

Chapter 2: Nematodes (Nematology)

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Introduction

- Nematology is the scientific discipline concerned with the study of nematodes.
- It is a field alongside disciplines such as agricultural entomology, mycology, virology and bacteriology, all of which together constitute plant pathology.
- Nematodes belong to the phylum Nematelminthes, or the former “roundworms”.
- This phylum contains a single class, namely the nematodes.
- Some are free-living, while others are parasites of humans, animals or plants.

1. Nematodes and agriculture

1.1. Importance of the nematode class

- Free-living nematodes that feed on decomposing organic matter seem to have a beneficial role by participating in the decomposition process.
- Insect-parasitic nematodes can have a positive influence by limiting outbreaks of harmful insects.
- Zoo-parasitic nematodes living at the expense of humans and domestic animals are of very great economic importance; their study is part of parasitology.
- Plant-parasitic nematodes, or parasites of cultivated plants, are of very great economic importance; their study, among other subjects, is part of nematology.

1.2. Particular characteristics of plant-parasitic nematodes

- In general, nematodes are cylindrical, worm-shaped organisms with an elongated, unsegmented body.
- Plant-parasitic nematodes exclusively inhabit the soil.
- They mainly colonize roots, but also the stems of cultivated plants.

- Morphologically, they differ from other trophic groups by the presence, in the anterior part of the digestive tract, of a piercing stylet followed by an oesophageal canal leading to a muscular bulb that acts as a suction and pumping mechanism.
- Once the plant has been pierced by the stylet, digestive enzymes produced by the salivary glands are injected by this pump; the pump then aspirates the products of digestion and releases them into the intestine.
- Some are obligate parasites, while others are facultative parasites.
- Depending on the parasitic strategy of the nematode—ectoparasite, endoparasite or ecto-endoparasite—the stylet may differ in shape and length.

Figure 20. Diagram of a plant-parasitic nematode

1.3. Morphological characteristics of the main genera and families of plant-parasitic nematodes

- They belong to four main orders: Triplonchida, Aphelenchida, Tylenchida and Dorylaimida.
- Dorylaimidae are characterized by: phasmids absent; stylet without basal knobs; cuticle annulation; strongly muscularized oesophagus, without a median bulb and with five gland cells.
- Tylenchidae are distinguished by: phasmids present; stylet with basal knobs; cuticle annulation; weakly muscularized oesophagus in three or four parts (procorpus, median bulb, isthmus, basal bulb); opening of the dorsal gland located just behind the stylet; presence of three gland cells; mainly parasitize roots.
- The most important order and the one causing the greatest damage to plants is Tylenchida.
- It comprises nine families, the most important of which are Heteroderidae = cyst nematodes and Meloidogynae = root-knot nematodes.

Key to plant-parasitic nematodes

- 1. Is a stylet present?
 - 1.1. YES: it is a plant-parasitic nematode (2).
 - 1.2. NO: it is not a plant-parasitic nematode.
- 2. Is the median oesophageal bulb present?
 - 2.1. YES (5).
 - 2.2. NO (3).
- 3. What is the body size?
 - 3.1. Less than 1 mm with a small curved stylet: genus *Trichodorus* (stubby-root parasites).
 - 3.2. More than 1 mm with a long straight stylet (4).
- 4. Are stylet guides present?
 - 4.1. YES: genus *Xiphinema*.
 - 4.2. NO: genus *Longidorus*.
- 5. What is the body shape?
 - 5.1. Swollen: genera *Heterodera* and *Globodera* if cysts are found, and genus *Meloidogyne* if nodes (galls) are found on the roots.
 - 5.2. Vermiform (6).
- 6. Are rings present?
 - 6.1. YES: genus *Mesocriconemella*.

- 6.2. NO (7).
- 7. What is the shape of the tail?
 - 7.1. Rounded (9).
 - 7.2. Pointed (8).
- 8. Body size?
 - 8.1. More than 1 mm: genera Hemicycliophora and Ditylenchus.
 - 8.2. Less than 1 mm: genera Paratylenchus, Pratylenchus and Radopholus.
- 9. Are knobs present on the stylet?
 - 9.1. YES: genera Noplolaimus, Belonolaimus and Scutellonema.
 - 9.2. NO: genera Aphelenchus and Aphelenchoides.

1.4. Nature of damage caused to plants

- The plant-health problems caused by these pests have a very significant economic impact worldwide because they attack field crops as well as vegetable, flower and fruit crops.
- It is generally recognized that plant-parasitic nematodes reduce agricultural production by approximately 11%, representing a harvest loss of several million tonnes each year.
- In Europe, they are responsible for damage reaching 10% of cereal production and cause harvest reductions of 20–30% in Mediterranean citrus orchards.
- The damage they cause in the USA represents 6 billion dollars annually.
- In tropical and warm temperate regions, which are highly favorable to their development, they are among the main enemies of plantations and crops of coffee, cotton, banana, pineapple, maize, sorghum, etc., which are major bases of development in these countries.
- The species most widespread and causing the greatest damage worldwide belong to the genus *Meloidogyne* (root-knot nematodes).
- All plant-pathogenic nematodes possess a hollow oral stylet that allows them to pierce plant cells to absorb their contents and inject salivary secretions.

Symptoms and types of damage

- The nature of damage differs from one genus to another.
- Typical symptoms include: stunting, dwarfing, yellowing, wilting and leaf deformation for *Ditylenchus*; galls for *Meloidogyne*; root deformations for *Belonolaimus*; cysts for *Heterodera*; and root rots for *Pratylenchus*.
- Direct damage caused by plant-pathogenic nematodes: weakening of the plant.
- Indirect damage: aggravation and transmission of fungal and viral diseases.
- Root nematodes can be distinguished, with their entire life cycle taking place in the soil. Some are mobile at all stages and are external parasites (*Tylenchus*) or internal parasites (*Pratylenchus*); others are sedentary: cyst nematodes (*Heterodera*, *Globodera*), root-knot nematodes (*Meloidogyne*), and aerial-part nematodes, many of which include *Ditylenchus* and *Aphelenchoides*.

1.5. Role of nematodes in the dissemination and development of plant diseases

- Wounds caused to root cells provide an opportunity for other pathogens (bacteria, fungi and viruses) to enter the roots.
- Nematodes belonging to the genus *Xiphinema* are all important virus vectors.

- If this nematode carries viral particles, the damage threshold is reduced to only a few individuals per 100 cm³ of soil, since a single nematode is sufficient to transmit the virus.
- Nematodes of the genus *Xiphinema* are all vectors of NEPO viruses (Nematode Polyhedral particles), including viruses such as tobacco ringspot virus (TRSV) and tomato ringspot virus (TmRSV).
- The lesion nematode *Pratylenchus penetrans* can have additive and synergistic effects with other soil-borne pathogenic organisms such as *Verticillium albo-atrum* and *V. dahliae*, particularly in the Solanaceae family.
- Some nepoviruses, such as those transmitted by *Xiphinema index* and *X. italiae*, are transmitted by nematodes and are associated with grapevine fanleaf disease.

2. Nematodes and crops

2.1. Stem and bulb nematode

- The best-known species is *Ditylenchus dipsaci*.
- It can attack both the upper parts (stems) and lower parts of plants (bulbs), such as onion and others.
- It uses water films to move up the plant stem.
- L4 juveniles enter the plant through the plant tissues of stems or bulbs.
- The larvae can move upward and enter shoots through buds, petioles or stomata.
- Once inside the host plant, the larvae molt into adults, reproduce, feed as migratory endoparasites and destroy the various infected organs.

Figure 21. Diagram of a bulb infected by nematodes

2.2. Nematodes of field crops

- The quintessential cereal nematode is *Heterodera avenae*.
- Yield losses in wheat and barley following attacks by this nematode have been reported throughout the world.
- Yield losses in Morocco were around 40–50%, 20–40% in Australia and 50% in the USA.
- *H. avenae* is a particularly harmful pathogen of durum wheat in Tunisia.
- The hosts of *H. avenae* are mainly grasses, including economically important cereals: oats, bread wheat, durum wheat, barley and rye.
- The first symptoms become visible from the tillering stage of cereals.
- Plants are stunted and the tips of the leaves turn red in some cases.
- The root system is poorly developed, with proliferation of thick, short rootlets from “nodes” corresponding to the sites where infective larvae penetrate.
- Some plants disappear in cases of severe attack.
- At heading, small white spheres can be observed on the roots.
- Larval infestation causes a superficial development of the wheat root system, which limits plant growth and production when rainfall is insufficient.
- Reductions in wheat production result from alterations in yield components (number of ears, number of grains per ear and 1,000-grain weight), which are strongly correlated with the initial nematode densities.
- It is generally accepted that soil particle-size characteristics are aggravating factors for damage, especially when soils have a light structure.

2.3. Nematodes of vegetable crops

- Vegetable crops are attacked by a large number of nematodes.
- Root-knot nematodes of the genus *Meloidogyne* are probably the most serious enemies of vegetable growers at all latitudes.
- Nematodes of this genus are one of the main limiting factors for the development and profitability of vegetable crops.
- They are considered to be among the most widespread species and those causing the greatest damage worldwide.
- They attack most vegetables, with a certain preference for cucurbits (melons, cucumbers, etc.), solanaceous crops (tomatoes, eggplants, peppers, etc.) and composites (lettuces, chicories).
- The damage they cause to fruits and vegetables in the USA is estimated at 6 billion dollars per year.
- Yield losses are rarely noticeable during the first year of infestation because the nematode population is too low.
- However, if susceptible crops follow one another for two or three years, the harvest may be seriously compromised as early as the third year, and yield losses may reach 50% in vegetable production.

Meloidogyne life cycle

- The genus *Meloidogyne* is subdivided into numerous species, the most widespread being *M. incognita*, *M. arenaria*, *M. hapla* and *M. javanica*.
- The dispersal stage is L2; it moves through the film of water covering soil particles.
- This larva enters the root as far as the vascular bundles, which it pierces with its stylet.
- It feeds on sap and disrupts cell multiplication in the root.
- This results in the formation of a gall.
- The larva hypertrophies while developing through stages L3 and L4, finally reaching the sexually mature adult form.
- The male remains thread-like and leaves the root, whereas the female, unable to move, remains embedded in the tissues.
- She becomes pear-shaped and continues feeding at the expense of the plant.
- Once fertilized, she lays eggs on the root surface (approximately 300 eggs per mass).
- The eggs are the resistant stage; development passes through the L1 stage, which remains enclosed within the egg shell.
- At the L2 stage, the larva leaves the egg and colonizes new roots.
- The duration of this cycle varies greatly according to external conditions (3 to 8 weeks at 25°C).

Figure 22. *Meloidogyne* (spherical gourd-shaped form)

Symptoms of *Meloidogyne* attack

- The symptoms of a *Meloidogyne* attack are characteristic and easy to notice.
- They cause plant stunting, wilting, chlorosis, reduced growth, small fruits of poor quality and sometimes plant death.
- However, the characteristic symptom of these nematodes is the galls that form on the plant root system.
- These galls vary considerably according to the *Meloidogyne* species, the crop and the cultivar, and may sometimes be observed on roots and tubers.

Figure 23. Massive deformation and clustering of galls on the root system of vegetables attacked by *Meloidogyne* spp.

Other nematodes of vegetable crops

- Other nematodes: *Globodera rostochiensis*, also called the golden potato cyst nematode, and *G. pallida* are considered among the principal obligate parasites of potato, tomato and eggplant, causing considerable damage to potato crops.
- Currently, *G. pallida* and *G. rostochiensis* are defined as quarantine organisms.
- They cause damage to potatoes that can result in yield reductions of up to 20%.
- This nematode was first reported in the Algiers coastal region in 1954 and subsequently spread to several provinces of the country, the most important being Aïn Defla, Tipaza, Chlef, Mascara and Sétif.
- Biologically, these nematodes are sedentary endoparasites.
- They pass through juvenile stages and an adult stage.
- The first molt occurs in the egg. L2 juveniles enter through the root elongation zone and then move directly toward the central cylinder, destroying cortical cells until reaching the endodermis.
- Lysis of the walls between these cells leads to the formation of a multinucleate giant cell, with dense cytoplasm, called a syncytium.
- The L2 juveniles then transform into L3 and L4 before molting into adults.
- The thread-like males become mobile again.
- The females remain in place and enlarge until they rupture the root epidermis. Their cuticle transforms into a cyst, thereby protecting 200 to 1,200 eggs.
- The L2 juveniles can remain viable for up to 20 years inside the protective cyst wall.
- Only one generation per year is observed in *G. pallida* and one to two generations in *G. rostochiensis*.
- The symptoms associated with the golden nematode are not specific.
- They may be confused with symptoms caused by a lack of water or mineral deficiency.
- There may be yellowing, wilting or death of foliage, which can result in small tubers.
- In addition, damage caused by nematodes leads to water deficiency and disruption of nutritional metabolism.

Figure 24. Potato roots with white females of *G. rostochiensis* attached along the root surface, giving them a beaded appearance

2.4. Nematodes of flower crops

- The main nematode genus encountered on flower crops is *Pratylenchus*.
- The main species are *P. penetrans* on begonia, cyclamen, narcissus and conifers; *P. vulnus* on lily; *P. pratensis* on lily-of-the-valley; and *P. scribneri* on chrysanthemum.

Figure 25. *Pratylenchus*

Additional observations

- These nematodes can lead to root rots through extensive migration, causing necrosis and death of plant tissues and roots.
- Secondary bacterial and fungal infestations frequently develop and contribute to rotting.

- Another genus encountered is *Aphelenchoides*; these are ecto- or endoparasitic nematodes.
- They parasitize leaves, buds and meristems of ornamental crops.
- These nematodes overwinter in soil, dead leaves and aerial organs of contaminated plants.
- When activity resumes, they reach the leaves by moving over the leaf surface, facilitated by a water film, and enter through the stomata.
- The feeding activity of the nematodes causes characteristic interveinal chlorosis and necrosis of the leaf, which eventually kills it.

Figure 26. Diagram of a plant infected by foliar nematodes

***Aphelenchoides* symptoms**

- The genus *Aphelenchoides* causes streaks, whitening and discoloration of leaves.
- Plants suffering from biotic or abiotic stress, such as fungal attack or low water availability, may sustain serious damage.
- On cyclamen, invasion by these nematodes results in yellowish spots that then become brown or black depending on the plant; these are very characteristic because they are clearly limited to the main veins.
- The leaves dry out, collapse, become scorched and blackened while remaining attached to the stems.
- Attacks begin in the lower parts or in the upper parts and then progress during humid periods.
- The plant consequently experiences slowed growth.
- Irregular flower opening is also observed, and the flowers develop a scorched appearance.

2.5. Overview of some nematodes of tropical crops

- Tropical crops such as banana, coconut and mango are often attacked by nematodes.
- In Senegal, papaya roots are often attacked by *Meloidogyne javanica*.
- Banana is attacked mainly by *Radopholus similis*.
- This endoparasitic nematode species is widespread in banana plantations.
- This nematode was first encountered in Côte d'Ivoire and Guinea in 1934, then in the West Indies in 1939 and Madagascar in 1947, and later in Cape Verde and Senegal in 1951.
- Banana plants attacked by this nematode show the following symptoms: initially, the peripheral leaves begin to yellow and the plant remains more or less stunted, with very delayed development.
- Examination of the roots reveals that many are completely brown and rotten.
- The remaining functional roots show multiple purple, brown or black spots, representing necrotic areas of root tissue where the parasite proliferates.
- *R. similis* can also parasitize other plants: sugarcane, pineapple, sweet potato, pigeon pea, etc.

Figure 27. Collapse of a banana plant caused by *Radopholus similis*