**An Introduction to Nematology"**
- Carter (1943) discovered the **nematicidal properties of DD mixture.**
- Christie (1945) discovered the nematicidal properties of

  Ethylene Di bromide (EDB)
- In 1951 Tom Goodey published a book "**Soil and Fresh Water Nematodes"** which was revised by his son, J B Goodey, in 1963.
- 1961: **Society of Nematologists** (SON) was formed in USA.

Milestones/ Landmarks in History of Nematology

- 1941: Discovery of the golden nematode, ***Globodera rostochiensis*** in the potato fields of Long Island led
  U.S. quarantine officials on a trip to the potato fields of

  Europe, where the devastating effects of this parasite had been known for many years earlier.
- 1943: The introduction of the **soil fumigants, D-D (Dichloropropane – Dichloropropene)** by Carter for nematode control
- 1945: Christie discovered another fumigant petroleum byproduct **EDB (ethylene dibromide)** for nematode control on a field scale.
- 1951: Christie and Perry demonstrated several ectoparasitic nematodes like ***Xiphinema, Longidorus, Trichodorus, Dolichodorus, Hemicycliophora*** etc. to act as primary plant pathogens.
- 1953: Suit and Ducharme discovered that the burrowing nematode, ***Radopholus similis*** was responsible for causing „Spreading decline of citrus‟ in Florida, USA. Serious problem of **'Pepper Yellows'** in Bangka islands of Indonesia that shattered the economy of the country was also discovered to be caused by this nematode.
- 1955: **Society of European Nematologists (SON)**was formed. In 1956, this society started publishing first ever exclusive journal in the field of Nematology by the name of **Nematologica (name now changed to 'Nematology').**
- 1958: First report of **virus transmission** by plant parasitic nematodes was given

by Hewitt, Raski and Goheen when they demonstrated ***Xiphinema index*** to transmit **fan leaf grapevine virus** in grape vines.

- 1971: ***Bursaphelenchus xylophilus*** was found to be responsible for serious „Pine wilt‟ disease in Japan that devastated vast pine forests

History of Nematology in India

- 1901: Barber reported root knot nematode infecting tea in South India – **first ever report of plant parasitic nematodes from India.**
- 1919: Butler reported that **Ufra disease of rice** was caused by ***Ditylenchus angustus*.**
- 1934: Ayyar reported root knot nematode infesting vegetables and other crops in South India.
- 1936: **White tip disease of rice** caused by

  Aphelenchoides besseyi was reported by Dastur.
- 1958: **Molya disease of wheat and barley** (caused by ***Heterodera avenae)*** recorded in Rajasthan by Vasudeva.
- 1959: Siddiqi discovered **citrus nematode** and other plant parasitic nematodes from Aligarh soil in UP.
- 1961: Jones reported **golden nematode of potato** from Nilgiri Hills in Tamil Nadu.
- 1961: Nematology unit was established at the Central Potato Research Institute, Shimla.
- 1964: International Nematology Course at IARI, New Delhi participated by FGW Jones, J B Goodey and D J Raski.
- 1966: Nair, Das and Menon reported burrowing nematode, ***Radopholus similis* on banana** in Kerala for the first time.
- 1966: Division of Nematology was started at IARI, New Delhi.
- 1967-68: First South East Asia Nematology course held at AMU Aligarh and IARI, New Delhi.

- 1969: **Nematological Society of India** was founded and first All India Symposium was held at IARI, New Delhi.
- 1971: Nematological Society of India commenced publication of its biannual journal **"Indian Journal of Nematology"**
- 1977: All India Coordinated Research Project (AICRP)
  on nematode pests of crops and their control was started at 14 centers with the headquarters of project coordinator at IARI, New Delhi.

Development of Nematology; Why so late?

Although nematological investigation dates back to the days of Aristotle or even earlier, Nematology as an independent discipline has its recognizable beginnings in the mid to late 19th century. Its relative late recognition as an independent Science was due to following reasons:

- Microscopic size and non-availability of good microscopes.
- Hidden mode of life as most of them complete their life cycle below ground in soil/roots only. A very small fraction of plant parasitic forms are parasitic on

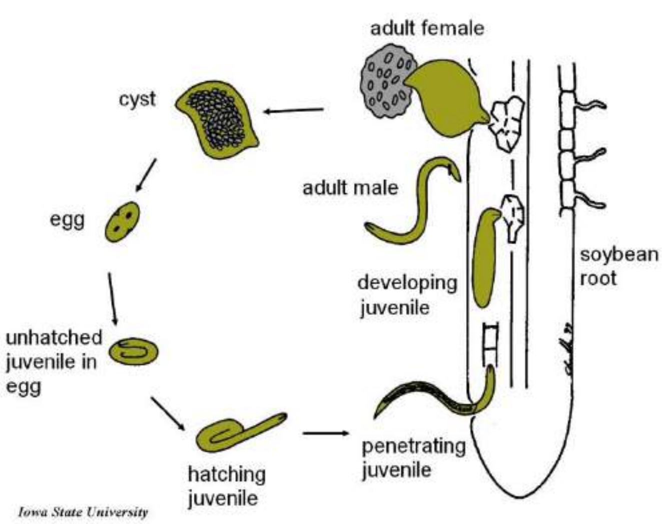
above ground parts of the plants.

- Non-specific symptoms except in few cases like root- knots or ear cockle of wheat which are sure indications of nematode infestation.
- Techniques of extraction were not known till early twentieth century.
- Difficulty in proving their pathogenicity as they are obligate parasites and cannot be cultured on artificial media
- Lack of trained personnel.
- Unawareness among the farmers/growers.

Economic Importance of Plant Parasitic Nematodes

The science of Nematology is relatively young compared to its contemporary disciplines of Entomology and Plant Pathology. Thus, despite the significant role of nematodes in agriculture, still much is yet to be understood and learnt in this discipline. Nematodes are ubiquitous, present in all moist to watery ecological niches in diverse situations like cold oceans, hot springs, mountain peaks, soil ecosystem, plants as well as animals. Phytoparasitc forms comprise about 15% of all the forms of nematodes that exist in various habitats and have different feeding behaviours. Phyto-nematodes parasitize all types of plants - from lower thallophytes (algae) to highly developed angiosperms including all plants and trees and cause billions of dollars worth of damage to world food crops as well as tree crops, turf and ornamentals. There are about 6000 known species of phyto-parasitic nematodes belonging to 197 genera. Being obligate parasites, they must draw their nutrition from plant hosts and in the process, must debilitate the plant. A handful of soil from around the roots of any plant would yield hundreds of plant parasitic nematodes belonging to at least 4-5 genera. A single wheat gall may contain up to 30,000 wheat gall nematodes, one gram of coconut root may contain about 4000 eggs, juveniles and adults of burrowing nematode or about 5000 individuals of coconut ring nematode.

Figure 2.1 Nematodes by life style



Plant parasitic nematodes present some of the most difficult pest problems evaluated in our agricultural economy, because nematode damage is often overlooked due to mostly non specific symptoms, although the yield losses may equal to those associated with more severe and easily identifiable plant damage. The extent of direct damage by the nematodes to plants depends on several factors. These include-

- Initial nematode population
- Nematode density in soil
- Nature of parasitism (ectoparasite or endoparasite, migratory or sedentary)
- Host susceptibility
- Cropping pattern
- Edaphic factors (soil texture, moisture etc.)
- Ambient climatic conditions
- Maximum temperature and moisture.

Nematodes, by themselves, rarely kill the plants to ensure their own survival. However, in nature, they are involved in all sorts of interactions with other micro-organisms (fungi, bacteria, viruses) leading to disease complexes. Also, their high population build up in soil has been the cause of „Soil exhaustion‟ that compelled the farmers to migrate to the newer areas since old times. „Replant problem‟ is another common experience in nematode infested orchards, plantations and forests.

Nematode problems in the tropical and sub-tropical zones are generally more damaging and varied because:

- Higher temperature and longer growing seasons result in more generations per year; higher the population more will be the damage.
- The more number of susceptible crops per year in warm areas results in higher nematode build up.
- Some of the most damaging species like *Meloidogyne. incognita* are prevalent in warm areas.
- More severe disease complexes occur in warmer areas.
- Some exceptions to these are *Globodera rostochiensis* (potato), *Heterodera schachtii* (sugarbeet), *Anguina tritici* (wheat) etc. which prefer cooler environmental conditions.

Economic losses caused by nematodes

- In the tropical and sub-tropical climates, crop production losses attributable to nematodes were estimated at 14.6% compared with 8.8% in developed countries.
- Overall average annual loss of the world‟s major crops due to damage by plant parasitic

nematodes was estimated to be 12.3% which is one third of the losses attributed to pests and diseases in general.

- For the 20 major life sustaining crops that serve as man's primary food source, annual yield loss of l0.7% was estimated.
- For another group of 20 crops mainly of commercial importance, a 14% annual yield loss was assessed.
- Developing countries suffer a crop loss of 14.6% compared to 8.8% in developed countries, when estimated losses for all the 40 crops were considered.
- **Monetary losses** due to nematodes on 21 crops were estimated at US $ 77 billion annually based on 1984 production figures and prices.

    - 11% in vegetables ($267 per year fruit)
    - 6% in field crops ($110 million/year)
    - 12% in fruits and nuts ($225 million/year) and
    - 10% loss in ornamentals ($60 million/year).

In Florida, losses due to *Tylenchulus semipenetrans* were assessed at 50-80% in grapefruit and 40-70% in sweet orange. In UK, loss of potato due to golden nematode has been put to 2 million pounds.

Plant parasitic nematodes of utmost significance

- About 100 nematode diseases are of global economic significance.
- Presently 25 genera of plant parasitic nematodes include species that are economic pests of crop plants.
- Ten most important nematode genera in order of their significance at global level are *Meloidogyne, Pratylenchus, Heterodera, Ditylenchus, Globodera, Tylenchulus, Xiphinema, Radopholus, Rotylenchulus*

  and *Helicotylenchus.* Others may assume significance in near future as their host parasitic relationships are properly understood.

In India, the nematodes that cause most severe damage to horticultural crops include:

- *Meloidogyne* and *Rotylenchulus reniformis* in vegetables
- *Radopholus similis* in banana, black pepper and coconut (c.o. toppling disease of banana, slow wilt of pepper and coconut)
- *Pratylenchus coffeae* in coffee
- *Tylenchulus semipenetrans* in citrus (c.o. Citrus decline/Slow decline of citrus)

Similarly, among the cereal crops:

- *Ditylenchus angustus* (c.o. ufra disease of rice) *Aphelenchoides besseyi* (white tip of rice), *Hirschmanniella* spp. and *Meloidogyne graminicola* in rice
- *Heterodera avenae* (molya disease in wheat and barley), *Anguina tritici* (ear cockle

of wheat) in wheat are most important.

Some other examples of economically damaging nematodes of specific crops in one or the other region of the world are

- *Aphelenchoides besseyi* (summer crimp of strawberry)
- *Heterodera schachtii* (causes "beet sickness" and sickness of cole crops)
- *Bursaphelenchus xylophilus* (causes lethal "pine wilt" and is responsible for destruction of large areas under pine forests in counties like Japan and USA)
- *Bursaphelenchus* (=*Rhadinaphelenchus) cocophilus*

  (causing "red ring of coconut")
- *Radopholus similis* (c.o. toppling disease of banana, slow wilt of coconut and pepper)
- *Radopholus citrophillus* (c.o. spreading decline of citrus)
- *Tylenchulus semipenetrans* (in citrus causing slow decline).
- Many nematode genera infest tropical forest plants.

Besides, some major nematode problems that have not been reported from India so far are:

- "Spreading decline" of citrus caused by *Radopholus citrophilus* (in Florida)
- Onion bloat caused by *Ditylenchus dipsaci*
- Beet sickness caused by *Heterodera schachtii*
- Cotton disease caused by *Belonolaimus longicaudatus.*

Some nematodes that cause wide spread problems in wet and cool temperate regions are:

- *Ditylenchus dipsaci* (stem and bulb nematode on bulb crops)
- *Ditylenchus destructor* (potato rot nematode)
- *Globodera rostochiensis and G. pallida* (latter species more important in India) on potato
- *Bursaphelenchus xylophilus* (Pine wilt nematode)

The annual loss in the country due to:

- Cereal cyst nematode, *Heterodera avenae* in wheat and barley was estimated to be Rs 32 million and 25 million, respectively, in Rajasthan alone.
- Seed gall nematode, *Anguina tritici* (causing „Ear cockle of wheat when alone and „Tundu disease‟ when in combination with bacterium) was estimated to be Rs. 70 million in wheat only in North India.
- *Pratylenchus coffeae* in an area of about 1,000 ha in Karnataka was estimated to be Rs. 25 million is assessed in coffee due to.

- *G. rostochiensis* is a limiting factor. In Nilgiris, about 3000 ha area is infested with this nematode and total crop failure has been reported number of times.

Gaur and Seshadri (1999) estimated a loss of Rs 24230 million per year due to plant parasitic nematodes on different crops in India. Some of the economically important nematodes in various crops in the country are

- *Meloidogyne* spp. attack more than 3000 crop plants which include vegetables, tuber crops, pulses, number of fruits, ornamental crops, tobacco etc.
- *Aphelenchoides besseyi* (white tip), *Ditylenchus angustus, Hirschmanniella spp., Heterodera oryzae* etc in rice
- *Radopholus similis* in banana, coconut, arecanut, pepper and many other spice crops in South India.
- *Tylenchulus semipenetrans* in citrus crop in many citrus growing states of the country.
- *Aphelenchoides* spp. and *Ditylenchus myceliophagous* in mushroom are responsible for slow pace of development of mushroom industry in the country as their infestation leads to poor crops or total crop failures in number of mushroom growing states of the country.

Root-knot nematode (*Meloidogyne* spp.) ranks first as far as damage to crops at global level is concerned because of their world wide distribution , extremely wide host range, destructive nature of the diseases caused by this nematode and their role in many destructive disease complexes. High percent yield losses in solanaceous vegetables by root-knot nematode have been assessed in various parts of the country. Avoidable yield losses to the tune of 28.1, 33.7, 46.2, 43.5 and 28.6 per cent have been assessed in okra, brinjal, tomato, French bean and cowpea, respectively.

Nematodes are excellent bio-indicators for environmental change as once they are present in a habitat and in proximity of hosts conducive to their development, they may rapidly multiply. Indigenous species that have remained in balance may emerge to pest status on agricultural crops with small changes to their habitat, either through changes in cropping practice (crop, cultivars, rotation cycle etc.) or climate. A good example of this is illustrated by the rapid and alarming emergence of *Meloidogyne minor* in Europe.

Disease Complexes

- Plant parasitic nematodes often interact with fungal, bacterial and viral pathogens to cause disease complexes.
- The nematodes may play the role of an aggravator, incitant, or vector in many such situations.
- Of the many disease complexes, root knot nematode + bacterial wilt are the most lethal.
- There are instances where controlling the primary organism (nematode) has led to management of disease complexes.
- The quantification of the crop losses due to nematodes in such disease complexes

is difficult to assess, nevertheless, nematodes do contribute substantially to crop losses in combination with other soil organisms.

Beneficial nematodes:

In addition to the harmful plant parasitic forms, there are groups of nematodes which are beneficial as they parasitize the harmful insects and mollusks and thus can be exploited as biological control agents against these pests. The entomopathogenic nematodes *Steinernema* and *Heterorhabditis* spp. and slug parasitic nematode *Phasmarhabditis hermaphrodita* in a mutual association with bacteria have proved to be successful biocontrol agents and are now being commercially produced in many countries.

General Characters of Plant Parasitic Nematodes

Nematology is the scientific discipline conventionally concerned with the study of phyto- nematodes which parasitize plants and are of economic importance to agriculture, horticulture and forestry.

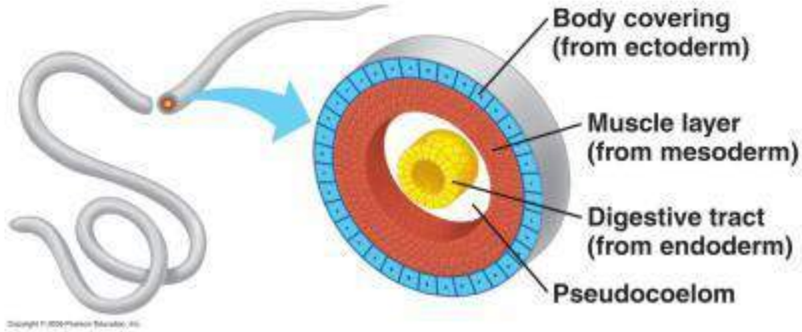
Nematodes may be defined as bilaterally symmetrical, triploblastic, pseudocoelomic unsegmented invertebrates with four hypodermal chords, a tri-radiate oesophagus, circum oesophageal nerve ring and a definite tail but lack circulatory muscles and specialized organs for locomotion and respiration. Nematodes belong to phylum **Nematoda.**

The **cuticle** of a typical plant-parasitic nematode is transparent, thus allowing the viewing of internal systems when viewed under the microscope, .

General Characters of plant parasitic nematodes

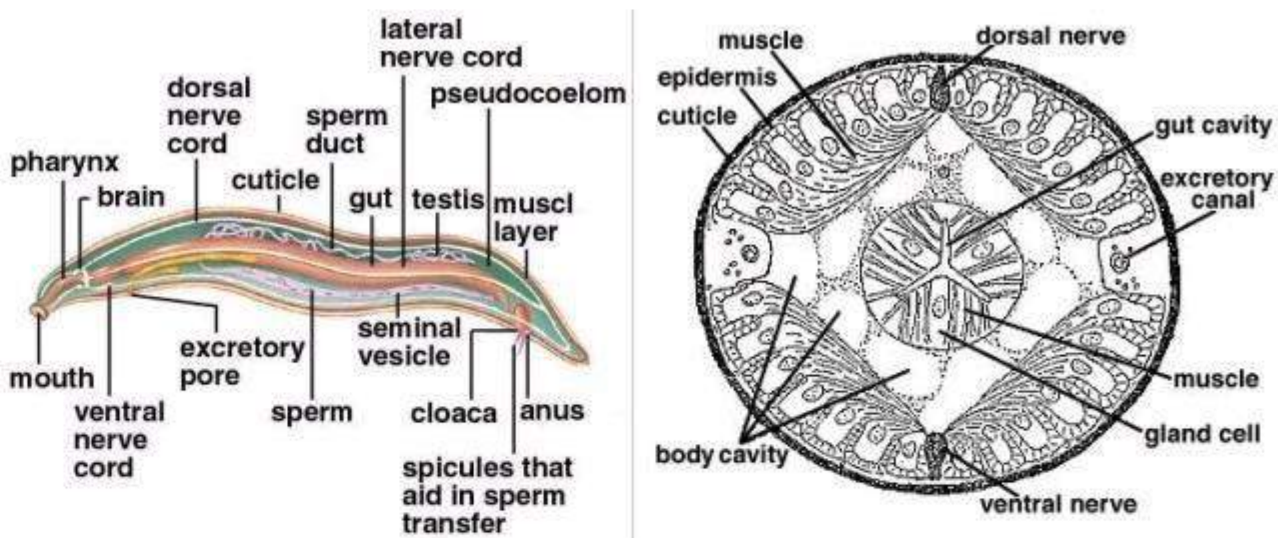
1. Plant parasitic nematodes in general are elongated, cylindrical, bilaterally symmetrical, unciliated worms with body tapering towards both the ends and having maximum diameter in mid body region. Variety of other shapes is also present, especially in sedentary semi-endoparasitic and endo-parasitic females which turn obese and acquire shapes other than normal cylindrical forms. Males, however, remain vermiform in all the genera of plant parasitic nematodes.
2. The body is covered by a transparent, tough, resistant cuticle that is secreted by a layer of hypodermal (epidermal) cells lying just beneath it.
3. Plant parasitic nematodes have a protrusible hypo- pharyngeal needle like knobbed stylet (spear) at the anterior end of the body, which is used to suck the cell cytoplasm from the host plants. Fungal feeding nematodes also possess stylet which may or may not be knobbed.
4. Nematodes possess a false body cavity or pseudocoelom i.e. a cavity lacking mesodermal lining internally or a cavity present between mesoderm and endoderm. Pseudocoelom is fluid filled and most part of it is occupied with intestine and components of reproductive system (Fig. 3.1).

Fig.3.1 Body Cavity



5. Oral aperture (mouth) is terminal and is surrounded by lips which contain sensory cephalic papillae. All other body openings like excretory pore, vulva and anus (in females) and cloacal aperture (in males)are ventrally located (Fig. 3.2).

Fig 3.2 Diagrammatic representation of nematode to show various body openings



General Characters of Plant Parasitic Nematodes Resource (Contd..)

6. Musculature consists of smooth longitudinal muscle cells located between the hypodermal chords and are directly connected to longitudinal nerves. Circulatory muscles are absent.

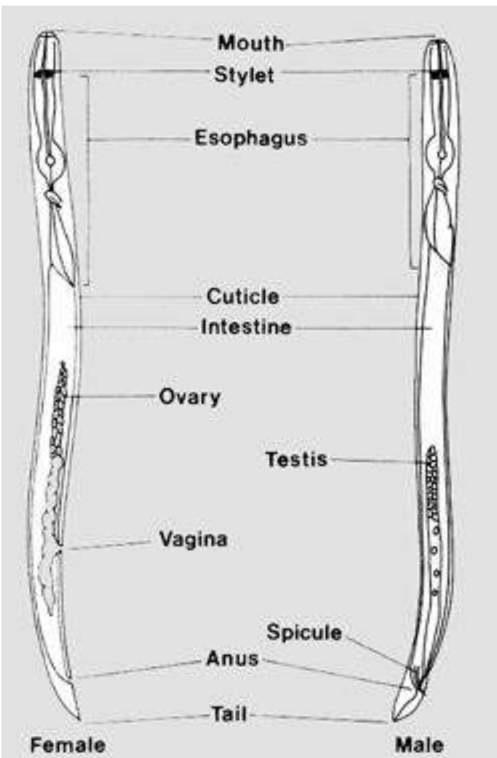
7. Digestive, reproductive, nervous and excretory systems are present. Well defined respiratory and circulatory organs are absent.

8. The digestive system consists of a feeding apparatus, pharynx (oesophagus), intestine and rectum. Pharynx in all tylenchids is tripartite but in plant parasitic dorylaimids it is bipartite. At the junction of pharynx and intestine, a pharyngeo-intestinal valve (cardia) is present that ensures unidirectional flow of food.

9. They are usually dioecious with tubular reproductive organs.One or two gonads may be present

10. The nervous system consists of a circum-oesophageal nerve ring and longitudinal nerves which innervate all body parts. In addition, transverse nerves are also present connecting the longitudinal nerves.
11. The secretory-excretory system is primitive and consists of primitive single ventral gland cell (renette) in adenophoreans but consists of two lateral excretory canals joined to each other by transverse canals in secernenteans. It lacks proto-nephridial cilia or meta-nephridial flame cells.
12. They do not have any specialized structures for locomotion.

Fig. 3.3 Typical plant parasitic female and male nematodes



General Morphology

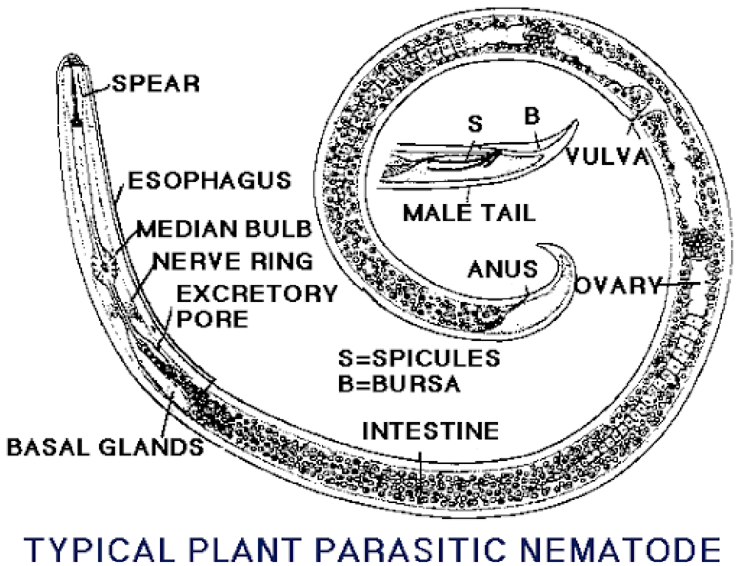
"Nematode" is a greek word (nema = thread, oides = form) i.e. thread like organisms as they look like tiny threads moving under microscope.

Female Male

Figure 4.1 Morphological features of typical plant parasitic nematodes (female and male)

Synonyms: Threadworms, eelworms (serpentile eel like body), round worms, nemas, paudh/padap krimi etc. **Body Shape:** Nematodes are generally vermiform having a cylindrical body tapering towards both anterior as well as posterior ends and having maximum diameter near mid body.

Figure 4.2 Cylindrical shape of a typical plant parasitic nematode



Some exceptions in shape:

1. **Filiform –** More elongated towards the body extremities e.g. *Xiphinema, Longidorus, Paralongidorus*

Figure 4.3 Filliform *Xiphinema*

2. **Sausage shaped or plump-** When body length is reduced but breadth remains same giving a plump look e.g. Criconemoid group

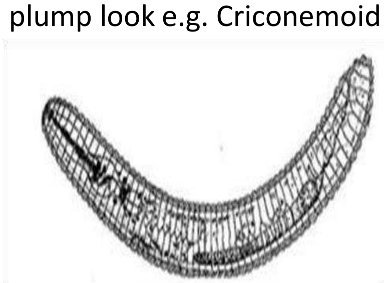
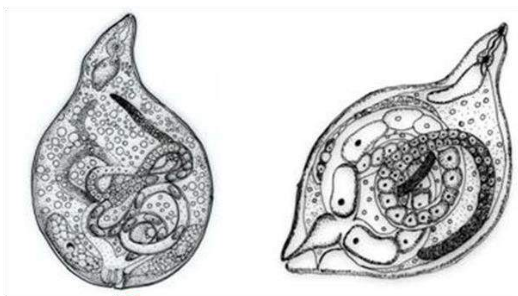


Figure 4.4 Sausage shaped *Criconemalla*

Figure 4.4 Sausage shaped *Criconemalla*

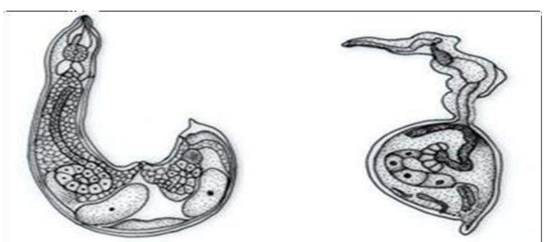
3. **Pyriform or flask shaped -** Females of certain Genera swell to acquire saccate, pear shape or flask like structure.

e.g. Females of *Meloidogyne* spp. and *Heterodera* cysts



Meloidogyne ***Heterodera***
Figure 4.5 Flask shapes /saccate nematodes

4. **Kidney shaped or Reniform-** eg. *Rotylenchulus reniformis*



Rotylenchulus reniformis Tylenchulus semipenetrans
Figure 4.6 Kidney shaped or Reniform nematodes

Rotylenchulus reniformis Tylenchulus semipenetrans

Sexual dimorphism:

Morphological differentiation between the genders of same species is referred as sexual dimorphism. Both sexes look alike in most of the nematode species; males being smaller than females. However, sexual dimorphism has been observed in number of genera of order Tylenchida which are sedentary semi-endoparasitic/endoparasitic in their feeding behaviour. while the females of these forms become obese to acquire spherical or semi-spherical shapes, males, if present, remain vermiform. e.g. females of *Meloidogyne* and the cysts of *Heterodera* and *Globodera* are saccate. The females of *Nacobbus, Rotylenchulus, Tylenchulus* etc. are sub-spherical / kidney shaped.

Male and female of *Meloidogyne* spp. Male and female of *Heterodera glycines*

Figure 4.7 Sexual dimorphism in plant parasitic nematodes Body posture Habitus

The specific property of the various nematodes genera to acquire a definite posture on relaxation/ killing by gentle heat which is specific of the genus is called "Habitus" eg. *Pratylenchus* spp. acquire almost straight or slightly irregularly curved posture on relaxation by heat.

Hoplolaimus spp.adopts slightly ventral curve. *Tylenchorhynchus* spp., *Paratylenchus* spp. etc.curve in a 'C' shape.

Helicotylenchus spp. and *Rotylenchus* spp.attain spiral shape. The habitus has some taxonomic significance as it gives some indication of the presence of a particular species at low magnification.

Figure 4.8 Body postures (Habitus) in different plant parasitic nematodes

As a rule, the inside curvature of nematodes body is always towards ventral side with only one exception of genus

"*Dorsalla*" which curves in a "C" shape dorsally.

Body size:

Plant nematodes are generally microscopic with their body size ranging from 0.3 to 2.0 mm.

Smallest – *Paratylenchus minutus*

Longest - *Paralongidorus epimikis* (up to one cm in length)

Segmentation:

Nematodes have an unsegmented body. The outer cuticle is often marked with superficial transverse grooves (striations) which form rings round the body. Striae are generally shallow and narrow (fine striations) but in Criconematids the striae are very deep and are referred as annules. In addition to transverse striations, the longitudinal markings known as lateral lines are also present in the lateral fields of the body.

Figure 4.9 Cuticular striations and Annulations

Coloration:

Nematodes are colourless and their body wall is transparent.

Body regions:

- Nematode body is tubular without any distinction of regions. However, for the sake of convenience, the anterior end bearing mouth, lips and stoma is referred as „**Head'** and the region beyond the anus is rightly termed as „**Tail'.**
- Longitudinally, the nematode body is divisible in to four zones; the ventral bears the openings of digestive (anus), excretory (excretory pore), and reproductive (vulva, cloacal aperture) systems; the side exactly opposite to the ventral is dorsal. The other two sides located at right angles to the dorsal and ventral sides are right and left laterals.

Symmetries:

- The nematode body is basically bilaterally symmetrical i.e. when the body is cut in to two equal halves through the saggital (dorso-ventral) plane, one half is the mirror image of the other.

- Structures like lips show hexa-radiate symmetry and stoma and pharynx show tri-radiate symmetry. Nervous, reproductive and excretory systems show asymmetry.

Body Organization

The nematodes body is tubular. It consists of two tubes.

- **Outer body tube** - Wider, larger, represents the body wall.
- **Inner body tube** - Smaller, narrower, represents the Alimentary canal.The two tubes join anteriorly to form lip region and are posteriorly connected through rectum.

Figure 5.1 Tubular body organization

The outer body tube (body wall) consists of three layers:

- **Cuticle**
- **Epidermis (Hypodermis)**
- **Somatic Musculature (muscles of body wall)**

Cuticle:

- It is a non-cellular, non-living, tough but elastic, multilayered external covering secreted by hypodermal cells that acts as an exoskeleton and protects the inner soft body tissue.
- Apart from covering the body externally, the cuticle invaginates in to the body at oral aperture, excretory pore, vulva, anus etc., and lines the alimentary canal, excretory duct, vagina, rectum/ cloaca and some sensory structures.

- The cuticle covering the body is called **external cuticle** and that lining the internal structures is called **internal cuticle.**
- Tail region of the males of most of the plant parasitic nematodes bears a wing like lateral cuticular extension known as **bursa** (Caudal alae) which helps to clasp the females during mating.

Functions

1. Cuticle along with hypodermis forms the exoskeleton of nematodes. It prevents radial deformation of the body during undulatory motion caused by the longitudinal muscles.
2. Being elastic, it maintains turgor pressure of the body.
3. Being selectively permeable, it acts as a barrier to harmful elements in the environment and plays a role in uptake of the substances. It allows the transport

of gases,.
4. Cuticle is the seat of many sensory structures.
5. Longitudinal alae of the cuticle assist in locomotion.
6. It supports the musculature.

Hypodermis:

- It is made up of a single layer of cells or some times syncytial in nature which lies between the cuticle and musculature.
- While basically it is a thin layer, it thickens characteristically in dorsal, ventral and lateral positions to form four longitudinal chords (one dorsal, one ventral and two lateral chords) of which lateral chords are more conspicuous.

Figure 5.2 Cross section of nematode to show the body layers

Functions

1. Hypodermis secretes and maintains the cuticle.
2. It accumulates proteins and nucleic acids at the time of moulting.
3. Hypodermal glands act as osmotic and ionic regulators.

Somatic musculature:

- Somatic muscle cells are arranged **longitudenally** beneath the hypodermis in the four inter-chordal zones just beneath the hypodermis.
- In addition, there are some specialized muscle cells that are attached to specific organs like stylet, spicule etc. to enable these organs to make specific movements.

A muscle cell comprises of two distinct zones;

1. Contractile fibrillar zone that contains myofibrils
2. Non-contractile sarcoplasmic zone that contains nucleus and cytoplasm.

Types of muscles in nematodes

Muscle cells have been differentiated in to three types on the basis of their shape and arrangement of contractile fibres.

Platymyarian muscles: Wide flat-base with contractile fibres limited to the base lying closest to the hypodermis. Present in smaller nematodes like plant parasitic forms.

Coelomyarian muscles: Narrow base with contractile fibres extending up the sides of the muscle cells. More common in large nematodes

Circomyarian muscles: Round muscles with contractile fibres all along its circumference. (Rare; found in the stylet, vulva & spicules etc.)

Platymyarian muscle

Coelomyarian muscle Circomyarian muscle

Figure 5.2 Types of muscles in nematodes

Two types of muscle arrangement is usually observed.

- Meromyarian having two to five muscles in each inter- chordal zone.
- Polymyarian having more than five muscles in each inter-chordal zone.

Platymyrian muscle cells are meromyarian and coelomyarian muscle cells are polymyarian in arrangement.

Functions: Musculature helps in locomotion and other movements specific of organs.

1. They also act as reservoirs of the stored food material.

General Morphology

SENSORY STRUCTURES: Though, a part of nervous system, sensory structures are made up of cuticle and hypodermis. The sensory structures receive stimulus and transfer it to the nerve centre.

Two types:

Exteroceptors - Peripheral in location; keep the nematodes aware of external environment.

Interoceptors - Internally located on the cuticular lining of digestive and reproductive system. Perceive stimuli of the internal environment of the animal and pass to nerve centre

1. **Cephalic Sensory Structures:**

- The lip region is typically hexaradiate with oral aperture (mouth) in the center; encircled by six lobe like structures referred as lips or labia. Two of these lips are sub dorsal, two are sub ventral and two are lateral in their location.
- There are 16 labial papillae present on the lips.
- Papillae are arranged in two circles; an inner circle of six papillae one on each lip towards the oral aperture and ten in outer circle.
- The arrangement of ten labial papillae in the outer circle; two are dorso-dorsal, two are latero-dorsal, two are ventro – ventral, two are latero-ventral and two are lateral in their location.

Function

- Outer labial papillae are purely mechanoreceptors also referred as tactoreceptors as they are sensitive to touch.
- Inner labial papillae are bimodal in function i.e. they act both as mechano as well as chemoreceptors.

Figure 5.3 En face view of head to show the location of labial (cephalic) papillae

2. Amphids: These are the paired structures located laterally in the cephalic region. They are of varied shapes in different groups of nematodes. They are chemoreceptors in function i.e. they perceive chemical stimuli.

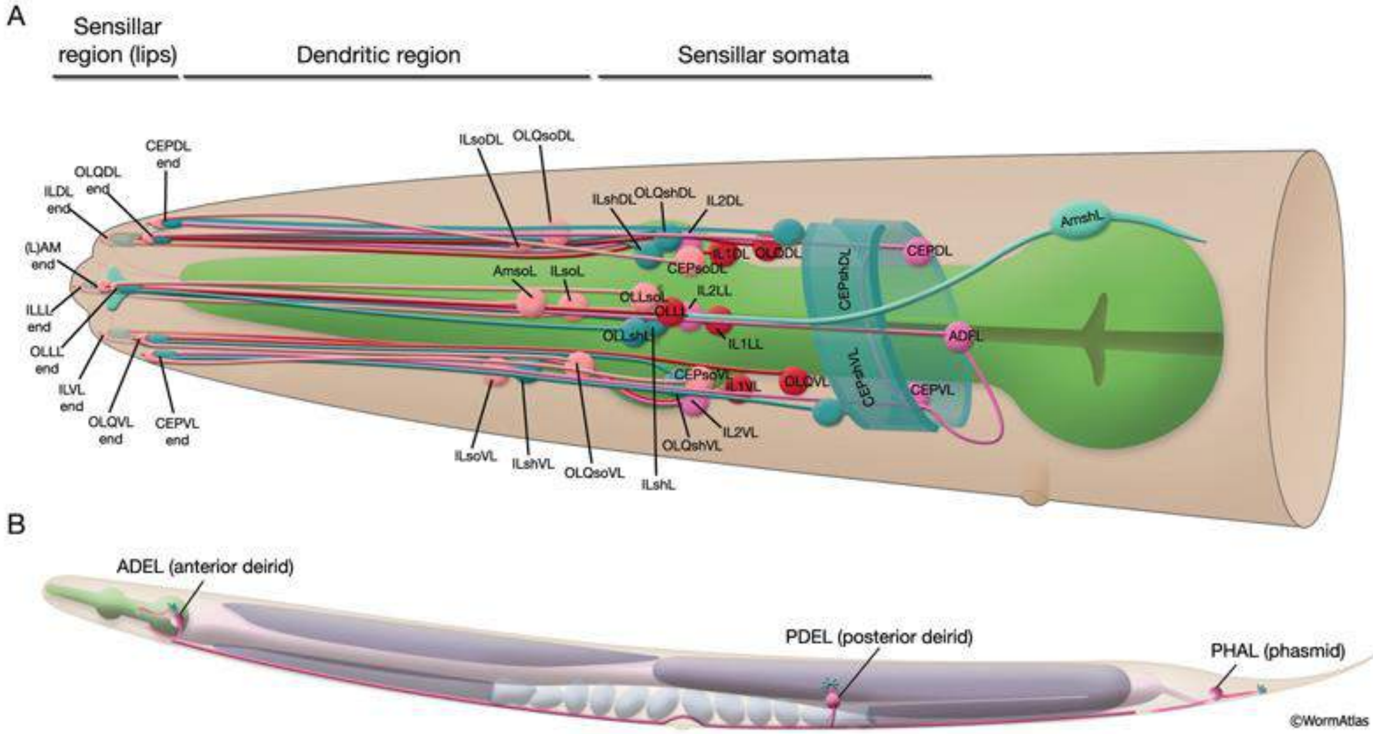


Figure 5.4 Structure of amphid

3. Phasmids: Paired sensory structures located laterally on each side of the tail and open to the exterior through a minute pore. Mainly chemoreceptors but may also perform some secretary function.

4. Deirids: A pair of small protuberances, one on each lateral side in the centre of lateral fields in the oesophageal region at about the level of excretory pore. They act as mechanoreceptors. Other sensory structures are hemizonids and hemizonoins (near excretory pore), cephalids (one or two pairs in head region) and caudalids (one pair in tail region).

THE INNER BODY TUBE (ALIMENTARY CANAL)

The inner body tube forms the alimentary canal (digestive system) of nematodes.

Feeding Habits

- Soil-inhabiting nematodes can be classified on the basis of their feeding habits as microbivores, herbivores (plant parasitic), predatory or even animal parasitic including human parasites.
- The structural organization of their stoma/mouth parts differ as per their feeding habits.

Microbivores. Many kinds of free-living nematodes feed only on microbes e.g. bacteria, which are always extremely abundant in soil. In these nematodes, the "mouth", or stoma, is a hollow tube for ingestion of bacteria.

Figure 5.5 Head regions of microbivore, predatory and plant parasitic nematodes

Predators: These nematodes feed on other soil nematodes or other animals of comparable size. They possess an armed stoma havingdenticles.

Plant parasitic (Herbivores): This group includes many members of the order Tylenchida, as well as a few genera in the orders Aphelenchida and Dorylaimida. The **mouthpart is a hypo-pharyngeal needle like stylet** which is used to puncture cells during feeding. Fungivores that feed on fungi, also possess a stylet to puncture hyphal walls of fungi.

Alimentary Canal

Alimentary canal of plant parasitic nematodes can be distinguished into 3 zones; **the stomodaeum** (fore-gut), **the mesenteron** (mid-gut) and **the proctodaeum** (hind-gut). Stomodaeum and proctodaeum are internally lined with cuticle

.

(I) Stomodaeum

- It starts at the oral aperture or the mouth which is located terminally and is surrounded by 6 lips. (2 sub- dorsal, 2 sub-ventral and 2 lateral in position).
- The oral aperture leads internally into a cavity known as stoma or buccal cavity.
- Among plant parasitic nematodes, the stomal walls fuse together to form a hypodermic needle-like structure called **stylet** (stomatostylet or spear) having a fine lumen of less than 1µm.
- The stylet is a protrusible organ and when pushed inside the plant cell, helps in ingestion of the cell cytoplasm through its lumen.
- The movement of the stylet is regulated by stylet protractor muscles.

Figure 5.8 Structure of stomatostylet

The lumen of the stylet is continuous with that of the oesophagus/ pharynx, the next part of the stomodaeum.

- **Oesophagus/pharynx** is basically a pumping organ which sucks in and pushes the ingested food material into the intestine.
- The structure of the oesophagus is also variable in nematodes of different feeding habits. It may be cylindrical throughout (1 part or uni-partite) as in predatory mononchids or narrow anteriorly and broader posteriorly (2 part or bottle like or bipartite) as in Dorylaimids, or it may have one cylindrical procorpus and two bulbous structures (3 part or tripartite) as in case of most plant parasitic nematodes.

Figure 5.9 A. Unipartite, B. Bipartite, C. Tripartite oesophagi

- The various parts of a tripartite oesophagus are **procorpus, meta corpus /median bulb** and a narrow isthmus leading to the **terminal/ basal bulb.** Variations within 3-part oesophagus are seen among different groups of plant parasitic nematodes.
- Procorpus is a narrow anterior portion which enlarges to form a muscular median bulb (meta corpus). Meta corpus is highly muscular and armed with valves. The pulsation of median bulb helps in the ingestion of cell cytoplasm through the stylet into the oesophagus, and further pushing of the ingested food material into the intestine.
- Following this is a narrow zone, the isthmus which is linked to the basal bulb in which three oesophageal glands (1 dorsal and 2 sub-ventrals) are located.
- In plant parasitic tylenchids, the **dorsal oesophageal gland** opens near the base of stylet in the anterior part of pro corpus. The **sub-ventral glands** join the oesophageal lumen in the median bulb.
- These glands secrete the „saliva‟ for the digestion of food.
- In certain nematodes the oesophageal glands are more developed and cannot be accommodated within the basal bulb. In such cases ,these extend (overlap) over the anterior part of the intestine to some distance on any of the various sides i.e. dorsally, ventrally or laterally.
- The oesophageal lumen is triradiate and is lined by cuticle.
- The junction of oesophagus with the intestine is guarded by an oesophageo-intestine valve referred as **cardia** which ensures the uni-directional flow of food from oral aperture to intestine without regurgitation.

Figure 5.9a The Stomodaeum Mesenteron:

- It consists of a simple straight tube i.e.the **intestine** running most of the length of the body.
- The intestine is composed of a single layer of endodermal epithelial cells.

- Internally, these cells bear a layer of finger-like projections (microvilli), which are absorptive and secretory in function.

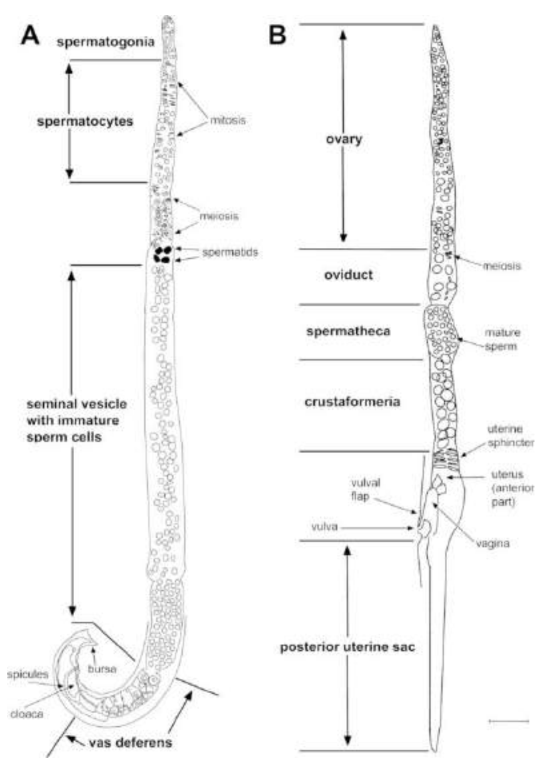
Proctodaeum

- It consists of a short flat tube called **rectum** which is lined internally by cuticle.
- Rectum opens to the outside ventrally through **anus** in females.
- In case of males, the reproductive system joins the rectum to form a common tube called **cloaca,** which opens to the outside through **cloacal aperture** on the ventral side.

REPRODUCTIVE SYSTEM

- Nematodes are dioecious i.e. males and females are separate.
- In general appearance, both the sexes look alike except in the region of tail which is more arcuate in male nematodes due to presence of copulatory structures called **spicules** and usually bursa.
- Reproductive system is tubular and is often referred as **genital tract.**
- Reproductive system remains suspended in the pseudocoelom/body cavity.

Female Reproductive System



- The various parts of the female genital tract are ovary (gonad), oviduct, spermatheca, uterus, vagina and vulva.
- The oocytes are formed in the apical zone of ovary from where they move down and grow in size in the growth zone.
- On maturation, they pass down to spermatheca via oviduct. Spermatheca, if present stores the sperms after mating and when the oocytes pass through it, they get fertilized.
- Further layers on the egg (ovum) are laid while it is passing through the **glandular crusta formeria** of the uterus.
- Vagina helps in the expulsion of egg to the outside and opens on the ventral side through a slit-like opening, the vulva.
- Females may possess only one gonoduct (monodelphic) which may be directed anteriorly (prodelphic) or posteriorly (opisthodelphic).
- In those females which possess 2 gonoduct (didelphic), the uteri of two gonoducts unite to form a common vagina leading to vulva.
- In didelphic forms, one gonoduct may be directed anteriorly and other posteriorly (amphidelphic) or both may be directed anteriorly (prodelphic), or posteriorly (opisthodelphic).

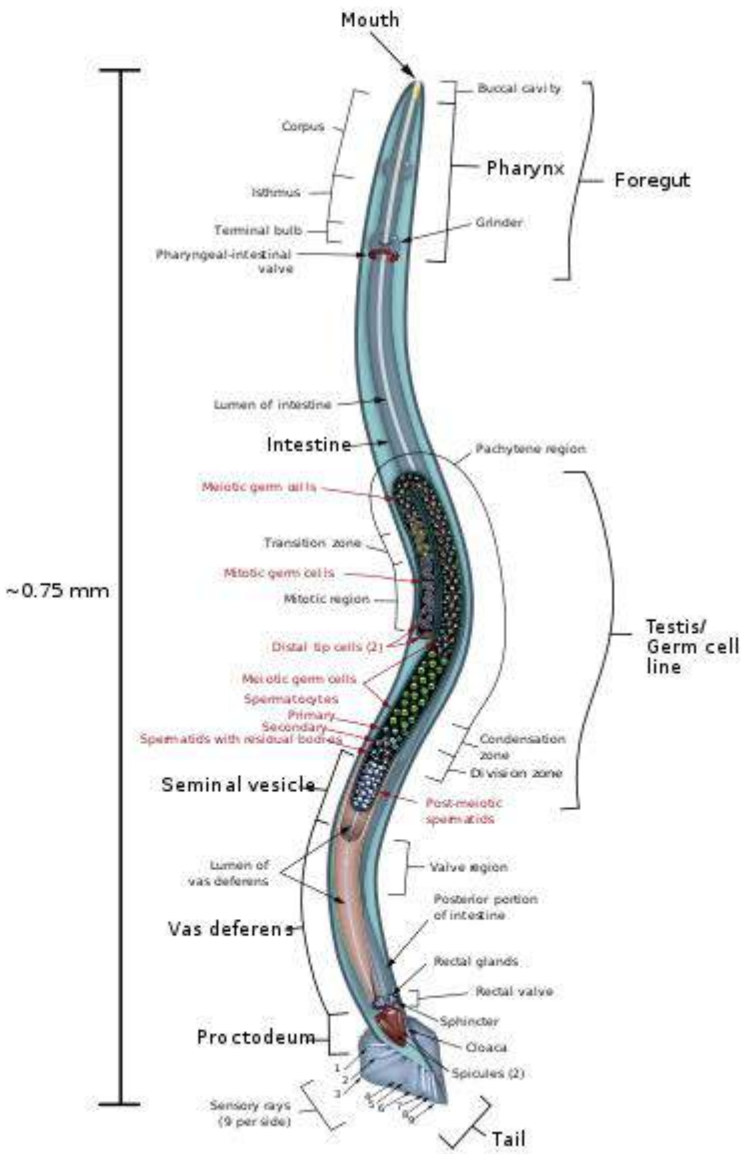
Pro-monodelphic Opistho-monodelphic Pro-didelphic Amphidelphic

Figure 6.1 Different arrangements of tubular reproductive organs in various female nematodes

Male Reproductive System:

- Among plant parasitic nematodes, males generally have a single genital tract (monorchic), butsome genera may possess two genital tracts (diorchic).
- Various parts of male genital tract are: testis, seminal vesicle, vas deferens, cloaca and cloacal aperture.
- Sperms are formed in the testis, and may be temporarily stored in the seminal vesicle.
- Vas deferens joins posteriorly with rectum to form cloaca.
- A pair of hard curved structures, the **spicules** are located in a cloacal pouch .
- The spicules are protrusible and help in the insemination of females during mating.
- The movement of spicules is guided by a sclerotized plate-like structure, the **gubernaculum.**
- A flap like structure called **bursa** is usually present covering the tail region.
- Bursa helps to clasp the female during mating.

Figure 6.2 Male Reproductive System



Nervous System:

- In general, nematodes have a highly developed nervous system.
- In plant parasitic nematodes, because of their small size, the only part visible in whole mounts is the nerve ring, the so called **'brain'** of the nematodes.
- The nerve ring encircles the oesophagus, usually in the isthmus region, and hence is often referred as **circum- oesophageal commissure.**
- Six longitudinal nerves extend from the nerve ring anteriorly to innervate the cephalic sensory organs.
- Posteriorly, 4 main nerves-dorsal, ventral and 2 laterals arise from the nerve ring, run in the respective hypo dermal chords, and innervate various parts of the body.
- Transverse commissures inter-connect the longitudinal nerves throughout the body.

Associated with the nervous system are sense organs. (already covered in cuticle).

EXCRETORY – SECRETORY SYSTEM

Two types of excretory systems are present in nematodes- the **Canalicular** and the **Glandular.**

A. Canalicular type

- The longitudinal excretory canals/ tubes run almost the entire length of nematode body in the lateral hypodermal chords.
- These canals are interconnected and form a terminal excretory duct, which opens to outside through excretory pore, usually located in the oesophageal region on the ventral side.
- Most of the plant parasitic tylenchid nematodes have the canalicular type of system.
- Excretory duct is the only part visible in the whole mounts.

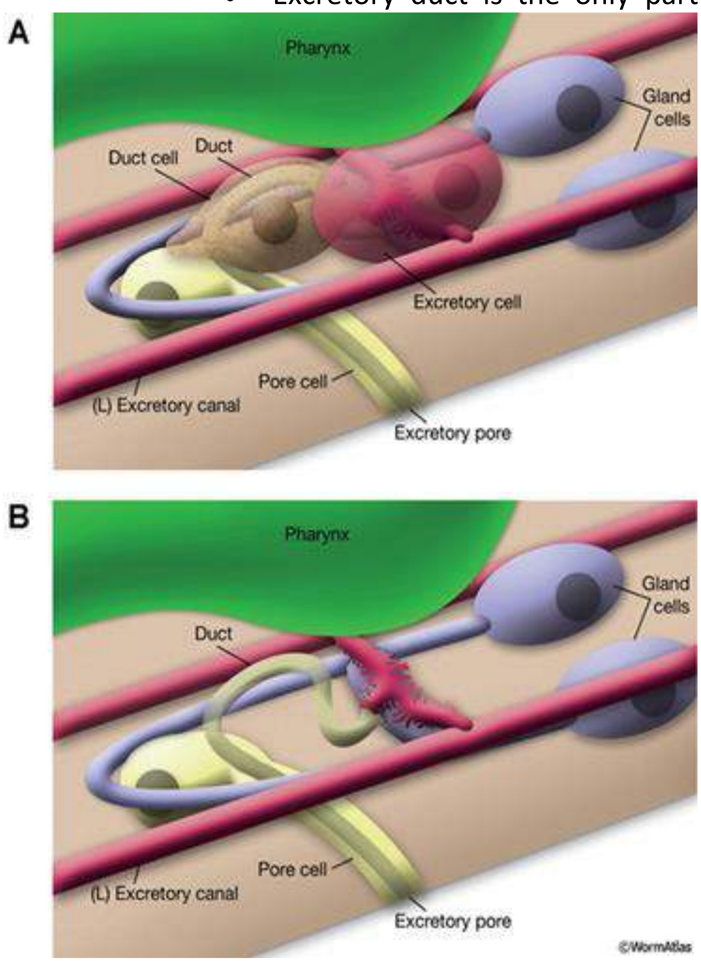


Figure 6.7 Types of secretory-excretory systems in nematodes

B. Glandular type

- This type of excretory system consists essentially of a single cell **renette (sinus, ventral gland cell** or **cervical cell**) which leads to an excretory duct that opens to the outside through a n excretory pore on the ventral side.

- The whole system lies freely in the pseudocoelom.
- Based on the type of excretory system, nematodes are divided into two taxonomic groups-**Secernentea** (having canalicular excretory system) and **Adenophorea** (having glandular excretory system).

Function:

- The exact function of the so called „excretory‟ system is a matter of conjecture. The main nitrogenous waste materials are excreted by body wall and digestive system. Moreover, the "excretory" system is known to "secrete" gelatinous materials in certain nematodes (e.g. citrus nematode) in which eggs are deposited.
- It is also speculated that the „excretory‟ system plays important role in osmo-regulation.
- Considering the diversity of functions performed by "excretory" system, now-a-days, it is also referred excretory-secretory system.

RESPIRATORY AND CIRCULATORY SYSTEM

- The well-defined organs for respiration and circulation are lacking in nematodes. However, the systems do work. Oxygen required in the aerobic plant parasitic nematodes is believed to diffuse through the body cuticle.
- Pseudocoelomic fluid filled in the body cavity serves the function of circulatory system. The fluid is continuous throughout the body length and bathes the different organs.

Biology of a typical plant parasitic nematode

- The life cycle of a typical nematode is simple and direct.
- It starts with a one celled egg, passes through four juvenile stages to finally convert in to a matured female/ male adult making it to total of six stages.

  - **Nematode Egg**:
- The Nematode eggs are usually oval or elliptical in shape, enclosed in an egg shell and are deposited either singly or in an egg mass. Egg shell is secreted by the egg itself and comprise three layers. they are:

  - Outer most vitelline layer made up of lipoprotein
  - Middle chitin-protein membrane
  - Innermost lipoprotein/only lipid membrane

  - **Oogenesis:** Formation and maturation of egg is defined as oogenesis.

- After insemination, the sperms are stored in the spermatheca of the female.

- As the egg cell passes through spermatheca, it is fertilized.
- As soon as the sperm enters the egg cell, a fertilization membrane appears around the egg and the egg protoplasm contracts. The shell begins to form endogenously immediately after fertilization.
- Nematode embryo shows determinate cleavage.
- Perhaps nematodes are the only animals in which the first cleavage is equatorial, cutting the egg axis horizontally.

Embryogenesis starts with in a few hours after deposition.

- **Embryogenesis:**

Embryogenesis is the process through which a single celled egg transforms in to a multicellular embryo through a series of cell divisions.

- A series of transverse and longitudenal mitotic cleavages of the single celled egg leads to the formation of a bunch of cells, each with a predetermined function in body organization
- Once all the cell types have been differentiated,only one particular cell retains the full chromosome compliment that will form the gonads in future.
- The embryo at this stage is a hollow ball of cells, the Blastula.
- It is followed by gastrulation and reorganization which eventually produces a worm shaped embryo i.e. first stage juvenile with in the egg shell itself.
- Since destiny of each dividing cell is predetermined (i.e. which cell will form which organ), the cleavage is said to be „Determinate‟.

- **Eclosion/Hatching:** (Greek word; e=out; clauses=shut i.e. shut out meaning hatching)

- Once the embryogenesis is complete, first or second stage juvenile (J1 or J2), as the case may be, emerges out of the egg shell.
- While in most of the secernenteans, first stage juvenile (J1) undergoes first moult within the egg, in most of the adenophoreans, J1 comes out of the egg and undergoes first moult to develop in to second stage juvenile (J2).
- Hatching in certain genera of plant parasitic nematodes occurs under normal suitable conditions, but some like *Globodera rostochiensis* require stimulus in form of root exudates from the host plant to hatch out. In *Xiphinema,* certain secretions from the oral aperture of nematode itself bring some structural changes in the egg which leads to its rupture. Once the juvenile is ready to hatch, it starts moving slowly within the egg.
- The process of breaking down of egg shell may be mechanical or enzymatic or both.
- The secretions from the oesophageal glands dissolve the lipid layer of the multilayered egg shell to facilitate the hatching process.
- Juveniles of *Globodera rostochiensis* repeatedly hammer their stylet tip mechanically to make a row of close perforations which merge to form a slit in the egg shell. It is through this slit that the juvenile emerges out of egg shell. Similarly, juveniles of *Meloidogyne, Pratylenchus, Paratylenchus* etc. use mechanical force to

hatch out of the egg. Emergence is generally head first, though tail first is also not uncommon.

Figure 7.1 Hatching

Moulting/ Ecdysis:

- Moulting is the most remarkable feature of post embryonic development. Periods of growth are separated by moults in which the cuticle is shed.
- Nematodes undergo **four moults** to attain adulthood. At each moult the old cuticle is shed off and is replaced by the new one.
- Moulting in nematodes is controlled by certain enzymes and hormones.
- Once the moulting is to be initiated, the nematode becomes sluggish but its hypodermis becomes thickened and metabolically active with enlargement of its nucleus and nucleoli as it is ready to secrete a new cuticle beneath the old one.
- Once the new cuticle is formed, the old cuticle is shed off.
- While the internal cuticle (cuticular lining of stoma, oesophageal lumen, vagina, rectum and cloaca) is reabsorbed enzymatically, it is epicuticle that is shed off in most of the tylenchids and aphelenchids.
- The cuticle may be shed off either in one piece or its anterior portion is shed off like a cap through which nematode wriggles out.
- Generally the old cuticle starts loosening first in the region of excretory pore followed by dissolution of exocuticle. The cuticular lining of excretory duct, oesophageal lumen and stylet are also renewed at each moult.

- During moulting, the embryo grows in terms of increase in size of the cells and not in number of cells. Plant parasitic nematodes increase 3-10 times in length.

Feeding:

- Being obligate parasites the juvenile on hatching must find a suitable host for feeding.
- Initially the juvenile moves randomly in the soil in search of a suitable host but

once it reaches near the vicinity of host plant roots, amphids located in its cephalic region become active.

- The amphidial glands secrete some cuticular receptors which bind with the specific biomolecules (chemo- tactic factors) exuded by the plant roots in the rhizosphere. These coupled biomolecules then diffuse in to the amphidial sensillum which passes the signal to the nervous system.
- Nervous system directs the nematode movement towards the roots of host plant.
- Once in the vicinity of roots, the cephalic papillae which are tacto-receptors help in selection of proper feeding site.
- The gentle probing of the stylet plays a supportive role in selection of feeding site which is preferably the growing tips of the feeder roots.
- Once the feeding site is selected, the juvenile inserts its needle like stylet into the host cell. The enzymatic secretions from dorsal oesophageal glands start flowing through the lumen of the stylet into the cytoplasm of the host cell where extra corporeal digestion takes place.
- At this stage the highly muscular median bulb starts pulsating at a very fast rate. As the muscles contract, the lumen of the median bulb is dilated, thus creating a negative pressure that sucks the semi-digested cell cytoplasm into the nematode stoma.
- As the food passes through the median bulb, the secretions from sub-ventral oesophageal glands mix with the food, which is pushed into the intestine for further digestion, assimilation and absorption.
- Oesophago-intestinal valve (cardia) located at the junction of oesophagus and intestine ensures the unidirectional flow of food.
- As the cell sap of the host cell is exhausted, nematode withdraws its stylet and moves to a new site for further feeding.
- The sedentary endoparasites and semi-endoparasites which do not move after settling at one feeding site ensure uninterrupted flow of nutrients for themselves by inducing certain adaptive cellular changes in the host tissue.

Life Cycle:

- After feeding is over, second and third moults generally occur in quick succession giving rise to third and fourth stage juveniles (J3 andJ4 respectively).
- Generally the juvenile forms resemble their adults except in size and development of reproductive system.
- The size of the nematode increases at every successive moult.
- After fourth and final moult, the adult male or female are formed. Though the precursors of reproductive system start showing in J2, completely developed reproductive system with vulval opening (in female) and spicules, gubernaculum and bursa (in male) appears only in adults.
- The duration of life cycle differs from species to species and is largely influenced by environmental factors like temperature, moisture, soil type, aeration and availability of host plant.
- The normal duration of egg to egg life cycle of most of the plant parasitic tylenchids under sub tropical and tropical conditions is 25-30 days.
- Aphelenchids have a short life cycle of 7-10 days.

- Some dorylaimids complete one life cycle in 1-2 years.

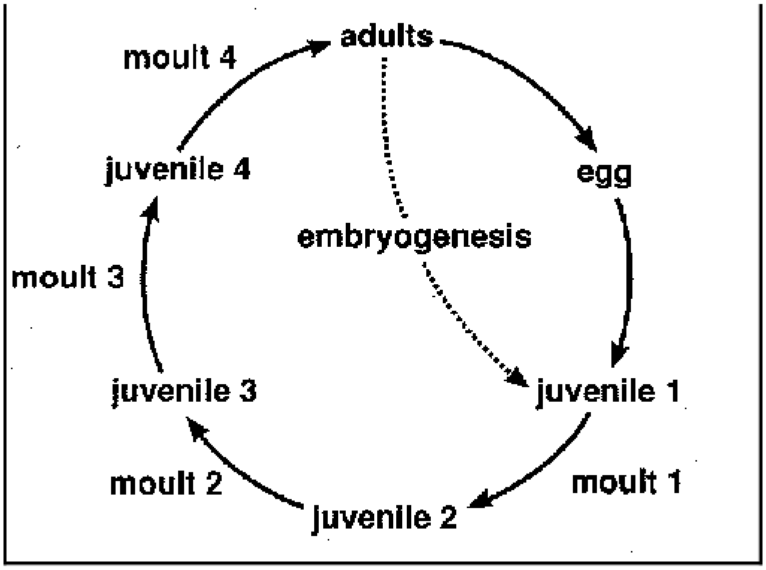


Figure 7.2 Life cycle of a typical plant parasitic nematode

Reproduction:

- Nematodes are basically dioecious, (separate males and females) and amphimictic (sexually reproducing) which need to find their mates for survival.
- The sex attractants (pheromones) released by the females are perceived by the phasmids of the males for mating. During mating, the protrusible spicules are inserted into the vagina of females.
- Bursa, the wing like cuticular extension in the tail region of male nematodes supports it to clasp the female during mating.
- Sperms pass through the cloaca into the female genital tract and are stored there in the spermatheca.
- As the oocytes pass through the spermatheca, the sperms fertilize them.
- Additional layers of the eggshell are formed in the uterus before the eggs are laid by females.
- Reproduction by Parthenogenesis (Gk. Parthenos=virgin+ genesis=come in to being) is often observed in nematodes species in which males are either rare or absent. In such cases young ones develop from unfertilized eggs. Parthenogenesis is commonly observed in Meloidogyne, Heterodera etc.
- Hermaphrodites (Herma= male Aphrodite= female) in which gonads are capable of producing both male and female gametes for self fertilization are extremely rare in nematodes.

Oviposition

The oviposition behavior in nematodes varies depending upon their mode of parasitism.

- Most of the soil dwelling ecto-parasites lay eggs singly in soil itself.
- Migratory endo-parasites generally lay the eggs singly inside the plant tissue.

- Sedentary endo-parasites lay their eggs clumped together in a gelatinous substance (egg mass). While rectal glands secrete gelatinous matrix in root knot nematode, in citrus nematode it is the secretion of excretory system.
- In cyst nematodes the eggs are retained within the body of mature female.
- The fecundity (number of eggs laid by a female)also differs in different nematodes. Generally it ranges between 10-30 for ectoparasites and migratory endoparasites and 50-500 in sedentary semi- endoparasites/ endoparasites.

Introduction to Symptology Define

Symptom

"Visible expression or indication of any infection/disease is called symptom". Symptom may also be defined as "the external or internal reactions that occur as a result of infestation by pest/pathogen".

Significance: Symptoms are important means for diagnosis of a disease and management practices can be undertaken only when the correct information about the disease and its etiology is available.

Kinds of Symptoms:

Non Specific symptoms like poor growth, stunting and discolouration of foliage in patches and wilting are most often the result of nematode infestation but may also be caused by some organisms other than nematodes, nutritional deficiency or soil effects.

Specific Symptoms are better means of diagnosis and are produced by root-knot nematode and most of the above ground nematodes like *Anguina tritici, Ditylenchus dipsaci, Aphelenchoides* spp. etc.

(A) Above Ground Symptoms

Important above ground symptoms caused by nematodes are:

i. Retarded growth in patches

ii. Increased growth (in a few specific cases)

iii. Discoloration of foliage

iv. Distortion and abnormal growth

v. Temporary wilting

i. Retarded growth

- Slow growth and stunting of plants are common non- specific symptoms of nematode attack. However, stunting of plants when occurs in the patches in field, gives an indication of infestation by nematodes due to their uneven distribution in the field.

- If host crops are grown in continuation, such patches grow in periphery, season after season.
- Many nematodes like *Pratylenchus penetrans* and *P. pratensis* in crops like cherry, fruit trees and seedlings, *Heterodera avenae* (in wheat and barley), *Globodera rostochiensis* (in potatoes), *Meliodogyne incognita* (in many vegetable and ornamental hosts) cause retardation in plant growth.

Nematode infested patches in tomato field

Patches and stunting in carnation under protected cultivation due to root-knot nematode

- Stunting and dieback in walnut trees is caused by its primary pathogen *Pratytenchus vulnus.*
- Poor growth and stunting of vines as a general syndrome of decline can be attributed to nematode species like *Meloidogyne incognita, M. javanica, Pratylenchus vulnus* and *P. scribneri*

ii. Increased growth

- Nematode infestation though more than often causes growth retardation, in a few very specific cases an increase in growth is also recorded.
- *Ditylenchus dipsaci* produces multiple crowns in sugar beet and increased tillering in oats (nematode not recorded from India so far).

iii. Discoloration of foliage

Generally indicative of nutritional deficiency, foliage discoloration is also caused by nematodes, thus making it a non specific symptom. Discoloration due to nematode infestation may range from chlorosis, light yellow to deep red, purple or even black and at it best serves only as an indication of possible nematode attack.

A few examples of non specific symptoms of discoloration caused by nematodes are:

- *Meloidogyne exigua* and *Pratylenchus coffeae* cause leaf chlorosis in coffee and *Ditylenchus dipsaci* in Narcissus.

- Premature yellowing of Narcissus leaves can also be due to attack of *Pratylenchus* spp.
- Premature yellowing of peanut foliage can be due to attack of Mesocriconema spp. and Premature yellowing of cotton foliage can be due to attack of Hoplolaimus coronatus.
- Light green foliage of potato can be indication of the presence of *Globodera rostochiensis.*
- *Pratylenchus zeae* causes stunting and yellowing of ginger.

Stunting and Yellowing in ginger due to *Pratylenchus zeae*

- However, some nematodes cause very specific symptom of chlorosis on their host plants which confirm their infestation. e.g.
  - White (or pale yellow) tips of rice leaves (about 1 inch of the leaf tip) is due to *Aphelenchoides besseyi.*
  - Clear interveinal discoloration in leaves of strawberry and chrysanthemum producing angulr spots is caused by chrysanthemum foliar nematode., *A. ritzemabosi* .
  - A fine mottle on the leaves of lemon and orange trees is caused by citrus nematode, *Tylenchulus semipenetrans.*

Symptom of white tip of rice leaves infested with

Aphelenchoides besseyi

Source:

Angular spots on chrysanthemum and Bronzing of strawberry leaves (after Sasser,1971)

iv. Distortion and abnormal growth

Nematodes like *Ditylenchus* spp., *Anguina* spp. and *Aphelenchoides* spp. which feed on the aerial parts (mainly leaves, stem and buds) of the plants cause symptoms of distortion which are generally specific in nature.

Distorted rice ears due to *Ditylenchus angustus* and *Aphelenchoide besseyi* respectively

Foliage distortion in chrysanthemum is caused by *Aphelenchoides ritzemabosi.*

Introduction to Symptology (Contd.)

A. Crinkled or distorted foliage: Foliage distortion in onions, strawberry, lucerne and red clover is due to infestation of D. dipsaci. This nematode has so far not been reported authentically from India.

Garlic distorted by Ditylenchus dipsaci

Crinkling of wheat ear is due to attack of Angunia tritici and of Paddy ear is due to Aphelenchoides besseyi and Ditylenchusangustus

Crinkling of wheat ear *by A. tritici*

B. Seed Galls: Black shrunken galls at the place of normal wheat grains are produced in presence of Anguinatritici. Healthy wheat grains and Black shrunken galls(due to Anguina tritici) Photo by: Ulriche Zunke Nemapix

C. Leaf galls: Anguina graminis and Ditylenchus graminophilus produce leaf galls in many grasses. Anguina balsamophilla produces similar galls on balsam leaves Leaf galls produced by Anguina balsamophilla

D. Spikkles: Ditylenchus dipsaci causes light yellow, raised pimple- like structures called spikkles on narcissus and daffodil leaves. Spikkles on daffodil leaves caused by Ditylenchus dipsaci

Daffodils infected by stem and bulb nematode Photoby :G Caubel,Nemapix Vol.2

E. **Leaf spots and lesions:** Nematodes sometimes enter through stomatal opening and produce water soaked areas which later turn brown. Such leaf lesions are produced by *A. ritzemabosi* on its host plants.

F. **Dead or devitalized buds:** Many *Aphelenchoides* spp. which attack the growing points of the host plant cause "blind" i.e., no production of flower primordia as it attacks buds.

Dead and devitalized buds due to *Aphelenchoides* spp.

G. **Aerial necrosis:** Red ring nematode of Coconut, *Bursaphelenchus (=Rhadinaphelenchus) cocophilus* causes necrotic banding on the trunk of coconut plants.

T.S. of coconut trunk showing band of necrotic red ring, Photo by: W F Mai

H. **Toppling Disease –** Burrowing nematodes causes „toppling‟ of banana plant. Banana roots are so severely affected that they cannot hold the tree upright once the extra weight of the developing fruit is added and the whole plant topples down

Toppling of banana plantation due to *Radopholus* root rot, Photo: D J Hooper

V. Temporary wilting: Wilting though an above ground symptom is a result of root damage caused by the nematodes. The plants attacked by nematodes show a tendency of temporary wilting in hot weather (although enough moisture may be present in soil) and may recover during cooler hours. Wilting is more pronounced on broad leaved plants.

- *Heterodera schachtii* causes wilting on sugar beet.
- *Globodera rostochiensis* causes wilting on potato

- *Meloidogyne incognita* causes wilting on tobacco and many vegetable crops like tomato, capsicum, cucurbits etc

Wilting in tomato and capsicum (under protected cultivation) due to root-knot nematode

Under Ground Symptoms

The common symptoms shown on below ground parts of the plants suffering from nematode infestation are:

1. Reduced root system and injured root tips
2. Root lesions
3. Root rots
4. Root Proliferation (Root Sprangling)
5. Root knots or Root galls
6. Cysts on roots

1. Reduced root system and injured root tips

Depletion of root system is the common symptom of nematode attack but the way in which a reduced system occurs, varies from species to species.

Reduced root system in Carnation roots pruned due to root-knot nematode

- *Tylenchorhynchus claytoni* and *Trichodorus spp.* apparently inhibit root growth without any other recognizible symptom.
- **Coarse roots** are produced by *Belonolaimus longicaudatus* on corn. The growth of lateral roots is stopped just as most of them are breaking through the cortex or while they are very short, an open root system consisting of main roots largely but devoid of small branch rootlets. Sugarcane infested with *Tylenchorhynchus* and *Pratylenchus spp.* and citrus infested with *Radopholus similis* shows such symptoms.
- **Curly tip of roots** of seedless grapes is specifically produced due to infestation of *Xiphinema index*.
- Injured root tips may be caused by the nematodes feeding on or near the root tips and may cause them to stop growing and die. **Short stubby** and malformed roots are caused in this case. e.g. corn affected by *Trichodorus christiei* and sugarcane infested with *Tylenchorhynchus* etc. The branch rootlets manage to attain a moderate length before their growth is stopped. The resulting root system has numerous, short stubby branches, often arranged in clusters.

Short stubby corn roots due to *Trichodorus sp*.

2. Root lesions

- Root lesions are the discoloured and often collapsed portion of the root consisting of cells on which nematodes have already fed.
- Primarily burrowing and lesion nematodes producedead areas on roots.
- They vary in size from a few cells to the lesions girding the whole root. Primarily ring nematodes (*Criconemoides* spp.) generally produce only small lesions. *Radopholus similis* causes big lesions on banana roots.

Root lesions on banana root caused by *Radopholus similis*

3. Root rots

- When nematodes enter the fleshy structure, they initiate the injury leading to the extensive tissue destruction. Through the decayed tissue, the other plant pathogens like bacteria or fungi may attack and as a result rot is produced.
- The potato rot nematode *Ditylenchus destructor* is involved in this type of injury (so far not reported from India).

Tuber rot caused by *D. destructor*

4. Root Proliferation (Root Sprangling)

Some species of nematodes do not produce root decay or lesions but numerous short lateral roots may form in the vicinity of nematode injury causing excessive root branching or a hairy root condition. The formation of such numerous small roots at the expense of more deeply penetrating larger roots often renders the plants more susceptible to wilting and these plants are easily uprooted and their ability to absorb nutrients is also impaired.

- This effect is often caused by cyst nematodes (*Heterodera avenae* on oats, *H. glycines* on soybean, *H. schachtii* on sugarbeet and *Globodera rostochiensis* on potato). *Meloidogyne hapla* causes excessive branching in tomato. Sprangling on crops such as carrots and turnips, render them unmarketable. .

Fig 9.5a: Root proliferation of beet root by *H. schachtii* ig.

9.5 Root proliferation in summer squash Photo by Stephen Lewis, Nemapix Vol. 3

Under Ground Symptoms (Contd..)

5. Root knots or Root galls

The abnormal galling or swelling of the roots is a specific diagnostic symptom of nematode infestation.

Meloidogyne spp. produce characteristic galls on the roots and host plants.

The size and number of galls vary from species to species and host to host.

- While woody plants like cotton and carnation show small galls, very large galls are produced on cucurbits which may coalesce with each other in a way that the entire root looks swollen and deformed.
- Extensive galling is often observed on crops like tomato, okra, brinjal etc.

Extensive galling of okra roots and Heavily galled cucurbit roots

Heavy galling in tomato seedlings under nursery conditions and Polyhouse grown cucumber roots infested by Root knot nematode

Small galls produced on carnation roots and Cabbage roots infested by root knot nematode

- *Ditylenchus radicicola* produces small galls on grass roots.
- *Globodera rostochiensis* produces swellings on tomatoes roots where they may reach a size resembling galls.
- *Nacobbus serendipiticus* produces large galls on tomato.
- *N. batatiformis* produces large galls on beet.
- Galls and distorted roots may also appear in strawberries and soybean attacked by *Xiphinema diversicaudatum*
- *Hemicycliophora similis* induce galling in cranberry and *Hemicycliophora sp.* produces similar galling on lemon roots.

6. Cysts on Roots

Cyst nematodes do not cause major malformations or lesions on roots. However, their "pearly" white swollen cysts (dead females) are often observed adhering to the root which can be seen easily by careful examination of roots with a magnifying glass.

Cysts of Heterodera avenae on wheat roots

Nematode Pests of Vegetable Crops

Plant parasitic nematodes comprise one of the major limiting factors in vegetable production. The extent of damage, however, depends mainly on the farming system employed. In general, nematodes play a less significant role under multiple intercrop farming systems in subsistence agriculture as well as in widely spaced rotations of commercial farming systems. They are highly damaging in intensive production systems like protected cultivation where mono-cropping is practiced. Extensive damage by nematodes occurs where nematode-infested planting material in the form of seedlings is used for planting. Though, more than 70 genera have been reported to be associated with vegetables in India, only three viz., *Meloidogyne* spp., *Rotylenchulus reniformis* and *Pratylenchus* spp. are of utmost significance. Besides, *Tylenchorhynchus brassicae* causes economic damage to crops like cauliflower, cabbage, knol-khol, radish etc.

(I) Root- knot nematode (*Meloidogyne* spp.) Etymology: *Meloidogyne*: a greek word; melo= apple, oid = resembling; gyne= female meaning apple-like female; the shape the female of this genus acquires on maturity. Its common name root-knot nematode is given for the characteristic symptom of knots or galls produced by this nematode on the roots of host plants.

Distribution and host range

- Root knot nematodes are cosmopolitan in distribution, attacking almost all the major crops including vegetables, fruits, ornamental plants, pulses, cereals, plantation crops, cash crops and even weeds.
- Although over 90 species of *Meloidogyne* have been described to date, four species viz., *M. incognita, M. javanica, M. arenaria* and *M. hapla* with their cosmopolitan distribution and widest host range are of particular economic importance to vegetable production.
- Of these, whereas, *M. incognita, M. javanica* and *M. arenaria* commonly inhabit the tropics with an average temperature of 36°C or lower in the warmest months,
  M. hapla is common in the temperate regions with occasional occurrence in the cooler upland tropics.
- *M. incognita* and *M. javanica* are highly pathogenic to vegetables like tomato, egg plant, okra, chillies, cucurbits, carrot, potato and beans.
- *M. hapla* is encountered in Jammu and Kashmir, Himachal Pradesh and hilly areas of Assam where it is a problem on potato and mentha.
- Severity of nematode damage increases manifold under protected cultivation.

Biology and life cycle

- Root-knot nematode females are **sedentary endoparasites.**
- Pyriform females remain embedded inside the root galls, with heads located near the vascular tissue and terminal portions near the root epidermis.
- Reproduction is through parthenogenesis as vermiform males remain in soil and are free living.
- Female lays 200-400 eggs in the gelatinous matrix secreted by their rectal glands. Embryogenesis takes about 10-15 days as a result of which first stage juvenile (J1) is produced within the egg..
- First stage juveniles (J1) moult within the egg shell to become J2s.
- J2s hatch out and move about in the soil in search of a suitable host and on getting the one, penetrate the roots just behind the root tip with the help of repeated thrusts of their protrusible stylet.
- J2s fix their head near the vascular tissue with rest of the body in cortical region and initiate the development of feeding site known as „giant cells‟. Giant cells (6-8 in number) are multinucleate cells produced due to karyokinesis without cytokinesis(nuclear division without the division of cytoplasm).
- As feeding commences, J2s destined to be females assume swollen shape with V-shaped genital primordium.
- Second moult occurs in about seven days.
- J3 and J4 retain their old cuticle; the pointed tail of J2 still visible as a spike and hence these stages are also referred as „spike tailed stages‟. These stages lack stylet and thus are non-feeding. The third moult occurs quickly and the juvenile changes to J4.
- At the last moult, adult female becomes sac-like with fully developed reproductive system.
- Adult males remain vermiform, come out of the soil and are short-lived.
- The whole life cycle takes about 25 days at 25-30^{o}C.
- *M. incognita* may have eight or more generations per year on tomato.

Figure 10.1 Longitudenal section of giant cells caused by root-knot nematode Courtesy: Photo by Victor Dropkin , Nemapix Vol.1
Figure 10.2 Root-knot nematode juvenile inside a galled root, Courtsey: Photo by Jonathan Eisenback Nemapix Vol.1

Symptoms

- The presence of **galls** on the root system is the primary and **specific symptom** associated with *Meloidogyne* infection. The size and form of the galls depend on the species involved, the number of nematodes in the tissue, host and plant age. In cucurbits, extremely massive, fleshy galls are formed whereas in crops like capsicum, galls are small. Other vegetables like tomato, eggplant, radish, carrots etc. may have small to large, firm galls.
- Symptoms of root knot on monocotyledonous crops such as onion and leek are very discrete, the main symptom being the presence of the protruding egg masses on the root surface.
- In case of severe infestation, the normal root system is reduced to a limited

number of severely galled roots with a completely disorganized vascular system. Rootlets are almost completely absent. The roots are seriously hampered in their main functions of uptake and transport of water and nutrients.

- Plants wilt rapidly, especially under dry growing conditions from which they recover during cooler part of the day. Broad leaved plants show severe wilting.
- Plant growth is retarded and leaves may be chlorotic.
- In case of seedling infection, numerous plants die in the seedbed and seedlings do not survive transplanting. Even the plants that do survive transplanting show reduced ?lowering and fruit production in the field.
- The symptoms caused by *M. hapla* on vegetables differ from those produced by most other species in that only small, more or less spherical galls are produced with profuse root branching originating from the galled tissue causing a **'bearded root'** system.
- Infection of the taproots (carrot and radish etc.) results in **hooking and forking** and tuber deformation. Tuber infection also makes long-term storage impossible as these tap roots begin to rot due to fungal infection associated with nematode gall degradation.
    - In leguminous vegetables, nematode induced galls differ from rhizobium nodules in the following respects: Bacterial nodules are the side appendages whereas nematode induced galls are swellings of the roots itself.
    - The rhizobium nodules can be easily separated from the root but not the root gall.
    - Nodules are spongy in nature but galls are hard in texture.

Patchy growth in okra field due to nematode infestation and Root galls formed on okra roots by *Meloidogyne* sp.

Survival and dissemination

- Being obligate parasites, the absence of suitable host plants for prolonged periods leads to the disappearance of Root-knot nematodes.
- In the absence of susceptible crops, they often survive on weed hosts.
- During stress, when nematode populations rapidly decline, a proportion of the eggs in the egg mass goes in diapause and ensures perpetuation of the species.
- Under adverse environmental conditions, emergence and juvenile activity are reduced, thus increasing the chances of survival. Survival is influenced mainly by moisture content of the soil and to a lesser extent by temperature.

Economic importance

- Vegetable crop losses in the tropics ranged from 17 to 20% on egg plant and 24 to 38% on tomato.

- In intensive commercial production, where sequential cropping of one susceptible crop after another is practiced with up to four crops per year, the lack of effective root-knot control would lead to total crop failure.
- Crop loss due to *M. incognita* under intensive cultivation ranged from 30 to 60% on brinjal.
- Nematode damage in protected cultivation, where susceptible crops are repeatedly planted in the same soil is very severe.

Management of root-knot nematode Management of

root-knot nematode

- **Fallow:** In areas where climate is characterized by a prolonged and severe hot, dry season, fleaving the fields empty during the dry season followed by growing of non-hosts during the wet season result in significant reductions in *Meloidogyne* populations.
- **Root destruction:** Since root-knot can survive and reproduce on the roots left in the soil after harvest, galled roots should be uprooted and destroyed. IThis nematodecan even survive and reproduce in excavated roots and tubers over many weeks.
- **Soil Tillage:** Repeated tilling and turning of the soil at regular intervals for 30 days during hot and dry seasons between crops reduce root-knot nematode densities in the upper horizons due to desiccation of eggs and juveniles. Tillage also eliminates alternative weed host and volunteer plants from the previous crop.

- **Organic amendments:** Incorporation of large amounts of organic material (5quintals/hectare) into the soil reduces root knot densities. Oil cakes, coffee husks, neem, marigold leaves, crustacean skeletons, sawdust, urea, chicken manure and bagasse comprise a few examples of organic amendments. Control may be due to:
    - toxic compounds present in the organic material as in neem;
    - toxic metabolites produced during microbial degradation;
    - enhancement of nematode antagonists.
    - Organic amendments also improve soil structure and water-holding capacity, reduce diseases and limit weed growth which ultimately leads to a stronger plant and improved tolerance to nematode attack. Neem-based oil cakes and related products have been studied intensely in India for control of root knot nematodes.
- **Soil Solarization:** The lethal temperature for control of plant parasitic nematodes is considered to be around 45°C. Soil solarization with plastic mulches, which leads to the development of lethal temperatures in the soil, is being used in some countries for control of root knot nematode and soil-borne diseases. The technique is most effective in regions where high levels of solar energy are available for long periods of time.
- **Use of healthy planting material:** Since early root infection by this nematode leads to severe crop loss, all crop nematode management strategies are useless if transplants are infested with root-knot nematode.

Nematode-free seedlings should be selected for transplanting. Nurseries must be free of root-knot nematodes in order to reduce dissemination into root knot-free production areas. Seedbeds should be selected on sites which previously were not planted to host plants.

- **Non host crops:** Cruciferous crops which are either moderately resistant or tolerant to root knot nematodes are successfully rotated with a smaller number of highly susceptible vegetable crops. Vegetables considered moderately susceptible or tolerant to root knot are cabbage, cauliflower, all cruciferous crops, onion, leek and broccoli. A rotation of cauliflower, garlic and brown sarson (*Brassica campestris* sub. sp. oleifera) is effective in reducing root-knot densities. A rotation of sesame, maize, groundnut, sorghum, cabbage, velvet bean and then resistant sweet potato is effective in controlling *M. incognita.*
- **Trap crops:** In trap cropping, a good host crop is planted for a short duration of time to ensure good nematode penetration and then the developing sedentary juveniles in the root tissue are killed by removal of root from the soil. **Lettuce** and **radish** are used as trap crops for root knot management programs at some places. Lettuce is harvested with the shoot and root system intact before the completion of nematode life cycle which usually completes within a month. The roots are discarded before marketing, resulting in trapping and death of large numbers of root-knot juveniles.

- **Antagonistic crops:** Antagonistic plants are those which produce nematicidal compounds. Marigold, sunhemp, castor-bean, asparagus and sesame are some of important antagonistic crops used for nematode control activity. The best studied antagonistic plant is marigold (*Tagetes*) known to produce terthienyl and derivatives of bithienyl that are toxic to root knot nematode. *Tagetes erecta,* grown 2.5 months prior to tomato reduced root knot densities in greenhouses.
- **Resistance:** Nematode resistant tomato cultivars like **PNR 7, Hisar Lalit, Karnataka hybrid, Mangla hybrid** etc. have been developed for cultivation in recommended areas. Resistant cultivars should not be grown continuously for years to avoid the emergence of resistance breaking biotypes of the nematode.
- **Chemicals:** It is important that users realize the stigma of human and environmental toxicity before applying any of the nematicides. Use of nematicides should be preferably confined to nurseries only at recommended doses. Under unavoidable circumstances they may be used under field conditions.
    - A number of granular nematicides (phorate @ 1 Kg a.i./ha, carbofuran @ 3 Kg a.i./ha, oxamyl, thionazin, terbufos, isazophos, aldoxycarb, ethoprophos, fenamiphos, cadusafos and avermectins) are effective against root-knot nematodes on vegetable crops under field and green house conditions. Granular nematicides are either broadcast over the soil surface and incorporated into the soil before planting or banded into or over the plant furrow. Liquid

formulations allow application by surface and drip irrigation. Application through drip irrigation places the material directly in the rhizosphere and allows treatment at will or treatment when necessary during the growing season. It also allows splitting or extending application over specific time intervals to coincide with optimum control. For example, oxamyl applied to tomato by drip irrigation is more effective than granular nematicides applied at transplanting in controlling root-knot nematodes.

  - Dip treatment or treatment of transplants in nurseries is more practical. For example, dip treatment of seedlings of egg plant and tomato with fenamiphos, fensulfothion or carbosulfan @500ppm for 30 minutes or 1000ppm for one hour significantly reduced *M. incognita* galling.
  - Seed dressing of bold seeded vegetable crops like okra, french bean and cucurbits with Carbosulfan 25DS @ 3% a.i. on w/w basis (120g per kg seeds) is effective.

- **Biological control:** Four approaches are now important for management of root knot nematodes with antagonists in vegetable production:
  - Application of fungal pathogens, parasites or predatory fungi that infect eggs, juveniles or adults in the soil or on the root surface. *Paecilomyces lilacinus* and *Pochonia chlamydosporia* which are oviparasitic fungi are effective when their commercial formulations are applied @ 50g/m2 along with sufficient quantity of

    FYM/vermicompost at the time of nursery preparation. FYM/ vermicompost helps in colonization of these fungi.
  - Field inoculation and management by using the obligate bacterial parasite *Pasteuria penetrans*- an obligate parasite of *Meloidogyne* spp. @ 50g/m2 in nursery or 20kg/ ha in field conditions. The spores formed, can resist both drought and exposure to non-fumigant nematicides. The parasite seems to be more effective on warm soils and soils low in organic matter, which characterizes most tropical soils where root knot is a problem.
  - Promotion of the naturally occurring antagonistic potential in soils with amendments or crop rotation.
  - Biological enhancement of transplants or planting material with plant health-promoting rhizosphere- or endorhiza-associated bacteria or fungi.

- **Quarantine:** Quarantine, if practiced, can add greatly by preventing introduction of a pest into a country or local region. In order to protect local production, effective quarantine laws and of course border inspections are needed for nematodes. At the national level, monitoring systems can be used to prevent local spread of nematodes by close scrutiny of commercial vegetable nurseries.

- **Integrated Nematode Management:** Seedlings may be raised in solarized nursery beds treated with carbofuran @ 0.3 g a.i./h (10 g/m2) + neem cake @ 500 Kg/ha in nematode infested soil ten days before transplanting. Soil solarization combined with dazomet gives good control of root knot and increased tomato yield. Similarly, solarization together with carbofuran increased tomato yields by 96% and solarization with neem cake by 52%, coupled with a significant reduction in nematode population. Solarization for 2–4 weeks, combined with fenamiphos is considered a sustainable control measure in greenhouse tomato. Crop rotation and soil incorporation of *T. erecta* resulted in significant reductions in *M. incognita* root galling and increased yield.

Nematode Pests of Vegetable Crops

(II). Reniform nematode (*Rotylenchulus reniformis)*

- It is a **sedentary semi-endoparasite,** ranks next to *Meloidogyne* as far as damage to vegetables is concerned.
- This nematode is a limiting factor in vegetable production in tropical and subtropical areas.
- The nematode has a very wide host range and attacks over 100 plant species including many vegetable crops like tomato, brinjal, okra, cucumber, potato, cowpea, ginger, onion, sweet potato, beans etc.

Biology

- Immature females are infective, penetrate the root cortex, assume kidney shape and become sedentary.
- Males are not parasitic and remain vermiform.
- Egg to egg life cycle is completed on okra in 24–29 days.
- The first moult takes place in the egg itself. The nematode can develop up to immature stage in water through a series of three superimposed moults without feeding.
- The reniform nematode can survive in moist soil in the absence of hosts for 7 months and for 6 months in dry soil.

Symptoms

- Non specific above-ground symptoms include unthrifty plant growth, stunting, yellowing and leaf curling.
- Root necrosis in cortical region has been observed following infection.
- Females and their adhering egg masses can be easily observed under the dissecting microscope.
- Soil adhering to the gelatinous egg masses often gives them a dark appearance, aiding in detection.

Management

- **Cultural:** Nematode densities have been found to reduce in rotations with maize, sugarcane finger millet, groundnut, capsicum, chillies, sugarcane and other grasses. Soil amendments such as animal manure and cotton seed cakes play a supportive role in control of reniform nematode.

- **Physical:** Short periods of flooding also reduce nematode population in the field. The nematode can also be eradicated from infested soil following treatment with 50° C hot water for 5 min. Soil solarization may provide season-long control of *R. reniformis* on tomato even under conditions of abundant rainfall and extended cloud coverBiological: Very little has been done regarding biocontrol of this nematode, although it would be a good target for antagonists. Paecilomyces lilacinus are known to reduce nematode densities in field. Endomycorrhizal fungus Glomus fasciculatum reduces the penetration and reproduction of R. reniformis on tomato and cucumber. Crop rotation to increase mycorrhizae might be important in regulating population densities.
- **Chemicals:** A wide range of fumigant and non-fumigant nematicides is effective in controlling *R. reniformis.* The combination of nematicides and neem cake increased the yield of tomato and reduced nematode densities in field trials. Single foliar application of oxamyl reduced the nematode penetration. All granular nematicides reduce

  R. reniformis densities in tomato.
- **Integrated:** Soil solarization or soil mulching with clear plastic for 5 weeks combined with carbofuran @ 3kg a.i.
  /hectare or solarization with neem cake results in to a significant increase in tomato or cucumber yields and reduction in nematode densities.

(III) Root lesion nematode (*Pratylenchus* spp.)

It is a **migratory endoparasitic** nematode, ten species of which have been found in the rhizosphere or roots of vegetable crops. But only *P. indicus* has been found to be most prevalent under Indian conditions. It infests vegetables like tomato and brinjal.

Biology

- This nematode reproduces sexually and has a simple life cycle.
- Eggs are deposited preferably in root but may be deposited in soil also.
- The first moult occurs inside the egg and J2s emerge out and moult thrice before becoming adults.
- All the juvenile stages and adults are infective and capable of penetrating the root tissue.
- Egg to egg life cycle is completed in 30 to 90 days depending upon the species, host plant and environmental conditions.

Symptoms

- Stunted, chlorotic plants lacking vigour, poor fruiting and die back are the main aerial symptoms.
- Root symptoms are in the form of necrotic lesions which may coalesce with one another as the infection spreads and may girdle the root. These lesions are the ideal sites for infection by other microorganisms leading to disease complexes.

Control
Lesion nematodes can be controlled with fumigant and non- fumigant nematicides. Integrated management practices as in root-knot and reniform nematodes would control this nematode.

(IV) *Tylenchorhynchus brassicae* (Stunt/stylet nematode)

- Out of twenty-two species of *Tylenchorhynchus* found in the rhizosphere of vegetable crops, only *Tylenchorhynchus brassicae* which infects cabbage, cauliflower, knol-khol, lettuce, radish and tomato, holds economic significance in India.
- Though most of the *tylenchorynchus* species are **migratory ecto-parasitic** nematodes feeding on epidermal cells of the roots, *T. brassicae* has been observed to penetrate through out the cortex.
- The nematode causes poor germination and stubby root condition leading to stunting of cabbage and cauliflower.

Crop rotation with non host crops and inter-culturing with margosa has been reported to improve the growth of susceptible vegetable crops.

Nematode Pests of Tuber Crops and Management

Potato, sweet potato and yams are the important tuber crops that suffer economic damage due to nematode infestation.

1. Potato

Potato is the fourth most important life sustaining food crop globally, after cereals like rice, wheat and maize. Nematodes are among the most important pest constraint factors which adversely affect the production of potatoes from seed tubers or true potato seed. Though more than 140 species of nematodes have been reported to be associated with this crop, the major pests of significance at global level are *Globodera* spp. and *Meloidogyne* spp. *Ditylenchus destructor* (Potato rot nematode) though highly damaging, is not present in India.

a. Potato cyst nematode or Golden nematode of potato (*Globodera spp*.)

- Potato cyst nematodes, *Globodera pallida* (27 countries) and *G. rostochiensis* (Golden nematode of potato, 58 countries) comprise one of the most important plant protection problems on global basis.
- The original home for cyst nematodes is considered to be Andes mountains region of Peru in South America from where they spread to Europe.
- Today this nematode has become major potato pest in most of the potato growing areas in the cooler areas of tropical and subtropical zones and temperate regions of the world. The most recent record comes from Indonesia, where potato cyst nematode was reported in 2003.
- In India, the nematode was first reported by F G W Jones in 1961 from a potato field of Ootacamund in Nilgiri hills in Tamil Nadu.It is confined to about 4000 hectares of Nilgiri, Palani and Kodai kanal hills of the southern states due to effective implementation of domestic quarantine as per which the movement of

seed potato from infested areas is banned.

- It has recently been reported from Himachal Pradesh also. *Globodera pallida* is more prevalent than *G. rostochiensis* in India.

Host range

- Potato cyst nematodes are host specific and have a limited host range. In addition to potato, egg plant, tomatoes and a few solanaceous weeds are known to harbour the nematodes, but are not considered as efficient hosts.

Biology :

- Eggs inside the cyst remain viable in soil for a long period of time (up to 8 years).
- They contain the infective second stage juveniles (J2s), which hatch only on getting stimulation by potato root exudates.
- Juveniles become active at 10° C and maximum root invasion takes place at 16° C.
- Juveniles penetrate cells near their head to grow and accumulate nutrients; this is called a feeding site or syncytium. Syncytium is formed by the dissolution of cell walls of the cells surrounding the nematode head.
- Male nematodes leave the roots after the final moult, whereas female nematodes moult to become spherical and sedentary adults.
- The mature, enlarged females rupture the root tissue, but remain attached to the root by their heads and protruding necks, which stay inserted in the root tissue.
- The fertilized females become large and sub-spherical and go through a sequence of colour change prior to dying on roots of potato and becoming **cysts.**
- The life cycle is completed in about 5-7 weeks under Nilgiri conditions where a second generation may also occur.
- When females die, they become cysts, and their cuticles become brown or leathery, and contain as many as 500 eggs.
- Females of *G. rostochiensis* go through a yellow golden stage, while *G. pallida* females turn brown directly to become cysts.

Golden cyst nematode on potato Photo by: A D Cushmon, Nemapix

Pathotypes

- In India, out of five known pathotypes of *G. rostochienesis* only two i.e., Ro 1 and Ro 2 and all the three pathotypes of *G. pallida* i.e., Pa 1, Pa 2 and Pa 3 are found as mixed populations.

Symptoms

- Symptoms are not evident until appreciable build-up of population in the field. Stunting of plants in nematode infested patches is seen.
- Plants lose their lower leaves soon after sprouting; later shed younger leaves as well. Only a tuft of green leaves remain at the top.
- Yellowing of older leaves is followed by new leaves.

- Wilting of the foliage during hot sunny hours from which plants recover during cooler part of the day.
- Flowering is sparse or absent. Early senescence and proliferation of lateral roots are often associated with nematode infection. Root system is poorly developed.
- Tuber formation is drastically reduced in count and size.
- Small immature females of white and yellow stages can be observed on the roots at flowering. Females can sometimes be observed on the tuber surface.

Healthy and *Globodera rostochiensis* infested potato plant, Photo by: Christopher Hogger, Nemapix

Management

- Since, the nematode is host specific, rotation with non- host crops like radish, carrot, turnip, cabbage, cauliflower, beet root, strawberry etc. is recommended. However, since potato is a cash crop, farmers normally are reluctant to accept these recommendations.
- Clean planting material is the best way to control potato cyst nematodes and to restrict infestations of new land.
- Use of resistant varieties is the best means of managing them as they can reduce potato cyst nematode populations in the field. In India , **Kufri Swarna** has been released as a resistant variety and this occupies more than 40% area in Nilgiris.
- Strict domestic quarantine barring transport of seed tubers from infested southern hills of the country has confined the nematode to those areas only. However, recently, the nematode has been reported from Shimla hills (H.P.)
- Consumer and environmental concerns are making farmers look at non-chemical alternatives; however, in many areas, chemical control is still a key control measure. A massive chemical control campaign was launched under the Indo-German Nilgiri Development project during 1971-1975. Nematicidal treatment was made mandatory under the Tamil Nadu Pest Act 1971 and all the infested fields were treated with fensulfothion @ 30 kg a.i./ha in the first year and 15 kg a. i. /ha in the next year. Later, cabofuran @ 2 kg a.i./ha was found effective for the economic management of potato cyst nematode under Nilgiri Hills.
- Utilization of these various measures in an integrated management programme can help in keeping the populations below the damage threshold and reduce dissemination, as well as the emergence of new pathotypes.

b. Root knot nematode (*Meloidogyne* spp.)

Of the 90 species described, only seven have been associated with potato. Of these, only five species are of global importance; most widely distributed being *M. incognita,* prevalent in the tropics followed by *M. javanica* and *M. arenaria. M. hapla, M. chitwoodi, M. fallax* and *M. thamesi* are found principally in the cooler temperate regions.

Biology:

- Both roots and tubers are infected; however, the first generation occurs mainly on the root system, while the succeeding generations attack tubers.
- The second stage juveniles hatch out from the egg masses and infect the young roots wherein they form giant cells through which nematodes extract nourishment from the plant cells. The female juveniles enlarge gradually and undergo four moults to become pear-shaped.
- The male nematodes retain their thread-like appearance and come out freely in the soil from the root system.
- The females are sedentary in nature and deposit about 300-400 eggs into a gelatinous matrix which is usually found adhering to the root galls.
- Depending upon the suitable temperature conditions, five to twelve generations may be completed on the susceptible host.

Symptoms

- Non-specific above-ground symptoms are evident in the form of stunting of infested plants, yellowing of leaves, and tendency to wilt under moisture stress.
- Infected roots have galls or knots of various sizes and shapes. Galling incidence and size are dependent upon nematode density, and the nematode species. *M. incognita* produces large and distinctive root galls which give a warty appearance or can become deformed on the surface.
- Under favourable environmental conditions, tubers of all sizes can be infected. Pimple-like outgrowths are observed on tuber surface.
- The nematode females are usually found 1–2 mm below the skin. All species produce necrotic spots in the region between tuber surface and the vascular ring.

Fig. 12.1 Bump like pimples on potato tuber due to *Meloidogyne chitwoodi*

Management

- Deep ploughing and drying of soil in the summer months desiccates the infective juveniles, thereby reducing initial inoculum in the soil.
- Growing of trap crops like *Tagetes patula* and *T. erecta* in between 2 or 3 rows of potato improves the crop performance and also reduces the root-knot formation.
- Seed tubers from root knot nematode infested fields should not be used. The movement of the infested soil and water from the infested fields should be avoided.
- The use of resistant cultivars is probably the most economical means for controlling *Meloidogyne* species. Advanced clones arising from careful breeding of resistant *Solanum sparsipilum* show no galling.
- Good control of the nematode has been achieved by applying carbofuran @ 3 kg a.i./ha or ethoprop @10 kg a.i./ha . The efficacy of these pesticides was more when these were applied in two equal split doses i.e., once at planting and other at earthing time.

- Rotation with tomato and sweet potato varieties resistant to M. incognita.

c. Root lesion nematode (*Pratylenchus spp.*)

- A few important species are *P. crenatus, P. thornei, P. scribneri, P. andinus, P. penetrans, P. coffeae* and, *P. vulnus* that damge potatoes in the temperate, tropical and subtropical regions.

Nature of damage

- Damage is often caused by direct feeding usually confined to cortical tissue.
- Nematode survives in infected tubers which act as source of inoculum.

Symptoms

- Patches of poorly grown, less vigorous plants which turn yellow and cease to grow.
- extensive lesion formation on roots
- Infested tubers have small lesions on their surface.

Management

- Hot water treatment of infected tubers at 50°C for 45– 60 min reduces nematode spread.

2. Sweet potato

- Sweet potato a native of tropical America.Of all the world‟s root and tuber crops, sweet potato is second only to potato in importance. and *Meloidogyne incognita* and *Rotylenchulus reniformis* are the important nematodes of sweet potato.

a. Root knot nematode (*Meloidogyne spp.*) *Meloidogyne incognita* is the most important species of the genus attacking sweet potatoes and has a wide global distribuion.

Symptoms

- Infected plants exhibit general symptoms of damage associated with poor root growth, such as yellowing, stunting and the tendency to wilt during the warmer periods of the day.
- *Meloidogyne* spp. attack both roots and storage roots, causing swellings or galls of different shapes, but galls are not as prominent as on many other crops.
- Pruning effect is observed when the initial nematode population is high.
- They also cause general root tip necrosis in susceptible cultivars.
- Longitudinal cracking during development and swelling of the storage roots occurs.
- Females can be observed on sliced storage roots and are usually associated with brown, necrotic cells around them.

Management

- Crop rotation and intercropping for reducing nematode populations are difficult with *Meloidogyne* species because of their extensive host range. A crop highly susceptible to root knot nematodes should be avoided in the cropping system.
- Interculturing of antagonistic plants like *Crotalaria juncea* and *C. spectabilis* have shown some success against *M. incognita* and *Pratylenchus coffeae)* in sweet potato.
- In India, three high yielding cultivars, **Sree Vardhini, Sree Nandini** and **H268,** and two short duration cultivars, **Sree Rethna** and **Sree Bhadra,** are highly resistant to the local populations of *M. incognita.*
- *Pasteuria penetrans,* an obligate bacterial parasite of nematodes, has been used to control *M. incognita* on sweet potato.
- Hot water treatment of 65 min at 47° C and hot air treatment of 4–8 h at 50° C is effective in eliminating *Meloidogyne* from root propagative material.
- Chemical dip treatment of the propagation material in a solution of oxamyl or side dressing with nematicides at the time of planting provides early protection against nematodes.
- Since sweet potato cultivation is generally done on a low cash input, the application of chemical control measures is usually cost prohibitive.

b. Reniform nematode (*Rotylenchulus reniformis*)

Rotylenchulus reniformis is the most predominant nematode on sweet potato in Kerala, India.

Symptoms

- Infestation by *R. reniformis* may cause cracking of storage roots. The induced cracks are deep and the exposed surfaces are healed over by formation of callus and periderm. The population level necessary for cracking may be very low and is probably less than that for yield reduction.
- Root necrosis occurs and becomes more pronounced as the numbers of the nematode increase.

Management

- Nematicides in the organophosphate and carbamate group also showed good control of nematodes, resulting in improved quality and yields of sweet potatoes.
- Selection P-104 is reported to be resistant to cracking.

3. Yams

- Yams are probably one of the oldest food crops known to man. Yams are normally vegetatively propagated from small whole tubers, portions of tubers (setts) or bulbils. The nematodes of particular importance in yam roots and tubers are endoparasitic forms like Scutellonema bradys, *Pratylenchus coffeae*, *P. sudanensis* and Meloidogyne spp. All these are known to cause serious damage by mainly reducing tuber yield and quality.

Scutellonema bradys (*The yam nematode*)

The yam nematode, *S. bradys,* is the cause of a decay of yam tubers known as „Dry rot disease of yam‟. It is found in many yam-growing areas of the world, which include West Africa, the Caribbean, Brazil, Venezuela, Korea and India.

Host Range

Cowpea, sesame, green gram, pigeon pea, okra, tomato and melon are susceptible to *S. bradys.*

Nature of damage

- *Scutellonema bradys* is a **migratory endoparasite** present in yam soils, roots and tubers.
- All active stages are infective.
- It invades the young, developing tubers through the tissues of the tuber growing point, alongside emerging roots and shoots, through roots and also through cracks or damaged areas in the tuber skin.
- Nematodes feed intra-cellularly in tuber tissues, resulting in rupture of cell walls, loss of cell contents and the formation of cavities.
- They are mainly confined to the subdermal, peridermal and underlying parenchymatous tissues in the outer 1–2 cm of tuber.
- *S. bradys* continues to feed and reproduce in yams stored after harvesting.

Symptoms

- Dry rot of yams occurs in the outer 1–2 cm of tubers. The initial stage of dry rot consists of cream and light yellow lesions below the outer skin of the tuber showing no external symptoms at this stage.
- As the disease progresses, it spreads into the tuber, normally to a maximum depth of 2 cm but sometimes deeper. In these later stages of dry rot, infected tissues first become light brown and then turn dark brown to black.
- External cracks appear in the skin of the tubers and parts can flake off exposing patches of dark brown, dry rot tissues.
- The most severe symptoms of dry rot are seen in mature tubers especially during storage, when it is often associated with general decay of tubers.

Fig. 12.2 Scutellonema bradys infected and healthy yam tubers.

Survival and dissemination

- Infested seed tubers are the main source of nematode inoculum in yam ?elds.

Management

- The use of nematode-free propagative material is by far the most appropriate means of preventing nematode damage. The presence of dry rot in tubers without external symptoms can be determined by scraping away sections of tuber skin, or by the use of tuber pieces rather than whole tubers, enabling the grower to examine for dry rot symptoms before planting.
- Crops susceptible to *S. bradys* should be avoided. Crops such as *Tagetes* spp. and groundnut (peanut) have been recommended for use to lower nematode populations and restore fertility for yam production.
- Mulching and exclusion of weed hosts has also been reported to reduce nematode populations.
- Hot water treatment of 50–55° C for up to 40 min can reduce or eliminate *S. bradys* from tubers.
- Complete resistance to S. bradys has not been found and all the main food yams (D. alata, D. bulbifera, D. cayenensis, D. esculenta and D. rotundata) are susceptible to damage by S. bradys.
- Chemical control of *S. bradys* on yams has some a success. Granular nematicides like oxamyl, carbofuran or isazophos applied as post-plant treatments in yam mounds two weeks after planting @ 2 kg a.i./ha reduce soil populations of *S. bradys* with remarkable yield increase.

Nematode Pests of Fruit Crops and their Management - Banana

Fruits are the major source of vitamins and minerals with high nutritional status and are grown in all parts of the world. Though, they suffer heavy damage due to nematode pests, yet the information available on their nematode status is scanty and localized barring a few fruits like banana, citrus and grapes.

I. BANANA

Banana is the most popular fruit of the tropics and subtropics. Production of the crop is affected by as many as 71 species belonging to 33 genera of plant parasitic nematodes in association with banana roots. The most important and widespread among them are *Radopholus similis,* followed by *Helicotylenchus multicinctus.* A few other nematodes of significance in banana are*Pratylenchus coffeae, Heterodera oryzae, Meloidogyne* spp. and *Rotylenchulus reniformis*

a. Burrowing nematode (*Radopholus similis*)

Causal organism: Black head toppling disease/Banana rot/Black head/Banana decline/*Radopholus* root rot

Distribution

The nematode occurs in all the tropical and sub-tropical areas of the globe. In India, it is distributed in all the banana growing states viz.,Tamilnadu, Kerala, Karnataka Goa, Maharashtra, Gujarat, Madhya Pradesh, Assam and Tripura.

Host range

Though, the nematode has a very wide host range, it causes serious problem in crops like banana, pepper, coconut, arecanut, coffee, tea, cocoa, sugarcane, turmeric and ginger.

Biology

- The life cycle of the burrowing nematodes consists of an egg stage, four juvenile stages and adult stage.
- Juveniles and females penetrate roots and parasitize host tissues. Males are free living.
- More than one generation can occur inside the root but after deterioration of roots, the nematodes migrate to the soil.
- Females lay 4-5 eggs per day.
- The egg to egg cycle is completed in 20-25 days at 24- 32^{o} C temperature in which eggs hatch at 10-12 days and juveniles mature within 10-13 days.
- Nematodes can survive in corms until they remain succulent.

Nature of Damage:

- These are **migratory endoparasitic** nematodes which live in inter cellular spaces in cortical parenchyma from where they penetrate the nearby cells, suck their cell sap and destroy them by forming cavities.
- After destroying one site, the nematode moves to another site for feeding.
- These cavities coalesce with one another and produce characteristic reddish brown lesions throughout the cortex.

Symptoms:

- The above ground symptoms are characterized by dwarfing, leaf chlorosis, thin pseudostem, small bunches and premature lodging of plants.
- Root symptoms appear in form of dark red lesions on cortical or outer part of the root.
- Heavily infected roots show numerous depressed and open lesions which cause root to break.
- Infested plants with short necrotic roots cannot support the weight of the bunch or the stress of heavy winds and are thus dislodged or uprooted giving the name to the disease as „black-head toppling disease‟ of banana.
- The nematode also helps in causing the „Panama wilt‟, caused by the fungus *Fusarium oxysporum* f. sp. *cubense.* The fungus cannot invade healthy tissue unless there are wounds caused by nematodes.

Toppling of banana plantations due to Radopholus root rot and Longitudinal section of cord roots of banana to show cortical lesions

b. Banana Spiral Nematodes (*Helicotylenchus multicinctus*)

Distribution

Helicotylenchus multicinctus, especially important as a pest of banana, is widely distributed in almost all tropical and warm temperate banana growing countries including India. In tropical soils, this nematode often occurs along with *R. similis* but in cooler dry soils *H. multicinctus* alone is prevalent.

Host Range

Crops susceptible to *H. multicinctus* include banana, cocoa, sweet potato, citrus, sugar cane, coffee, rubber, oil palm, tea, rice, grapevines etc.

Nature of Damage

- Though, most of the 200 described species of *Helicotylenchus* are ectoparasitic, *H. multicinctus* is an **endoparasite** of outer layers of cortical tissue.
- Movement inside the root tissue has not been observed.
- The nematode reproduces through amphimixis.

Symptoms:

- Infested plants remain stunted, take longer to mature, yield smaller bunches and degenerate faster than uninfested plants.
- Extensive, discrete, superficial necrotic brown lesions on root surface which may even coleasce.
- The thin secondary and tertiary roots are also attacked and necrosis is more pronounced which eventually leads to debility of entire plant.
- The nematode also penetrates the corms, causing red lesions.
- Infested plants remain stunted, take longer to mature, yield smaller bunches and degenerate faster than uninfested plants.

Damage caused by *H. multicinctus* on banana roots

c. Lesion nematode (*Pratylenchus coffeae*)

Out of several species of lesion nematodes found to be associated with banana, the most important is *Pratylenchus coffeae.*

Distribution

Widely distributed in most of the tropical regions of Asia (India, Japan, Thailand), Africa, Australia and America.

Life cycle

- The life cycle and feeding behaviour of the lesion nematodes is similar to that of the burrowing nematodes except that in *Pratylenchus,* males of are also infective.
- The egg-to-egg cycle is completed in about 27 days at 26-32^{0}C.

Symptoms

- The symptoms caused by *P. coffeae* are very similar to the burrowing nematodes.

- Unlike *R. similis,* this nematode causes root decay also.

d. Root-knot nematode (*Meloidogyne* spp.)

The most common species that attack banana are *M. arenaria, M. incognita* and *M. javanica.* These species have a global distribution; confined to the tropics and subtropics.

Symptoms:

- The infested plants are stunted and chlorotic.
- The roots are heavily galled. The galls vary in size and occur at the tips as well as in other areas along the root.
- Such roots cease to grow and sometimes develop secondary roots above the gall.
- Necrosis is never associated with root-knot infection unless secondary organisms like fungi enter the root.

e. Reniform nematodes (*Rotylenchulus reniformis*)

The reniform nematode probably occurs in all tropical and subtropical areas of the world feeding as **sedentary semi- endoparasite** on the secondary or tertiary roots of banana

Biology:

- Only the immature female of this nematode is parasitic.
- Eggs are laid in a mass covered by gelatinous substance. An egg masse may contain 45 to 66 eggs.
- After hatching, juveniles($J2_s$) migrate in the soil and undergo three molts in quick succession without feeding.
- After the last moult, the female infects roots by penetrating the tissue with its head and leaving rest of the body outside the host tissue. At the same time the body enlarges and takes a kidney shape.
- Nurse cells are formed as a prerequisite of feeding.
- The egg to egg cycle is about 24-29 days at 28-31^{o} C.

Symptoms:

- Necrotic lesions are produced in the areas where females are attached to the roots. The posterior part of the female body and egg mass are protruded outside the host.
- High population of the nematodes causes severe necrosis and destruction of feeder roots.

Management

Management tactics include cultural, physical, chemical, biology methods, host resistance and integrated management.

Cultural methods include summer ploughing, organic manuring, crop rotation and destruction of infected crop residues.

- Ideally, uninfested banana suckers should be planted to uninfested land.
- Heavy mulching of organic matter minimizes the population of H. multicinctus. Propping up of the fruiting stems helps to prevent premature toppling.
- Intercropping with Crotalaria is known to reduce the R. similis population in root and increase plant growth.
- Crop rotation with sugarcane, sorghum, tobacco, cassava and grape fruit increased the yield of banana significantly with control of R. similis. Rice or green gram grown after the crop reduces the population of P. coffeae, H. multicinctus and R. similis and increases plant growth.

Physical methods include removal of infested tissues by paring and disinfecting them in hot water at 55^0 C for 20 minutes before planting. In Kerala, the practice of „sun drying‟ the rhizome before planting has been found effective in control of nematodes.

Chemical control

- Carbofuran and phorate at 2 g a.i./plant at planting are the most effective and popular granular nematicides used against banana nematodes. Ethoprop at 2-3g a.i./plant or carbofuran at 1.2 g a.i./ plant reduce the nematodes population with high cost benefit ratio.
- Pre planting treatment of banana suckers decreases or eliminates infestation. Paring of the corms i.e. removal of the infected portion followed by dipping in carbofuran (3%), aldoxycarb (3%) or oxamyl (1%) eliminated both *R. similis* and *H. multicinctus.*
- Application of 4 g carbofuran, fensulfothion or oxamyl per plant, applied to the soil at planting followed by repeated treatment four months later decreased nematode population and increased the yield.
- The best way of management of nematode population is obtained by paring (removal of infected part of the suckers) and pralinaging (coating of suckers with some nematicide) with carbofuran or fensulphothion at 42 and 17 g per sucker, respectively before planting.

Biocontrol: The promising biological agents include the fungus, *Paecilomyces lilacinus,* VAM, and bacterium, *Pasteuria penetrans.*

Resistance: A few germplasms like **Kadali, Kunnan, Pisang seribu** and **Ayiranka Poovan** are known to support low nematode populations.

Integrated: Integrations of paring of suckers and hot water dipping at 55^o C for 20 min., neem cake 400 g per plant and carbofuran 20 g per plant before planting significantly reduce the nematode population and improve the plant growth.

Nematode Pests of Fruit Crops and their Management - Grapevine

II. GRAPEVINE

Grapes are one of the cosmopolitan crops of agriculture, providing fruit, resin and wine to most of the world. There are many nematode species that attack grapes. The major ones are root knot nematode (*Meloidogyne* spp.), root lesion nematode (*Pratylenchus* spp.) and *Xiphinema* spp. The nematodes of minor importance are the reniform nematode (*Rotylenchulus reniformis),* the citrus nematode (*Tylenchulus semipenetrans)* and *Paratrichodorus minor.* All these nematode species reduce the effective root system through killing of many feeder roots.

a. Root-knot nematode (*Meloidogyne spp.*)

Of the six species of root-knot nematode reported on grapes in various parts of the world, *M. incognita, M. javanica, M. arenaria* and *M. hapla,* are most widely distributed.

Distribution

In India *M. incognita* and *M. javanica* are prevalent in grape cultivating regions of Tamil Nadu, Karnataka, A.P., Haryana, Punjab and Maharashtra.

Nature of Damage:

- **Endoparasitic sedentary** mode of parasitism.
- The freshly hatched second stage juveniles penetrate through young feeder roots, form giant cells around nematode head and feed upon the cell sap thus devitalizing the cells.
- As a result of nematode feeding, numerous fine rootlets are formed at the infection site, thus leading to a „hairy root‟ condition.

Symptoms:

- Patches of stunted vines with poor branching and scanty foliage
- Lowered yields
- Increased sensitivity to other micro-organisms.
- Distinctive root symptoms with small swellings or galls on feeders and young secondary rootlets.
- These symptoms are worse in sandy soil.

b. Root Lesion Nematode (*Pratylenchus spp.*) Distribution

The nematode exists in almost every grape producing region. Different species of this nematode prevail in grapes in different parts of the globe. The most prevalent are *P. vulnus, P. scribneri, P. brachyurus* and *P. minyus. Pratylenchus coimbatorensis* has been reported from South India.

- All the stages of these **migratory endoparasitic** forms are infective. The nematodes remain confined to cortical tissue.

- Affected plants exhibit non specific symptoms like poor growth and low yields. Young vines if infected, are unable to develop a root system and ultimately die.
- The roots system of matured vines is badly affected giving rise to a matted, **witch's broom effect** in some parts of the root system.

c. Dagger nematode (*Xiphinema spp.*)

Distribution

This nematode is a pest of grape vine world wide. Though number of *Xiphinema* spp. have been found from grape vines, only two viz., *X. index* and *X. americanum* are found to be of pathogenic significance. While *X. index* has been reported from Europe, South Africa, Victoria, USA, North Africa, Iraq and South America, *X. americanum* has been recorded from Indian vineyards.

- The nematode is highly damaging to grapevine seedlings where it feeds as a **migratory ectoparasite.**
- *X. index* causes characteristic „**Curly tip'** symptom on grape seedlings.
- Infested roots are necrotic, lack laterals, have root tip swellings, show cellular hypertrophy and multinucleate cells near nematode feeding site. This results in reduced root system.

Management:

- Certified, nematode free rootings should be grown for new vineyards or replants.
- Intercropping of marigold (*Tagetes patula)* reduces nematode population and improves the yields significantly.
- Old root system should be removed.
- Use of resistant root stocks viz., **1613, Dogridge, Saltcreek, Harmony (1613 x Dogridge), Lake Emrald, Tompa** etc. is beneficial against nematode.
- Soil application of carbofuran or phorate at 6 kg a.i. /ha is effective against the nematodes and results in the increased fruit yield.

Nematode Pests of Fruit Crops and their Management -

(I) CITRUS

Citrus is very important commercial fruit crop grown throughout the tropical and subtropical areas of the world. In India. it ranks third after mango and banana among the fruit crops. Over 200 species of plant-parasitic nematodes belonging to more than 58 genera have been detected on citrus roots worldwide. Out of these, approximately 122 species belonging to 57 genera are reported from India. Most important is Citrus nematode, T*ylenchulus semipenetrans.* Another very important nematode is "*Radopholus citrophilus"* but fortunately this species is not present in India. The other economically important nematodes are *Pratylenchus coffeae, Hoplolaimus indicus* and *Meloidogyne* spp.

a. Citrus nematodes (*Tylenchulus semipenetrans*)

Causal organism: “Slow decline of citrus” / “Citrus Decline”/ “Citrus Dieback”

- The citrus nematode, *T. semipenetrans* was first observed on orange tree in Southern California in 1912 by Cobb.
- In India, it was first reported from citrus in Aligarh by Siddiqi (1961).

Distribution

It is a world wide pest of citrus. In India, it is widely distributed in citrus orchards grown in Andhra Pradesh, Assam, Himachal Pradesh, Haryana, Punjab, Rajasthan, U.P., M.P., Bihar, Gujarat and Maharashtra.

Host range

It has a narrow host range as 50 species or hybrids of citrus and plants belonging to Family Rutaceae only are its hosts. Hosts belonging to families other than Rutaceae include grapevine, olive, pear, persimon and loquat.

Biology:

- The first stage juvenile develops within the egg and moult once before hatching as second juvenile.
- Hatching in soil occurs when environmental conditions including temperature, moisture and aeration are satisfactory.
- Eggs hatch in 12 to 14 days at about 24^{o} C.
- The second stage male juveniles develop to maturity within 7 days **without feeding** and the second stage female juveniles require 14 days to locate the host root, feed and moult.
- The life cycle from egg to egg is completed in 6 to 8 weeks.

Nature of Damage:

- Citrus nematode is a **sedentary semi-endoparasite** that attacks roots by burrowing its anterior end deep inside the root cortex while the posterior end remains outside in the soil.
- Feeder roots particularly in the upper soil layer are destroyed as nematode prefers to habitat upper soil layers, resulting in reduced uptake of water and minerals from the soil.
- While juveniles remain in superficial layers of the young root tissue, young females penetrate deep in the cortical tissue where they form „feeding site‟ consisting of 6-10 cortical cells called **‘Nurse Cells’.**

Symptoms:

- Initially symptoms are often unnoticed in the seedlings.

- General reduction in tree growth and vigour
- Yellowing and shedding of leaves
- Dieback of twigs and under-sized fruits resembling more or less symptoms of drought and malnutrition.
- Young trees develop slowly and production is delayed.
- In heavily infested roots, soil particles usually adhere with root-lets and finally the cortex separates readily from the vascular stele.
- Heavily infested roots are darker in colour with reduced branch rootlets.

Extent of damage mainly depends upon factors like age and vigor of the tree, density of the nematode population, and susceptibility of the rootstock. Mature trees can tolerate a considerable number of these nematodes before showing lack of vigor and decline symptoms. If, a heavily infested orchard site is replanted with a susceptible rootstock without soil fumigation, the roots of the young trees are heavily parasitized, tree growth is stunted, and fruit production is reduced. This condition is also referred to as the **citrus replant problem.**

Citrus plants showing symptoms of Decline

b. The Lesion Nematode (*Pratylenchus coffeae*)

Pratylenchus coffeae is a highly pathogenic nematode reported from citrus in India, Japan and U.S.A. and is causal organism for
"**Root-rot of Citrus"** In Florida (USA), it is known to cause "Citrus slump disease'.

Nature of damage:

- It is a **migratory root endoparasite,** the adults and juveniles of which invade the root tip and destroy the growing meristem.
- As a result, a lateral root usually initiates near the destroyed root tip.
- The adults and juveniles occur in the cortical tissue of feeder roots where they form small black lesions at their feeding site which expand to girdle the rootlets.

Symptoms:

- Non specific above ground symptoms appear in form of stunted plants, general dieback and undersized fruits.
- Brown black lesions girdle the feeder roots.
- The infected seedlings show marked reduction in root and shoot weight as compared to healthy ones.

c. The Lance Nematode (*Hoplolaimus indicus*) This nematode is prevalent in citrus growing sites of Delhi, Punjab, Rajasthan and Uttar Pradesh in India. It has so far not been reported from any where outside India. **Biology:**

- The first moult occurs within the egg and the development outside the egg consists of 3 moults giving rise J3, J4 and the adult stages.

- Temperature of 30^o C, moisture content of 16% and soil pH of 7.0 are the optimum conditions for multiplication.

Symptoms:

- In orchards nematode infestation show patches of unevenly grown plants.
- Symptoms are visible in 3-4year old sick orchards in the form of plants with reduced height and vigour.

d. Root-knot nematode (*Meloidogyne* spp.)

Three species of *Meloidogyne* i.e., *M. africana, M. indica,* and *M. javanica* are recorded on citrus from India. Symptoms and life cycle of the nematode are same as produced on other host plants.

Management:

Following are some of the possible ways which can be adopted to check the nematode populations build up.

- **Preventive**: Nurseries should never be established on or near old citrus orchards.
- **Physical**: The bare root treatment at 45o C for 25 min. or 46.7o C for 10 minutes can disinfect seedlings from citrus nematode.
- **Cultural**: Population of citrus nematode in soil and roots can be reduced by removing the old feeder roots before the growth flush. This practice is followed by application of FYM.
- Application of castor, neem, mahua, mustard or groundnut oil cakes in the tree basin effectively reduces nematode population.
- Irrigation of citrus orchard with sewage water has been found to reduce the nematode population significantly.
- **Plant resistance:** Varietal screening against citrus nematodes revealed that trifoliate orange (*Poncirus trifoliata),* **Carrizo and Troyer** are highly resistant, **Smooth lemon Assam, Saoner** and **Cleopatra mandarin Morrocco** are moderately resistant. Hybrid citrus root stocks developed by crossing Rangpur lime (*C. limonia)* with *P. trifoliata* viz. **CRH-3, CRH-5** and **CRH-41** are highly resistant to citrus nematode.
- **Chemical control:** Application of carbofuran @ 4 and 6 kg a.i./ha, benfurocarb @ 4 and 6 kg a.i./ha or combination of neem cake @ 1 kg/plant with carbofuran reduces nematode population significantly.

(II) PEACH

The important nematodes of peach include *Meloidogyne* spp., *Paratylenchus* spp., *Pratylenchus* spp., *Criconemella* spp. and *Xiphinema* spp.

a. Root-knot nematode (*Meloidogyne spp.*):

- At least five species of root-knot nematode have been reported to damage peaches in one or the other peach growing areas of the globe.
- In India, while *M. hapla* is restricted to colder regions of Himachal Pradesh, *M. incognita* and *M. javanica* are prevalent in warmer peach growing areas of Delhi, Punjab and Haryana.
- Nematode is a **sedentary root endoparasite.** Juveniles ($J2_s$) prefer root tips for penetration which are devitalized and root elongation ceases.
- Secondary and tertiary branches are produced with variable size of galls, giving roots the brush-like appearance.
- Uneven size of trees in the orchard, smaller ones showing poorly developed foliage, poor vigour, dieback of twigs give an indication of root-knot infestation.

b. Pin nematode (*Paratylenchus spp.*):

- These are the smallest representatives among the plant parasitic forms which attack herbaceous as well as woody plants.
- At least seven out of total of more than 100 species are associated with peach. Of these, *P. prunii, P. nannianus and P. curvitatus* are more common.
- The nematode produces non-specific symptoms like stunting of the plant, yellowing of foliage and under- sized fruits.
- The extent of damage depends upon the age and vigour of the plant at the time of infestation.

c. Lesion nematode (*Pratylenchus* spp.):

- Most of the eight species of root lesion nematodes reported from peach are from different parts of USA. Of these *P. penetrans, P. pratensis and P. vulnus* are more prevalent and damaging.
- *Pratylenchus coffeae* has been reported from peach in India.
- Root lesion nematode is a **migratory endoparasite,** juveniles and adults of which move inter and intra- cellularly in the cortical tissue causing extensive, dark lesions on the roots.
- Feeder roots are deteriorated fast.
- Above-ground symptoms appear in form of general nutritional deficiency symptoms like weak plants with reduced vigour that bear less number of under-sized fruits.
- Nematode poses **replant problem** in peach.

d. ***Criconemella xenoplax*.:**

- *Criconemella. xenoplax* is the only creconematide reported from peaches in India.
- It is a **sedentary ectoparasite** that causes pits on the roots and destroys the feeder roots.
- As a result stunting, chlorosis, leaf drop and loss of vigour of peach trees occur.

Management:

- Nursery should be raised in nematode free soil.
- Only healthy, nematode free planting stock should be transplanted in the field.
- Pre-plant soil fumigation, weed removal, nutritional supply in form of organic amendments and use of resistant root stocks help in keeping the nematode population under control.
- Root dip treatment in oxamyl @ 0.024g/litre kills the nematode population.

III. PAPAYA

- Papaya, a native of Tropical America is grown all over India leaving apart colder regions of North India.
- Out of several nematodes reported to be associated with papaya only root- knot nematode (*Meloidogyne incognita* and *M. javanica)* and reniform nematode (*Rotylenchulus reniformis)* have been reported to cause economic damage.
- General symptoms of nematode infestation appear in form of patches of poorly growing stunted plants with yellow foliage and poor vigour.
- Application of neem cake @ 2.5 tonnes / ha or carbofuran @ 6 kg a.i./ha successfully controlled the nematode population and increased the yield significantly.

IV. STRAWBERRY

Important nematodes of strawberry include *Aphelenchoides* spp. (*A. fragariae, A. ritzemabosi),* which are causal organisms for disease "**Dwarf Crimp", "Spring dwarf of strawberry" and "Red plant of strawberry". *Aphelenchoides besseyi*** causes **'Summer crimp of Strawberry'.**

- In strawberry the nematodes generally congregate about the plant crown where they primarily live as **migratory ecto- parasites** on buds and leaflets of the growing points or in leaf axils.
- Infested leaves are more brittle.
- Stunting and deforming of buds, leaves and flower occurs and if the main bud is killed, plant may fail to produce more leaves and often dies.
- Symptoms are more pronounced in spring when the young leaves are **'crimped'.**
- In severe cases, the central crown may be aborted resulting in the formation of secondary crowns and delayed flowering.
- Affect on flowering and fruiting results in to poor yields.
- The nematode requires cool, moist conditions to enable it to move on plant surfaces, where it feeds and reproduces.

- Pre-planting sucker dips in hot water at 43.3° C for 20 minutes or 46.5° C for 10 min followed by plunging in cold water results into healthy, vigorous strawberry plants, free of nematode infestation.
- A five minute dip in 0.2% thionazin effectively eliminates the nematodes.

V. KIWI

- The fruit is native to China and primarily known as Chinese gooseberry until 1962, when New Zealand growers began to market the fruit as kiwifruit.
- The only widespread nematode damage reported on kiwi fruit is caused by *Meloidogyne hapla* which induces small, discrete root galls associated with unthrifty plants.
- Reduced nematode population and improved plant status can be achieved with various organic amendments, mulches and biological control agents.

I. Chrysanthemum

Large areas in the states of Karnataka, Tamilnadu, Madhya Pradesh and Bihar are under chrysanthemum cultivation. Nematodes of major significance in chrysanthemum are *Aphelenchoides ritzemabosi* and *Pratylenchus coffeae.*

a. Chrysanthemum foliar nematode (*Aphelenchoides ritzemabosi*)

Nature of Damage:

It is an above ground migratory parasite **that feeds upon mesophyll tissue of leaf and growing buds as a result of which the tissue becomes necrotic.**

- Nematodes overwinter in dead, infested leaves on the ground or between the scales of infected buds.
- In the spring, the nematodes become active and swim up the plant stems.

Symptoms:

- The symptoms produced on chrysanthemum leaves are

  fairly characteristic.
- Initially, small yellow spots are visible between the large veins which turn brown with age. They also coalesce as the feeding continues and a large **V-shaped angular** area of necrotic tissue is formed.
- Eventually the entire leaf turns brown, becomes brittle, and is shed.
- Leaves arising from infected buds are distorted and smaller than normal.
- Their petioles and the stem tissue around the buds contain brown scars when nematode feeding destroys the cells.
- Nematodes may also feed on ray flowers and impede their normal development.
- Secretions from *A. ritzemabosi* cause **shortening of internodes (rosetting)** giving a bushy appearance to theaffected plants.Other symptoms caused by nematode secretions include production of low, premature side shoots and distorted leaves.

- A condition called **blindness** also occurs on infested plants. It is characterized by shoot browning and failure to grow.
- In the most severe cases plants die after producing a limited amount of normal foliage and marketable flowers.
- The disease tends to progress from the lower to the upper leaves as the nematode moves up the plant.
- While symptoms may be dramatic and readily visible, it is important to note that plants may survive as symptomless carriers. These plants can support a high number of nematodes and exhibit few, if any, visible symptoms.

Fif. 15.1 Damage caused by foliar nematode on chrysanthemum

Management

- **Sanitation.** Remove infected plants and debris in the fall and destroy it. Remove individual infected lower leaves from the plant before the nematode moves upward.
- **Healthy propagation.** Take cuttings from the upper portion of the plant. Disinfect dormant cuttings and stools with a hot water treatment (50o C for 5 min or 44o C for 30 min)
- **Cultural Practices.** Use a heavy layer of mulch over fallen leaves in ornamental plantings to prevent upward movement of the nematode. Avoid overhead irrigation and time irrigation to limit the foliage remaining wet. Space plants to allow good air flow and rapid drying.
- **Chemical Control.** Thionazin drench @ 0.2% twice in a fortnight is advisable in commercial cultivation.

b. Root lesion nematodes (*Pratylenchus* spp.)

- At least three species viz., *Pratylenchus coffeae*, *P. chrysanthus* and *P. fallax* have been recorded to be associated with chrysanthemum.
- These nematodes are responsible for extensive cortical lesions on the roots due to intra as well as inter cellular movement of the nematode in the root tissue that eventually leads to stunted growth of plants, premature yellowing and drying of leaves.

II. Rose

Rose is an ornamental shrub grown for its beautiful pleasantly smelling flowers of various hues in the gardens but its commercial cultivation is done for its flowers and rose oil in the states of Uttar Pradesh, Tamil Nadu, Karnataka, Rajasthan and Punjab.

Of the nearly 15 nematode species associated with rose, most common and damaging are *Meloidogyne* spp, *Xiphinema diversicaudatum, Hoplolaimus galeatus, Pratylenchus* spp., *Tylenchorhynchus dubius,* etc.

a. Root Knot Nematode (*Meloidogyne* spp.): Though *M. hapla, M. arenaria, M. incognita and M. javanica* have been mentioned as rose pests in the countries like USA, Russia, Israel and Poland only latter two have been reported from roses in India. Damage is at its worst in warm sunlit sandy soils that remain moist.

Nature of Damage:

- Sedentary endoparasites in which $J2_s$ preferably invade the roots near root cap.
- The parasitic nematodes suck and drain the fine hair like rose roots and create knots in the smaller roots thus, limiting the development of the root system.
- These tiny swellings (galls) appear all over the mass of the rose roots.
- The damaged roots can no longer take up water or nutrition into the upper parts of the plant.

Symptoms:

- Weak, stunted plants, don't have normal healthy green coloration.
- Flowering is sparse.
- The overall life span of the nematode affected rose is shortened greatly.

Management:

- Marigolds or *Alliums*as under plantings repel nematodes.
- Nematodes can be controlled by planting nematode-free plants into parts of the garden where nematodes haven't been a problem previously.

b. Dagger nematode (*Xiphinema diversicaudatum*):

- It is a major pest of roses in countries like USA, Russia, Canada, Australia, New Zealand, India etc.
- Its wide host range includes strawberry, raspberry, grapevine, apple, asparagus, cabbage, carrot, cherry, peach, hops etc. But it is most serious on rose and strawberry.
- It is a **migratory ectoparasitic** nematodethat mainly infects the root tips.
- It causes galling of root tips in roses. Besides, malformation, chlorosis and dwarfing of roses are recorded.
- Life cycle may take three years to complete.
- Females survive for more than five years and mate several times during this period with males which are as abundant as females.
- It can survive in the soil devoid of higher plants for up to three years.
- Eggs are killed at 5ºC, but juveniles and adults survive this temperature.
- Fallowing and crop rotation are practically not feasible against this nematode due to its vast host range.
- This nematode poses more threat as a virus transmitting agent.

Galling on rose roots caused by *Xiphinema diversicaudatum*

c Lesion nematode (*Pratylenchus spp.*):

- Important species are *P. vulnus, P. pratensis* and *P. penetrans.*
- Root symptoms appear in the form of dark lesions, reduced root system and death of feeder roots.
- Above-ground symptoms appear in the form of malnutritioned stunted plants showing leaf chlorosis and sparse flowering.
- Interculturing with marigold and post-planting drenches with DBCP (nemagon) controls the nematodes.

Crossandra, Gladiolus

III. Crossandra

Crossandra is commercially grown for flowers in the states of Karnataka, Tamil Nadu, Andhra Pradesh and in a few areas of Rajasthan. Major pests of crossandra are *Pratylenchus delattrei, Longidorus africanus, Meloidogyne incognita* and *Helicotylenchus dihystera* .

a. Lesion nematode (*Pratylenchus delattrei*) Biology:

- **Migratory endo-parasites;** all the juvenile and adult stages being infective.
- Eggs are laid inside the roots. Juveniles on hatching move inside the root tissue in cortex both inter as well as intra-cellularly causing extensive damage to the root tissue.
- The nematode takes about 46-55 days to convert from egg to adult.
- Nematode can survive up to eight months in moist soil in absence of the host crop. Survival period is reduced to three months in dry soil.

Symptoms:

- Infested plants are weak and stunted with pinkish to purple and yellow coloured leaves.
- Inflorescence and flower size is reduced. Root system is reduced and roots bear brown to black lesions.

Management:

- Application of FYM and inter-culturing of african marigold reduces the nematode population significantly.
- Carbofuran 3 G @ 1 g per plant is effective.

b. Needle nematode (*Longidorus africanus*) The nematode has been reported from crossandra in USA, Italy, Israel and India (Tamil Nadu).

Nature of Damage:

- The nematode is a **migratory ectoparasite** that penetrates its long stylet in to the parenchymatous cells and initiates hyperplasia of these cells.
- Hyperplasia progresses from periphery to centre thus pushing the meristem laterally which eventually leads to the formation of dark stained cells.

Management:

- Crop rotation with poor hosts like pea, carrot or onion or non-host crops like cabbage, cauliflower and radish reduces the nematode population significantly and improves the flower production.
- Inter-culturing of these crops also helps to reduce the nematode count.

IV. Gladiolus

Though a number of plant parasitic nematodes viz., Meloidogyne spp., Helicotylenchus dihystera, H. varicaudatus, Criconemella xenoplax, Pratylenchus spp. Tylenchorhynchus ewingii, T. mashhoodi, Paratylenchus curvitatus, Quinsulcius indicus and Hoplolaimus indicus have been found to be associated with gladiolus, only root-knot nematode poses a major problem.

a. Root-Knot Nematode (*Meloidogyne incognita*):

The nematode has been found to be associated with gladiolus in Himachal Pradesh and Karnataka. The nematode invades roots, daughter corms and cormels which develop after flowering and survives in the corm tissue in the soil as a source of inoculum for the next season. **Symptoms:**

- The infested plants are stunted and show a poor plant stand in form of short and thin floral stalks, low leaf count and hampered appearance of florets.
- Leaves of infested plants turn yellow followed by browning of the leaf tip and ultimately whole leaf dries off.
- Infested plants bear reduced number of daughter corms and cormels.
- Infested roots are heavily galled and have reduced root length.
- Gall size is small.

Management:

- Hot water treatment of corms at 57.8^{o} C for 30 minutes renders them nematode free.
- Corms dip in the organophosphates like fensulfothion or thionazin @ 0.5 g a.i. per litre of water also reduced nematode infection significantly.
- Interculuring and bordering of *Tagetes* helps to reduce nematode population.

Carnation and Tuberose

V. Carnation

Carnations are the important cut flowers that suffer about 5% loss due to nematodes alone in developed countries. Various plant parasitic nematodes have been found to be associated with carnation in India and elsewhere. Of these, the damage potential of *Meloidogyne* spp., *Criconemella xenoplax* and *Paratylenchus* spp. is well known.

Symptoms:

- Stunted and patchy plant growth.
- Reduced stem sturdiness i.e., weak stalks, leaf yellowing and delayed flowering occur due to infestation of these nematodes.
- In addition, roots bear numerous small galls in case of infestation with root knot nematode.

Management:

- Application of organic amendments like neem cake or mustard cake @ 25q/ha
- Application of phorate or cabofuran @ 2 kg a.i./ha reduced the nematode population and improved the plant status.
- Steam sterilization in the glass house is still the preferred method abroad as the crop is highly sensitive to the bromine present in most of the soil sterilants.

VI. Tuberose

Tuberose is grown in the states of Karnataka, Tamil Nadu, Maharashtra and West Bengal. The crop is highly sensitive to the infestation of *Meloidogyne* spp. and *Rotylenchulus reniformis.* Three species of root-knot nematode namely *M. incognita, M. javanica* and *M. arenaria* damage the crop in various states. *Aphelenchoides besseyi* has been found to infest tuberose in West Bengal and Orissa

Symptoms:

- Retardation in plant growth and yellowing of leaves which eventually dry
- Suppression of spike emergence and losses in yield.

Management:

Use of organic amendments and nematicides like carbofuran or phorate @ 2 g a.i./plant is effective against the nematodes.

List of some important nematodes and their ornamental hosts:

Sr.No.	Nematode	Ornamental Host
1	*Meloidogyne spp.*	Rose, Crossandra, Jasmine, Antirrrhinum, Phlox, Poppy, Naustertium, Carnation, Celosia, Begonia, Pyrogustia, Hedichium, Acalypha, Geranium, China aster, Cacti etc.
2	*Ditylenchus dipsaci*	Narcissus, Carnation, Phlox, Begonia, bulb crops
3	*Tylenchorhynchus claytoni*	Azalea, Ilex, Sedum
4	*Aphelenchoides ritzemabosi and A. besseyi*	Tuberose, Zinnia, Chrysanthemum
5	*Scutellonema brachyurum*	Begonia, Camellia, Carnation African violet
6	*Radopholus similis*	Anthurium, Canna, Celosia, Shoe flower, Ixora, Jasmine
7	*Pratylenchus penetrans*	Rose

SPICES

India is the major producer of number of spices like black pepper, cardamom, ginger, turmeric, cloves, cumin, cinnamon, nutmeg, coriander, fenugreek etc.

I. BLACK PEPPER Black pepper has its origin in the hills of South-Western India. Though, about 40 nematodes species have been reported to be associated with pepper, only two, viz. *Radopholus similis* and *Meloidogyne* spp. are important as far as distribution and economic damage is concerned.

A. *Radopholus similis:* 'Yellows' disease of pepper or Pepper Yellow' and the very similar 'Slow-wilt' disease of black pepper. Pepper Yellow�much wiped out 22 million pepper vines from Bangka Island in Indonesia within 20 years. In India, pepper vines in Kerala and Karnataka suffer from frequent incidence of 'Slow-wilt' disease.

Hosts:

- Coconut and arecanut, on which black pepper vines generally trail, are good hosts of this nematode. Intercrops like banana, ginger and turmeric are also susceptible to *R. similis.*

Nature of Damage:

- It is a **migratory endoparasite** that penetrates roots within 24 hours of inoculation and remains within the cortex and does not enter the steler region.

- The cells around the site of penetration become brown.
- The xylem vessels are seen plugged with a "gum-like substance"

Symptoms:

- Initial appearance of a few pale, yellow, drooping leaves whose number gradually increases and within a year or two the entire foliage becomes chlorotic. Chlorosis is more pronounced under drought conditions.
- This is followed by shedding of leaves, cessation of growth and die-back symptoms.
- In large plantations, affected patches are conspicuous with many barren standards.
- Young as well as old plants are affected.
- In the very early stage, the symptoms may disappear with the onset of south-west monsoon.
- In bearing vines spike shedding takes place.
- Affected vines die within a span of three to five years.
- The tender, thin, white, feeder roots show typical orange to purple coloured lesions.
- The root system exhibits extensive rotting with the main roots devoid of feeder roots. Extensive necrosis of large roots develops subsequently.

Management:

- Chemical control of the nematode in black pepper is difficult due to perennial nature of the crop and in India, where other crops grown in mixed perennial multi-crop systems are all susceptible and repeated applications of the nematicides may not be economically feasible.
- Aldicarb sulfone at 8 kg a.i. per ha gave best control of
  R. similis followed by fensulfothion. Under Indian conditions, phorate@ 3 g per vine applied in May/June and again in September/October controlled the nematode over a period of three years.
- Mulching with dead leaves improves the symptoms of Slow-wilt/pepper yellows.
- For heavily infested areas, an integrated method of management is suggested.
    - Planting nematode-free rooted cuttings
    - Uprooting affected vines and replanting after 9-12 months
    - Use of non-living standards and exclusion of *R. similis* susceptible trees as standards for trailing black pepper vines and avoiding susceptible intercrops such as banana, ginger, turmeric etc.

B. ***Meloidogyne*** **spp.** In India, Butler (1906) was the first to report root-knot nematode from black pepper in Kerala.

C. **Distribution:**

- *Meloidogyne javanica* and *M. incognita* have been reported from almost all pepper growing nations of Asia including India. *M. arenaria* has been found on pepper in

Sri Lanka.

Hosts:

- Most of the commercially used standards are highly susceptible to root-knot nematode. Large numbers of weeds found in pepper gardens are also highly susceptible to this nematode.

Nature of Damage:

- **Sedentary endoparastic** in their feeding behavior.
- J2s penetrate the meristmetic tissue, settle themselves in steler region and start feeding on pericycle cells. Feeding continues for weeks together with gradual swelling.

Symptoms:

Affected plants show prominently slow unthrifty growth and yellowing of leaves. The interveinal areas of leaves turn dense yellow but the leaf veins remain distinct with deep green colour. The roots show prominent galls.

Management:

- Among various popular cultivars of pepper screened for resistance, only one cultivar CLT-P-812 has been found resistant to *M. incognita.*
- *Paecilomyces lilacinus* and *Pochonia chlamydosporia* when introduced to sterile soil before inoculation of nematodes to potted plants infected egg masses of *M. incognita* on black pepper seedlings.
- Under Indian conditions application of aldicarb@ 1 g a.i. per vine twice a year (May/June and October/November) integrated with fertilizers (N = 100g, P = 40g, K = 140g per vine) in two equal split doses, earthing up to 50 cm radius at the base of the vines and mulching the base of the vines reduces foliar yellowing by 83% and *M. incognita* larval population by 33-88%.

II. CARDAMOM

Cardamom has its origin in the evergreen rain forests of the Western Hills of South India.

The most important nematode problem is the root-knot nematode, *Meloidogyne* spp.

Meloidogyne spp.

Distribution:

Meioidogyne incognita and *M. javanica* widely occurring in cardamom nurseries and plantations in Kerala, Karnataka and Tamil Nadu.

Host Range

Many annual weeds and common shade trees like *Erythrina indica* and *E. lithosperma* present in cardamom plantations are susceptible to root-knot nematodes.

Symptoms:

- In primary nurseries germination is reduced to less than 50%. Infected seedlings fail to establish in secondary nurseries.
- The roots show heavy galling.
- In secondary nurseries, infected plants exhibit stunting, yellowing, poor tillering and heavy galling of roots.
- Infested mature plants show stunting, yellowing, reduced tillering, delay in flowering, immature fruit- drop and reduction in yield.
- Interestingly, roots of matured plants do not show galling. Instead, they show excessive branching.

Management:

- The popular cardamom cultivars, **Malabar, Mysore** and **Vazhuka** are all susceptible to root-knot nematodes.
- Disinfesting nursery beds with methyl bromide @ 500 g per 10 m^2 is effective in controlling root-knot nematodes in cardamom nurseries. Seed beds can also be drenched with 2% formalin to a depth of 20-30 cms and covered with polythene sheets for three to seven days. Seeds can be sown two weeks after formalin application when the soil is free from formalin fumes.

- Application of aldicarb/carbofuran/phorate @ 5g and 10g a.i. per plant and neem cake @ 500g and l000 g per plant twice a year results in increase in growth and vigour of seedlings both in primary and secondary nurseries.

- Integration of the following practices can help in the successful nematode management.
  - Changing nursery sites frequently
  - Disinfesting nursery beds
  - Introduction of biocontrol organisms at nursery level
  - Control of susceptible weeds

- Exclusion of susceptible shade trees
- Destruction of infested crop residues
- Application of nematicide and neemoil cake
- Mulching with dead leaves

III. GINGER

Though the country of origin of ginger is not known with certainty, it is presumed to be in the region of India or China. Nematodes that cause economic damage to ginger include *Meloidogyne* spp. and *Radopholus similis. Pratylenchus zeae* has been found to be a major nematode pest of ginger in Himachal Pradesh

A. *Meloidogyne* spp. Nature of Damage:

- Second stage juveniles are infective. J2s penetrate fleshy and fibrous roots, form giant cells through which they suck the cell contents and develops to maturity within 24 days. But in rhizomes, it takes a longer period to mature.
- J2s attack the rhizome through axils of leaf sheaths in the shoot apex. Fleshy roots are invaded along the entire length, while in fibrous roots it is in the area of differentiation.
- Roots and underground rhizomes exhibit galling and rotting.
- Infested rhizomes help in long distance dissemination of nematodes.

Symptoms:

Heavily infested plants show stunting and chlorosis, withering of aerial shoots and marginal necrosis of leaves.

- Infested rhizomes have brown, water-soaked areas in the outer tissues especially in angles between shoots.
- *M. arenaria* causes typical symptoms of drying and twisting of leaves

Fig. 16.1 **Ginger rhizome infested with root-knot nematode**

B. Radopholus similis

R. *similis* infestation in ginger was first reported in India, from Kerala. The perpetuation and dissemination of the nematode take place through infested rhizomes used for planting.
Nature of Damage:

- The nematode is a **migratory endoparasite,** penetrates through cell walls and is found coiled within a single cell.
- Due to infection, large channels or galleries are formed within the rhizomes.

Symptoms:

- Affected plants exhibit stunting, reduced vigour and tillering, and mature and dry

out faster than healthy plants.
- The topmost leaves become chlorotic with scorched tips.
- The infected rhizomes exhibit small, shallow, sunken, water-soaked lesions.

Management:

- Application of well decomposed cattle manure or compost@ 25-30 tonnes per ha, neemcake @ two tonnes per ha, and mulching with green leaves @ 10-12 tonnes per ha at planting and mulching again during the growth period helps in reducing nematode population.
- Pre-plant hot water treatment of ginger rhizomes at 45^{o} C for one hour renders them nematode free.
- In Himachal Pradesh, application of phenamiphos @ 3 kg a.i. per ha resulted in 70-144% increase in yield of ginger in nematode infested fields.

Role of Nematodes in Plant Disease

Arable soil is a biotic complex in which plant parasitic nematodes share habitat with numerous other microorganisms including fungi, bacteria or viruses. All these micro-organisms sharing a common ecosystem in the soil are bound to have some sort of interaction with one or the other co-habitating organisms. This interaction may or may not affect each other but definitely affects the host plant. Based on these effects, interactions can be of two types:

a. Synergism:

b. A positive interaction between the interacting pathogens sharing same ecosystem in which either the presence of two pathogens benefit both the micro- organisms or at least one of the pathogens is benefitted. The pathogenic impact on the host plant in this case is always more than the amount of damage caused by either pathogen alone. Antagonism:

It is a negative interaction in which the pathogens sharing the same ecosystem adversely affect each other or at least one of the pathogen is inhibited due to the presence of the other. The pathogenic impact on the host plant in this case is always less than the amount of damage caused by either pathogen alone.

- There are three components of interaction viz. nematodes, plant pathogen (fungi, bacteria or viruses) and the host plant.
- Among these interaction studies, most well understood are the sedentary root parasitic nematode-fungus interaction, foliar nematode-bacteria interaction and virus transmission by dorylaimid group of nematodes.

1) Nematode- fungus interactions

Atkinson (1892) was the first to observe the involvement of nematodes in disease complexes when he recorded increased severity of cotton wilt caused by *Fusarium oxysporum* f.sp. *vasinfectum* in the presence of root-knot nematode.

- Nematodes play a supportive role in interaction with fungi and the nature of support depends upon various factors like nematode species, fungus species and the host plant involved in the interaction. Phyto-nematodes may play any of the following roles in their interaction with fungi:

- **Wound causing agents: Mechanical wounding by the nematode promotes the involvement of fungi and together both pathogens cause more severe damage than either of the pathogen alone.**
- Tobacco cultivars resistant to black shank disease caused by the fungus *Phytophthora parasitica* var. *nicotianae* suffered severe wilt in presence of root-knot nematode.
- Some migratory endoparasitic nematodes like root lesion nematode (*Pratylenchus* spp.) cause necrotic lesions/wounds on the host surface that serve as a food base for the establishment of facultative fungal pathogens. Later, the fungus invades the roots from this site. Lesions caused by *Pratylenchus penetrans* on brinjal and tomato make them susceptible to wilt caused by *Verticillium dahliae.*

b. Plant substrate/rhizosphere modifying Agents:

- Phytonematodes during feeding invariably cause modifications in the host substrate that is advantageous for fungal pathogens. These modifications are simpler in ectoparasitic nematodes but more extensive and complex in endoparasitic nematodes.
- Root-knot nematodes cause increased leakage of carbohydrates, proteins and amino acids from the giant cells and galled tissue which activate the resting spores of fungal pathogens. Prior infection of *Meloidogyne incognita* is essential for *Rhizoctonia solani* to cause root rot disease in tobacco and okra.

c. Resistance Breaking agents:

- In many instances, root nematodes turn the otherwise resistant cultivars of plants into susceptible ones. Probably the physiological changes brought by nematodes as primary pathogens in the host plant are responsible for breaking down the resistance.
- *Meloidogyne incognita* and *M. hapla* are known to reduce the resistance to Fusarium wilt in many cultivars of tomato.

d. Pathogenicity inducing Agents:

- Rarely nematodes are able to induce pathogenicity in saprophytic soil fungi. Soil inhabiting fungi like *Botrytis cineria, Penicillium martensii* and *Trichoderma harzianum* normally non pathogenic on tobacco, invaded tobacco roots infected with M. incognita and caused root damage.

e. Mycorrhizae antagonistic agents:

- While certain fungal feeding nematodes like Aphelenchids directly feed on beneficial mycorrhizae, other endoparasitic migratory nematodes cause extensive lesions on cortical tissue of the host plant root, thus, rendering it unfit for mycorrhizal colonization.

2). Nematode-Bacterium Interactions

Interactions involving nematodes and bacteria in plant diseases, though few, are **the most significant.** Micro-wounds caused on host plant root surface by nematodes during feeding facilitate the entry of numerous pathogenic bacteria. The increased exudation through surface punctures due to nematodes may also attract and favour bacterial growth at the site of punctures.

Following types of interactions between nematodes and bacteria have been recorded:

a. Expression of a disease entirely different from that caused by either pathogen alone

- The „Tundu‟ or „Yellow Slime Rot‟ disease of wheat is a result of essential interaction between *Anguina tritici* with bacterium *Clavibacter tritici* (= *Corynebacterium tritici).* Nematode alone causes „Ear Cockle of wheat‟, symptoms of which are entirely different from „Tundu‟.
- Similarly „Cauliflower Head‟ Disease of Strawberry is caused due to interaction between *Aphelenchoides fragariae/A. ritzemabosi* and bacterium *Clavibacter fasciens.* In this case bacteria when present alone has negligible influence. Infection by nematode alone results into weak stunted plants with abnormally narrow leaves (alaminate leaves). Plants infected with both the organisms show structural deformities in which plants continually produce axillary buds in the crown giving the appearance of small cauliflowers hence the name.

b. Nematodes predisposing the plants to Bacterial Disease

- Nematodes may assist the pathogenic bacteria to enter/damage the host plant by providing them ingress points at the site of nematode penetration, as carriers, vectors or as resistance breakers.
- Bacterial wilt of carnation increases manifold in plants infected with *Meloidogyne* or *Helicotylenchus* sp.

  Agrobacterium tumefaciens can cause crown galls in peach and raspberry only in presence of root-knot nematode. The incidence of wilt in alfalfa caused by *Clavibacter michiganense* var. *insidiosum* is very low generally but when roots are injured by *M. hapla,* the disease increases manifold.
- Some times the nematode juveniles carry bacterial cells on their body surface and establish them at the site of infection. *Ditylenchus dipsaci* is known to carry *Pseudomonas fluorescens* in garlic where it causes

  „Caif au lait‟ bacteriosis. Similarly *Globodera pallida*

  acts as a carrier for *P. solanacearum* in potatoes.
- In case of „Tundu‟ disease of wheat, bacterial cells are present in soil, on surface or inside the galls. The nematode acts as a vector carrying the bacterium on their surface. Tundu disease cannot develop without the involvement of nematode. Resistance in potatoes to *P. solanacearum* was broken down in plants infected with *M. incognita acrita.*

c. Nematodes as inhibitors of symbiotic Rhizobium bacteria:

- Phyto-nematodes play an antagonistic role in symbiotic rhizobium-leguminous plant systems as they adversely affect nodulation in plants.
- Soyabean plants infected with Heterodera glycines (race1) suffer from reduced nodulation by Rhizobium that eventually leads to reduced nitrogen fixation. The size of nodules is also drastically reduced.
- Meloidogyne spp. are known to parasitize nodules themselves and destroy them.

3). Nematode –Virus Interactions

Though long been suspected to act as virus transmitting agents, it was only in 1958 when Hewitt, Raski and Goheen experimentally proved that *Xiphinema index* was responsible for transmitting Grapevine fan leaf virus (GFLV). Presently, more than 100 species of root ectoparasites belonging to five genera viz., *Xiphinema, Longidorus, Paralongidorus, Trichodorus* and *Paratrichodorus* are known to act as vectors of viruses in plants. Interestingly, all these genera belong to order Dorylaimida, have global distribution and moderate to wide host range.

Viruses:

- Only soil-borne RNA viruses are transmitted by nematodes. They also have moderate to wide plant host range, and are transmitted by nematodes, seeds, pollens, etc. They are broadly classified into two groups on the basis of size and shape of virus particles.

1. NEPO (Nematode transmitted polyhedral particles) viruses:

- They measure 25-30 nm (1nm=10-9 m) in size, are polyhedral in shape and are transmitted by species of *Xiphinema, Longidorus* and *Paralongidorus,* e.g. GFLV, tomato ring spot virus (TRSV).

2. TOBRA or NETU (Nematode transmitted tubular particles) viruses:

- These rod-shaped viruses are transmitted by species of *Trichodorus* and *Paratrichodorus.* There are three main group of these viruses which differ in size and host response viz., tabacco rattle virus (TRV), pea early browning virus (PEBV), and pepper ring spot virus (PRV).

Potato infected with TOBRA virus vectored by a nematode Steps Involved in Virus

Transmission

Acquisition:

- Nematode ingest viruses and become viruliferous when they feed on roots of virus infected plants. As the nematode thrusts its long odontostyle/onchiostyle (in trichodorids) into the root, the pulsation of oesophageal bulb sucks in the cell sap. Viruses enter nematode body along with cell sap. All the four juvenile stages and adults of both the sexes are capable of acquiring and transmitting viruses.

Retention: Having ingested viruses, nematode vectors can retain them for long periods, particularly when nematodes do not have access to the host plant. Viruses passing through the stomodaeum along with the ingested food are selectively adsorbed on the cuticular lining of the stomodaeum. Sites of viral retention differ among genera. In case of *Xiphinema* sp., viruses are retained on the cuticular lining of lumen of odontophore (stylet extension) and oesophagus, and in *Longidorus* on guiding sheath and odonotostyle. The TOBRA viruses are retained on the cuticular lining of oesophageal lumen of *Trichodorus* and *Paratrichodorus.*

Viral particles can be retained inside the nematode body for weeks together. However, the viral particles are shed-off along cuticle during moulting. Virus particles are just retained and they do not multiply inside the nematode body.

Dissociation:

- When the secretions of oesophageal glands pass through stomodaeum during salivation, viral particle slowly get alienated from the site of retention. All the viral particles are not released simultaneously.

Inoculation: When viruliferous nematode penetrates and starts feeding upon the fresh healthy plant, the viruses enter inside the new plant host along with the secretions of oesophageal glands. Specificity of transmission: Virus transmission is specific in the sense that all the nematodes can not transmit all the viruses and vice versa, e.g. *X. index* transmit GFLV but can not transmit Cherry leaf roll virus. This specificity is determined by the chemical nature of lining at the site of retention and chemical nature of protein coat of virus. One of the puzzling questions has been why tylenchids, which constitute major group of plant parasitic nematodes, do not transmit viruses. It could be due to:

- Difference in the chemical nature of cuticular lining of stomodaeum,
- Very little space available for virus adsorption and dissociation as the lumen of dorsal oesophageal gland empties just posterior to the stylet knobs in tylenchids, and
- Contents of tylenchid saliva may inactivate viruses.

Table. Potential virus vector nematode species prevalent in India

Vector species : Virus

*Xiphinema americanum :*Cherry rasp leaf, Tobacco ring spot, Tomato ring spot

X. brevicolle: Tomato ring spot

X. diversicaudatum :Arabis mosaic

X. index: Grapevine fan leaf,

Longidorus elongatus: Rasberry ring spot (Scottish strain), Tomato black ring (scottish strain)

Paratrichodorus minor: Pepper ring spot, Tobacco rattle.