Algerian People's Democratic Republic

Ministry of Higher Education and Scientific Research

Hamma Lakhdar University – El-Oued –

Faculty of Natural and Life Sciences

Department of Agricultural Sciences

Laboratory of Biodiversity and Biotechnology Applications in Agriculture

Handout of Phytopathology

Plant diseases courses

Intended for Fifth Semester students in Agronomy

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Academic Year
2024 - 2025

Foreword

In their environment, plants often face stresses that can have a considerable impact on their development and productivity. These stresses, which are of a very varied nature, can be subdivided into two groups:

- **Abiotic stresses**, which include all the non-living factors responsible for alterations in plant growth and development (climatic factors, edaphic factors related to the soil and its properties, radiative, polluting agents, etc.).

- **Biotic stresses**, which include living agents responsible for infectious diseases (fungi, bacteria, viruses, mycoplasma, nematodes, etc.). To this last group, we can associate pests, which can also cause considerable quantitative and qualitative losses to crops.

All taxa in the plant kingdom can be attacked by parasites and pests during their development. Several studies reveal that each year, more than 30% of the world's crops are lost due to plant diseases, including fungal diseases, caused by fungi, while millions of people die of hunger.

Plant **pathology**, **plant pathology** is the science that studies plant diseases. Few documents are available on the basic concepts of plant pathology for students wishing to discover this discipline, pursue master's and doctoral studies, and specialize in this field, whose development is important to protect crops and preserve plant production, which constitutes the basis of human food and nutrition.in addition to their industrial, therapeutic and economic interests.

This course, intended for students in the 3rd year of the biology and plant physiology degree, will allow students to discover the field of plant protection.

Through this course, students will acquire knowledge on the different concepts of this discipline: notion of disease, notion of stress, the factors responsible for non-parasitic diseases, pathogenesis and stages of a parasitic disease, the main pests of crops and their characteristic symptoms....

Summary

Foreword

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Introduction

Introduction

The study of the various accidents or diseases affecting plants during growth and, after harvest, the alterations of their products, constitutes Plant Pathology. The term Phytopathology, commonly used, formerly included, in addition to diseases properly so-called, damage caused by insects; Possessing a more restricted meaning today, it is especially reserved for disorders caused by the action of living plant beings (parasitic diseases), viruses (viruses), external agents (non-parasitic diseases) or those resulting from a malfunction of the plant itself (physiological disorders)• A regrettable tendency is to consider most of them too frequently from the angle of mycology (study of fungi). However, if the latter are indeed responsible for many diseases, a more in-depth study of plant physiology shows that a large number of pathological symptoms are initially caused by a disturbance of various vegetative or reproductive functions, independently of any parasitic cause. There is, therefore, a true pathology of physiology, but these more subtle symptoms, its more obscure and more complex causes, have made it too misunderstood. From the outset, it is necessary to warn against too superficial an observation of plant diseases leading to e~ always directly blaming the very many lower organisms living, accidentally or secondarily on plants. The complexity of most of them results from its close relations with a host of factors relating either to the plant itself (anatomy, physiology, biology) or to the environment in which it lives (climate, soil); the understanding of pathological phenomena can only be correct and complete if it rests on foundations established in full knowledge of these elements. The diagnosis of a disease becomes, under these conditions, very delicate, if it is easy to identify microorganisms living on a diseased plant, it is often more difficult to prove their pathogenic action and, even if it really exists, to affirm that they are really at the origin of the disease. In this matter, therefore, one cannot be too cautiously circumspect in the conclusions to be drawn from the observations and in the interpretation of the experimental results

1 Chapter 1/ Kingdom fungi

1.1 What are Fungi?

Fungi are eukaryotic organisms that include microorganisms such as yeasts, moulds and mushrooms. These organisms are classified under kingdom fungi. The organisms found in Kingdom fungi contain a cell wall and are omnipresent. They are classified as heterotrophs among the living organisms. To name a few – the appearance of black spots on bread left outside for some days, the mushrooms and the yeast cells, which are commonly used for the production of beer and bread are also fungi. They are also found in most skin infections and other fungal diseases. If we observe carefully, all the examples that we cited involve moist conditions. Thus, we can say that fungi usually grow in places which are moist and warm enough to support them. Let us have a detailed overview of the structure, classification and characteristics of fungi.

1.2 Structure of Fungi

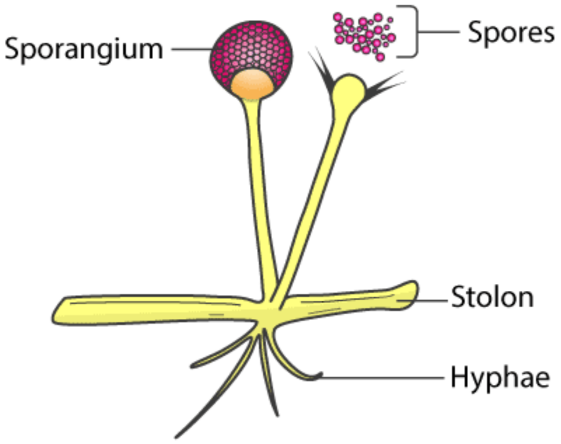


Figure 1. Structure of fungi

The structure of fungi can be explained in the following points:

1. Almost all the fungi have a filamentous structure except the yeast cells.
2. They can be either single-celled or multicellular organisms.
3. Fungi consist of long thread-like structures known as hyphae. These hyphae together form a mesh-like structure called mycelium.
4. Fungi possess a **cell wall** which is made up of chitin and polysaccharides.
5. The cell wall comprises a protoplast, which is differentiated into other cell parts such as cell membrane, cytoplasm, cell organelles and nuclei.
6. The nucleus is dense, clear, with chromatin threads. The nucleus is surrounded by a nuclear membrane.

1.3 Characteristics of Fungi

Following are the important characteristics of fungi:

1. Fungi are eukaryotic, non-vascular, non-motile and heterotrophic organisms.
2. They may be unicellular or filamentous.
3. They reproduce by means of spores.
4. Fungi exhibit the phenomenon of alternation of generation.
5. Fungi lack chlorophyll and hence cannot perform photosynthesis.
6. Fungi store their food in the form of starch.
7. Biosynthesis of chitin occurs in fungi.
8. The nuclei of the fungi are very small.
9. The fungi have no embryonic stage. They develop from the spores.
10. The mode of reproduction is sexual or asexual.
11. Some fungi are parasitic and can infect the host.
12. Fungi produce a chemical called pheromone which leads to sexual reproduction in fungi.
13. Examples include mushrooms, moulds and yeast.

1.4 Classification of Fungi

Kingdom Fungi are classified based on different modes. The different classification of fungi is as follows:

1.5 Based on Mode of nutrition

On the basis of nutrition, kingdom fungi can be classified into 3 groups.

1. **Saprophytic** – The fungi obtain their nutrition by feeding on dead organic substances. Examples: *Rhizopus, Penicillium* and *Aspergillus*.
2. **Parasitic** – The fungi obtain their nutrition by living on other living organisms (plants or animals) and absorb nutrients from their host. Examples: *Taphrina* and *Puccinia*.
3. **Symbiotic** – These fungi live by having an interdependent relationship with other species in which both are mutually benefited. Examples: Lichens and mycorrhiza. Lichens are the symbiotic association between algae and fungi. Here both algae and fungi are mutually benefited as fungi provide shelter for algae and in reverse algae synthesis carbohydrates for fungi. Mycorrhiza is the symbiotic association present between fungi and plants. Fungi improve nutrient uptake by plants, whereas, plants provide organic molecules like sugar to the fungus.

1.6 Based on Spore Formation

Kingdom Fungi are classified into the following based on the formation of spores:

1. **Zygomycetes** – These are formed by the fusion of two different cells. The sexual spores are known as zygospores, while the asexual spores are known as sporangiospores. The hyphae are without the septa. Example – *Mucor*.
2. **Ascomycetes** – They are also called sac fungi. They can be coprophilous, decomposers, parasitic or saprophytic. The sexual spores are called ascospores. Asexual reproduction occurs by conidiospores. Example – *Saccharomyces.*
3. **Basidiomycetes** – Mushrooms are the most commonly found basidiomycetes and mostly live as parasites. Sexual reproduction occurs by basidiospores. Asexual reproduction occurs by conidia, budding or fragmentation. Example- *Agaricus.*
4. **Deuteromycetes** – They are otherwise called imperfect fungi as they do not follow the regular reproduction cycle as the other fungi. They do not reproduce sexually. Asexual reproduction occurs by conidia. Example – *Trichoderma*.

1.7 Difference Between Algae and Fungi

Algae and fungi differ in their mode of nutrition. Algae are autotrophic. They have chlorophyll and perform photosynthesis. Fungi are heterotrophic, they are dependent on others for their nutrients requirement. They feed on dead and decaying organic matter.

Figure 2. Difference between algae and fungi

1.8 Algae vs Fungi

Some of the algae and fungi live in a symbiotic relationship, e.g. Lichens. In lichens, the algal partner provides food to fungi and in return, fungi provide shelter to algae.

Table 1. Difference between algae and fungi

Algae	Fungi
The word "Alga" means "Seaweed"	The word "Fungus" means "Sponge"
Algae are grouped in the kingdom Plantae. The unicellular blue-green algae are kept under the kingdom Protista	In the five-kingdom classification by Whittaker, fungi were placed in a separate kingdom Fungi
Autotrophic mode of nutrition	Heterotrophic mode of nutrition
They are not parasitic, have chlorophyll and make their own food by photosynthesis.	Some of the fungi are parasite

1.9 Similarities between Algae and Fungi

Following are the important similarities between algae and fungi:

- Vascular tissues are absent in algae and fungi both.
- Both have eukaryotic cells.
- Asexual reproduction by fragmentation occurs in both algae and fungi.
- Reproductive organs lack a protective covering.

1.10 Conclusion

Algae and fungi differ remarkably in their structure and mode of nutrition (Figure 1). They do coexist as lichens in a symbiotic relationship.

1.11 Reproduction in Fungi

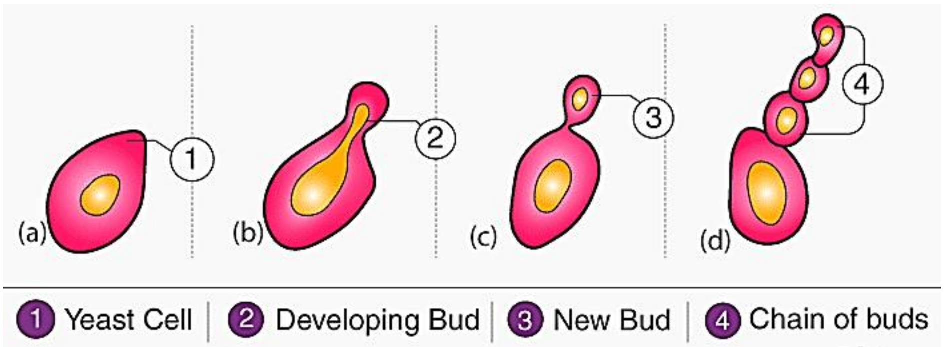


Figure 3. Reproduction in Fungi: Yeast

Reproduction in fungi is both by sexual and asexual means. The sexual mode of reproduction is referred to as teleomorph and the asexual mode of reproduction is referred to as anamorph.

Vegetative reproduction in fungi –This takes place by budding, fission and fragmentation.

Asexual reproduction – This takes place with the help of spores called conidia or zoospores, or sporangiospores.

Sexual reproduction – This occurs by ascospores, basidiospores, and oospores.

The conventional mode of **sexual reproduction** is not always observed in the kingdom Fungi. In some fungi, the fusion of two haploid hyphae does not result in the formation of a diploid cell. In such cases, there appears an intermediate stage called the dikaryophase. This stage is followed by the formation of diploid cells

1.12 Uses of Fungi

Fungi are one of the most important groups of organisms on the planet as they play a vital role in the biosphere and have great economic importance on account of both their benefits and harmful effects.

Following are some of the important uses of fungi:

1. **Recycling** – They play a major role in recycling the dead and decayed matter.
2. **Food** – The mushrooms species which are cultured are edible and are used as food by humans.
3. **Medicines** – There are many fungi that are used to produce antibiotics and to control diseases in humans and animals. Penicillin antibiotic is derived from a common fungus called *Penicillium*.
4. **Biocontrol Agents** – Fungi are involved in exploiting insects, other small worms and help in controlling pests. Spores of fungi are used as a spray on crops.
5. **Food spoilage** – Fungi play a major role in recycling organic material and are also responsible for major spoilage and economic losses of stored food.

1.13 Examples of Fungi

Following are the common examples of fungi:

- Yeast
- Mushrooms
- Moulds
- Truffles

1.14 Learning objectives

- Explain why the study of fungi such as yeast and molds is within the discipline of microbiology
- Describe the unique characteristics of fungi
- Describe examples of asexual and sexual reproduction of fungi
- Compare the major groups of fungi in this chapter, and give examples of each
- Identify examples of the primary causes of infections due to yeasts and molds
- Identify examples of toxin - producing fungi
- Classify fungal organisms according to major groups

The fungi comprise a diverse group of organisms that are heterotrophic and typically saprozoic. In addition to the well-known macroscopic fungi (such as mushrooms and molds), many unicellular yeasts and spores of macroscopic fungi are microscopic. For this reason, fungi are included within the field of microbiology. Fungi are important to humans in a variety of ways. Both microscopic and macroscopic fungi have medical relevance, with some pathogenic species that can cause mycoses (illnesses caused by fungi). Some pathogenic fungi are opportunistic, meaning that they mainly cause infections when the host's immune defences are compromised and do not normally cause illness in healthy individuals. Fungi are important in other ways. They act as decomposers in the environment, and they are critical for the production of certain foods such as cheeses. Fungi are also major sources of antibiotics, such as penicillin from the fungus Penicillium.

Characteristics of Fungi

Fungi have well-defined characteristics that set them apart from other organisms. Most multicellular fungal bodies, commonly called molds, are made up of filaments called hyphae. Hyphae can form a tangled network called a mycelium and form the thallus (body) of fleshy fungi. Hyphae that have walls between the cells are called septate hyphae; hyphae that lack walls and cell membranes between the cells are called nonseptate or coenocytic hyphae). (Figure 4).

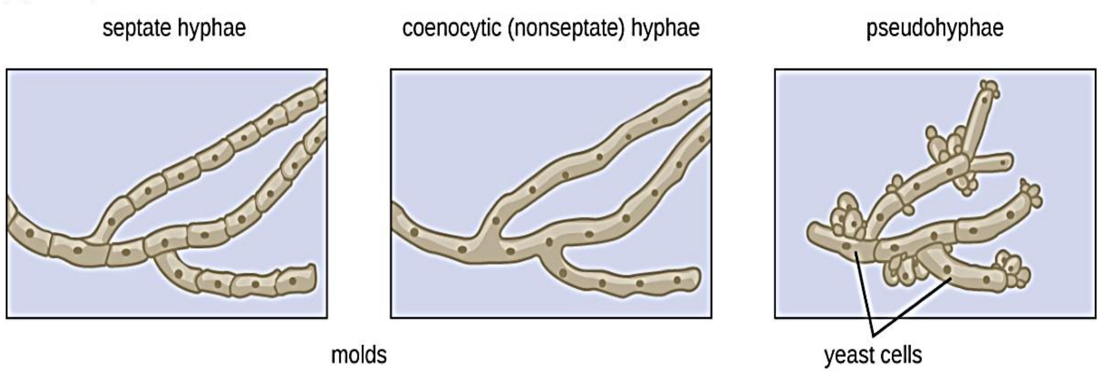


Figure 4: Multicellular fungi (molds) form hyphae, which may be septate or nonseptate. Unicellular fungi (yeasts) cells form pseudohyphae from individual yeast cells.

In contrast to molds, yeasts are unicellular fungi. The budding yeasts reproduce asexually by budding off a smaller daughter cell; the resulting cells may sometimes stick together as a short chain or pseudohypha (Figure 4). *Candida albicans* is a common yeast that forms pseudohyphae; it is associated with various infections in humans, including vaginal yeast infections, oral thrush, and candidiasis of the skin. Some fungi are dimorphic, having more than one appearance during their life cycle. These dimorphic fungi may be able to appear as yeasts or molds, which can be important for infectivity. They are capable of changing their appearance in response to environmental changes such as nutrient availability or fluctuations in temperature, growing as a mold, for example, at 25 °C (77 °F), and as yeast cells at 37 °C (98.6 °F). This ability helps dimorphic fungi to survive in diverse environments. Histoplasma capsulatum, the pathogen that causes histoplasmosis, a lung infection, is an example of a dimorphic fungus (Figure 5).

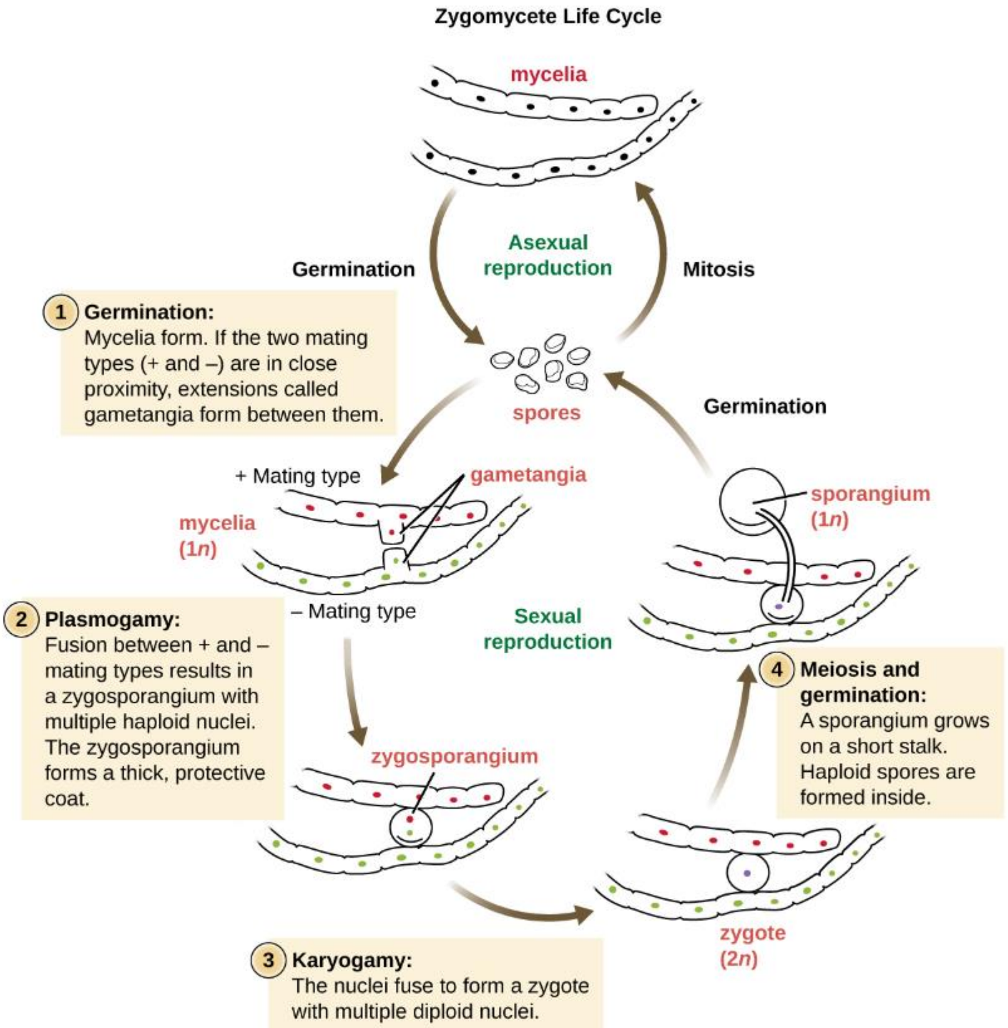


Figure 5. Zygomycetes have sexual and asexual life cycles. In the sexual life cycle, + and – mating types conjugate to form a zygosporangium.

Figure 6. These images show asexually produced spores. (a) This brightfield micrograph shows the release of spores from a sporangium at the end of a hypha called a sporangiophore. The organism is a Mucor sp. fungus, a mold often found indoors. (b) Sporangia grow at the ends of stalks, which appear as the white fuzz seen on this bread mold, Rhizopus stolonifer. The tips of bread mold are the dark, spore-containing sporangia. (credit a: modification of work by Centers for Disease Control and Prevention;

1.15 Fungal Diversity

The fungi are very diverse, comprising seven major groups. Not all of the seven groups contain pathogens. Some of these groups are generally associated with plants and include plant pathogens. For example, Urediniomycetes and Ustilagomycetes include the plant rusts and smuts, respectively. These forms reddish or dark masses, respectively, on plants as rusts (red) or smuts (dark). Some species have substantial economic impact because of their ability to reduce crop yields. Glomeromycota includes the mycorrhizal fungi, important symbionts with plant roots that can promote plant growth by acting like an extended root system. The Glomeromycota are obligate symbionts, meaning that they can only survive when associated with plant roots; the fungi receive carbohydrates from the plant and the plant benefits from the increased ability to take up nutrients and minerals from the soil. The Chytridiomycetes (chytrids) are small fungi, but are extremely ecologically important. Chytrids are generally aquatic and have flagellated, motile gametes; specific types are implicated in amphibian declines around the world. Because of their medical importance, we will focus on Zygomycota, Ascomycota, Basidiomycota, and Microsporidia. Figure 7.

summarizes the characteristics of these medically important groups of fungi.

The Zygomycota (zygomycetes) are mainly saprophytes with coenocytic hyphae and haploid nuclei. They use sporangiospores for asexual reproduction. The group name comes from the zygospores that they use for sexual reproduction (Figure 5), which have hard walls formed from the fusion of reproductive cells from two individuals. Zygomycetes are important for food science and as crop pathogens. One example is Rhizopus stolonifer (Figure 6), an important bread mold that also causes rice seedling blight. Mucor is a genus of fungi that can potentially cause necrotizing infections in humans, although most species are intolerant of temperatures found in mammalian bodies (Figure 6).

The Ascomycota include fungi that are used as food (edible mushrooms, morels, and truffles), others that are common causes of food spoilage (bread molds and plant pathogens), and still others that are human pathogens. Ascomycota may have septate hyphae and cup-shaped fruiting bodies called ascocarps. Some genera of Ascomycota use sexually produced ascospores as well as asexual spores called conidia, but sexual phases have not been discovered or described for others. Some produce an ascus containing ascospores within an ascocarp (Figure 7).

Examples of the Ascomycota include several bread molds and minor pathogens, as well as species capable of causing more serious mycoses. Species in the genus Aspergillus are important causes of allergy and infection, and are useful in research and in the production of certain fermented alcoholic beverages such as Japanese sake. The fungus Aspergillus flavus, a contaminant of nuts and stored grains, produces an aflatoxin that is both a toxin and the most potent known natural carcinogen. Neurospora crassa is of particular use in genetics research because the spores produced by meiosis are kept inside the ascus in a row that reflects the cell divisions that produced them, giving a direct view of segregation and assortment of genes (Figure 8). Penicillium produces the antibiotic penicillin (Figure 7).

Many species of ascomycetes are medically important. A large number of species in the genera Trichophyton, Microsporum, and Epidermophyton are dermatophytes, pathogenic fungi capable of causing skin infections such as athlete's foot, jock itch, and ringworm. Blastomyces dermatitidis is a dimorphic fungus that can cause blastomycosis, a respiratory infection that, if left untreated, can become disseminated to other body sites, sometimes leading to death. Another important respiratory pathogen is the dimorphic fungus Histoplasma capsulatum (Figure 3), which is associated with birds and bats in the Ohio and Mississippi river valleys. Coccidioides immitis causes the serious lung disease Valley fever. Candida albicans, the most common cause of vaginal and other yeast infections, is also an ascomycete fungus; it is a part of the normal microbiota of the skin, intestine, genital tract, and ear (Figure 6). Ascomycetes also cause plant diseases, including ergot infections, Dutch elm disease, and powdery mildews.
Saccharomyces yeasts, including the baker's yeast S. cerevisiae, are unicellular ascomycetes with haploid and diploid stages (Figure 7). This and other Saccharomyces species are used for brewing beer.

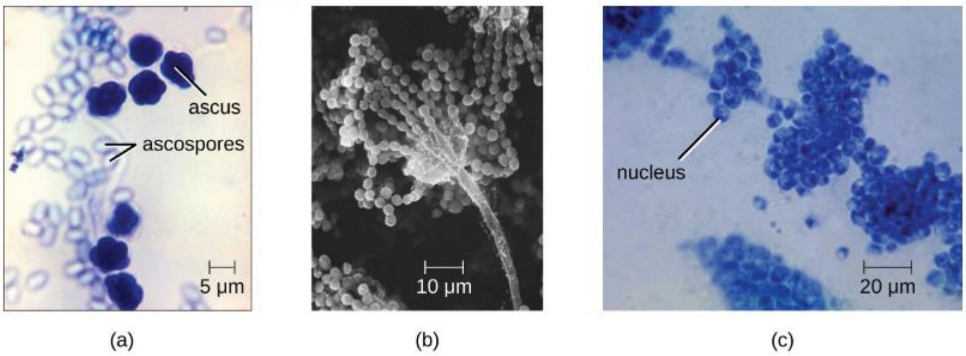


Figure 6. (a) This brightfield micrograph shows ascospores being released from asci in the fungus Talaromyces flavus var. flavus. (b) This electron micrograph shows the conidia (spores) borne on the conidiophore of Aspergillus, a type of toxic fungus found mostly in soil and plants. (c) This brightfield micrograph shows the yeast Candida albicans, the causative agent of candidiasis and thrush. (credit a, b, c: modification of work by Centers for Disease Control and Prevention)

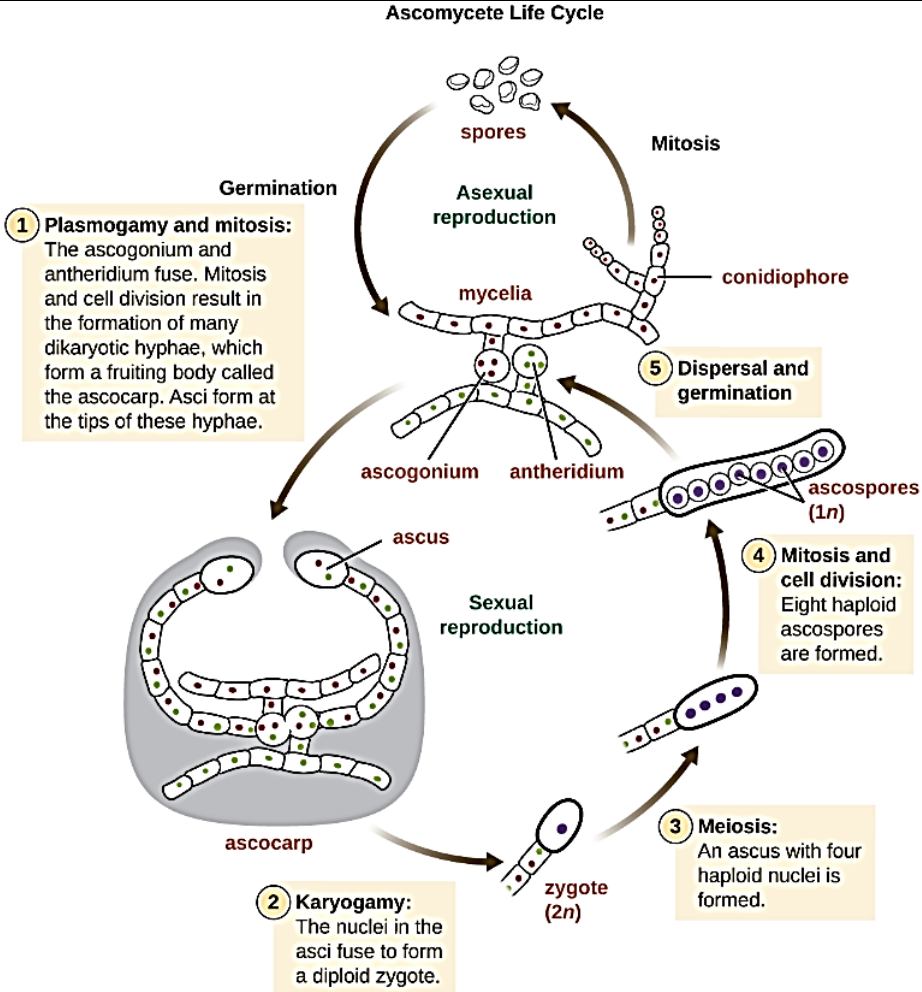


Figure 5.3.7: The life cycle of an ascomycete is characterized by the production of asci during the sexual phase. The haploid phase is the predominant phase of the life cycle

Figure 7. The life cycle of an ascomycete is characterized by the production of asci during the sexual phase. The haploid phase is the predominant phase of the life cycle.

The Basidiomycota (basidiomycetes) are fungi that have basidia (club-shaped structures) that produce basidiospores (spores produced through budding) within fruiting bodies called basidiocarps (Figure 8). They are important as decomposers and as food. This group includes rusts, stinkhorns, puffballs, and mushrooms. Several species are of particular importance. Cryptococcus neoformans, a fungus commonly found as a yeast in the environment, can cause serious lung infections when inhaled by individuals with weakened immune systems. The edible meadow mushroom, Agricus campestris, is a basidiomycete, as is the poisonous mushroom Amanita phalloides, known as the death cap. The deadly toxins produced by A. phalloides have been used to study transcription.

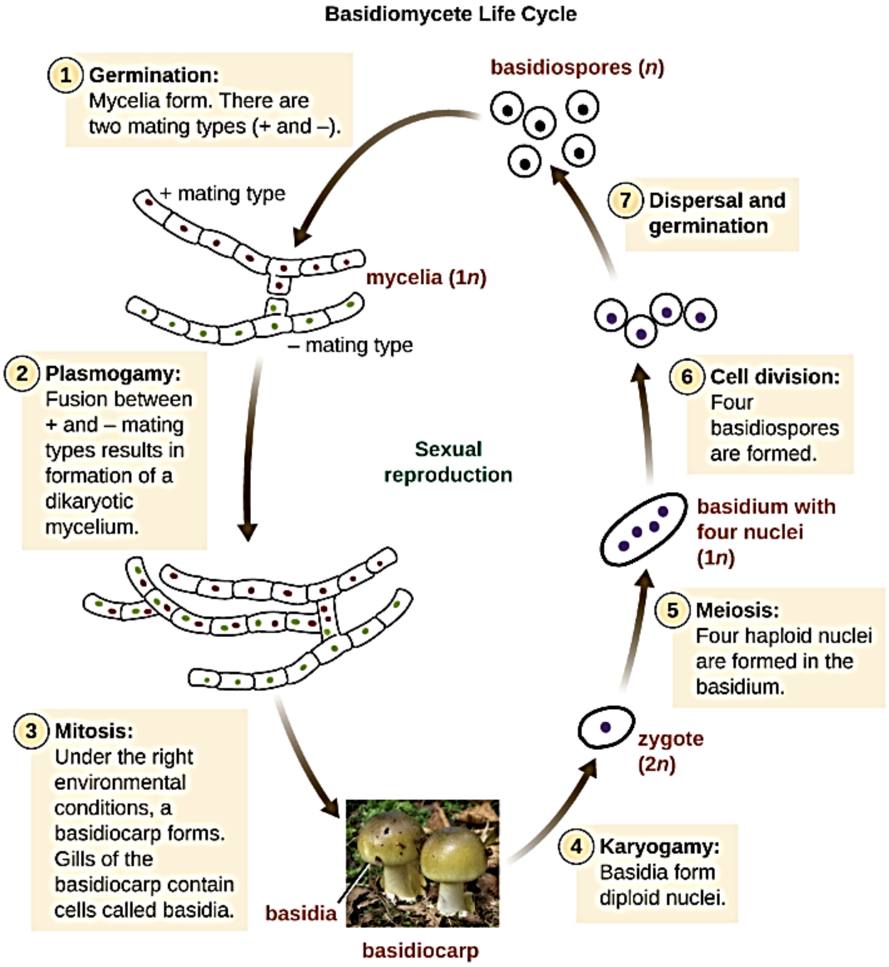
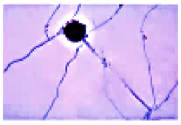
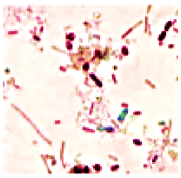
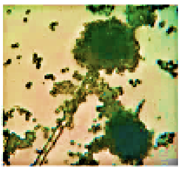


Figure 8. The life cycle of a basidiomycete alternates a haploid generation with a prolonged stage in which two nuclei (dikaryon) are present in the hyphae.

Finally, the Microsporidia are unicellular fungi that are obligate intracellular parasites. They lack mitochondria, peroxisomes, and centrioles, but their spores release a unique polar tubule that pierces the host cell membrane to allow the fungus to gain entry into the cell. A number of microsporidia are human pathogens, and infections with microsporidia are called microsporidiosis. One pathogenic species is Enterocystozoan bieneusi, which can cause symptoms such as diarrhea, cholecystitis (inflammation of the gall bladder), and in rare cases, respiratory illness.

Table 2. Select Groups of fungi

Group	Characteristics	Examples	Medically Important Species	Image
Ascomycota	Septate hyphae Ascus with ascospores in ascocarp Conidiospores	Cup fungi Edible mushrooms Morels Truffles *Neurospora* *Penicillium*	*Aspergillus* spp. *Trichophyton* spp. *Microsporum* spp. *Epidermophyton* spp. *Blastomyces dermititidis* *Histoplasma capsulatum*	 *Aspergillus niger*
Basidiomycota	Basidia produce basidiospores in a basidiocarp	Club fungi Rusts Stinkhorns Puffballs Mushrooms *Cryptococcus neoformans* *Amanita phalloides*	*Crytococcus neoformans*	 *Amanita phalloides*
Microsporidia	Lack mitochondria, perioxisomes, centrioles Spores produce a polar tube	*Entero-cystozoan bieneusi*	*Enterocystozoan bieneusi*	 Microsporidia (unidentified)
Zygomycota	Mainly saprophytes Coenocytic hyphae Haploid nuclei Zygospores	*Rhizopus stolonifera*	*Mucor* spp.	 *Rhizopus* sp.

2 Chapter II/ Notions of plant pathology

2.1 Introduction

Plant **pathology** or **phytiatry** is the science that deals with plant diseases. Phytopathological studies are based on the implementation of the notions of botany, microbiology, molecular biology, genetics, plant biology, biochemistry, plant physiology, ecology, pedology, phytotechnics, toxicology, epidemiology, economics, etc. They cover all the biological, chemical and physical data of a given ecosystem.

The science that studies the causes of disease is called **etiology.** These causes can be external (exogenous factors: environmental factors or pathogens), or internal (genetic mutations).

2.2 History and importance of plant pathology

In the beginning, our ancestors considered diseases to be manifestations of divine wrath or diabolical action, as in the case of *Robigus*, a deity against wheat rust, and animal sacrifices are performed to appease *Robigus*. The philosopher Theophrastus (370-286 B.C.) was the first to write about plant diseases, but his approach was descriptive rather than experimental. Around the 14th century, ergot in rye wreaked havoc in the Russian army, through the consumption of rye flour poisoned by alkaloids from the fungus: *Claviceps purpurea*. In 1846, the introduction into Ireland of the fungus *Phytophthora infestans*, the agent of potato downy mildew, caused mortalities in the population and led to mass emigration to America. It was also phytopathology that made the English tea drinkers, whereas they were coffee drinkers until around 1880, following the destruction of coffee trees by a rust-causing fungus: *Hemeleia vastatrix*, and their replacement by tea plants. In the 19th century, and with the work of Koch and Pasteur, different types of pathogens responsible for parasitic diseases were identified: viruses and viroids, prokaryotes, protozoa, fungi and plant parasitic phanerogams.

2.3 Terminology, specific and useful concepts for plant pathology

A " disease " can be defined as an impairment in the normal development of the plant.

The disease refers to pathological abnormalities produced at the level of phenotypes: symptoms.

The period between infection and the onset of symptoms is called the incubation or latency time.

Symptoms can be:

* Localized: Distributed over a part of the plant or an organ of the diseased plant.

* Generalized: Distributed throughout the diseased plant.

* Systemic: If they extend through the conductive system.

Depending on the speed of evolution of the symptoms, a distinction is made between:

1. Acute illnesses (short time and significant symptoms).
2. Chronic diseases (symptoms reduced for a long time).

Symptoms can result from inadequate ecological conditions: non-parasitic diseases, or they can be caused by parasitic pathogens: parasitic diseases.

Parasitic agents that develop at the expense of a living plant can be infectious (invade and multiply in the host) and contagious (spread from an infected plant to a healthy plant). Microorganisms that grow using dead organic matter as a food base are referred to as saprophytes.

A pathogen is an agent capable of causing an infectious (parasitic) disease.

Pathogenicity is the ability of a pathogen to cause disease.

Since pathogenesis is the period between the time of infection and the reaction of the host plant. It represents all the disease-inducing processes that lead to the expression of symptoms.

Disease control can be curative (by blocking the evolution of the developing disease on the host) or preventive (choice of species and cultivation techniques applied to it, elimination of potential sources of pathogens).

Epidemiology is the study of the spatial and temporal spread of diseases within a population of healthy plants, invaded by a pathogen.

2.4 Different types of plant diseases

Plant diseases can be classified according to several parameters:

- Depending on their symptomatology (wilting diseases),
- Depending on the type of organ affected (conservation diseases, which affect reserve organs, seedling and seedling diseases, root or crown diseases, stem diseases, foliar diseases, etc.),
- Depending on their origin,

Depending on their origin and the factors responsible, Plant diseases can be classified into two groups:

2.4.1 Diseases caused by abiotic factors

(Non-infectious diseases = Physiological diseases)

This group includes diseases caused by non-living agents: non-living diseases parasitic = non-infectious; they are diseases resulting in a general way, from a inadequacy of ecological conditions, they include:

- ***Physiological and genetic abnormalities:*** leaf spots, or chlorotic streaks of genetic origin (necrosis of hybrids).
- ***Alterations related to edaphic factors:*** The physicochemical properties of the soil, in particular, texture and structure, pH, the quantitative insufficiency of certain essential nutrients, as well as the excess of certain minor elements can cause growth alterations and sometimes considerable damage to plants.
- ***Alterations linked to climatic factors:*** water stress (water deficiency and flooding), heat stress (hot and cold), hail, snow, wind and photon stress (lack of light), can be the cause of various anomalies in plants.
- ***Alterations linked to pollutants and human activities:*** air pollution (O3, SO2, F,..), soil and water pollution (nitrate,...), particulate pollution (industrial dust: cement particles), pesticides (fungicides, herbicides, etc.), inadequate pruning and grafting, etc. are all altering factors in growth and development, and can cause considerable damage to plants.

2.4.2 Diseases caused by biotic factors

(Infectious diseases = parasitic diseases)

Diseases caused by live pathogens (fungi, nematodes, viruses, bacteria...) are called infectious diseases (infectious pathogens: invade tissues of the host and multiply). This group brings together:

- ***Fungal diseases:*** These are the most common diseases. They are caused by fungi that attack various organs of the plant. Plant pathogenic fungi belong to different classes:

- **Class of Ascomycetes:** which includes the cereal powdery mildew agent and the ergot agent of rye.
- **Class of Phycomycetes:** which includes the agent of late blight in potatoes and tobacco.
- **Class of basidiomycetes:** where the agents of rusts and smuts are found.
- **Class of Deuteromycetes:** also called imperfect fungi: which includes the agents of fusarium wilt.

- ***Bacterial diseases:*** The number of diseases of bacterial origin is very limited compared to fungal diseases. Phytopathogenic bacteria belong to different genera: *Agrobacterium*, *Corynebacterium*, *Erwinia*, *Pseudomonas*, *Xanthomonas*, etc.

- ***Virus and nematode diseases:*** In plants, viral diseases are less important than fungal and bacterial diseases, but phytophagous nematodes pose a real threat to some crops in infested soils.

- **Pests**

Insects, slugs, birds, and even mammals (rats) can be causing considerable damage to plants.

2.5 Symptoms and abnormalities that may be observed in diseased plants

The symptoms consist mainly of changes in color, alterations of organs, anatomical changes, abnormal production of substances and various alterations in metabolism:

2.5.1 Les modifications de la couleur

Les anomalies de la coloration (Tab. 3) affectent surtout les feuilles, mais peuvent également concerner les fleurs, les fruits, les tiges et les racines.

Table 3 : Anomalies de coloration pouvant être observées chez les plantes malades.

Symptoms	Features and causes
Hypochlorophyllose ou chlorose	The lack of chlorophyll results in a pale green color of the foliage (chlorosis). When chlorophyll is completely absent, yellowing is obtained due to the color of the carotenes and xanthophylls.
Albinism	This phenomenon is characterized by the absence of any pigmentation. It can be of genetic origin, or caused by external factors (herbicides).
Mosaic	The mosaic is characterized by alternating areas of pale or dark green coloration and chlorotic or yellowish zones, two types of mosaics can be distinguished: 1. Marbling: diffusion of separation of greenish and yellowish areas. • Variegation: alternation of different color ranges.

Hyperchlorophyllose	The intensification of the green tint of the organs gives them a bluish appearance. It often corresponds to a phosphorus deficiency or an excess of nitrogen in plants.
Anthocyanose	Elle correspond à un excès de pigments rouge-violacé, et peut résulter soit d'une destruction de la chlorophylle, Soit de la production anormalement abondante des anthocyanes suite à une cause pathologique.
Melanosis	It corresponds to an accumulation of dark substances (melanins) in the tissues.

2.5.2 Organ alterations

Table 4. Organ alterations concern leaves, stems and trunks as well as fruit

Symptoms	Features and causes
Necrosis	Necrosis corresponds to the death of the cells, they often appear over a limited area, but can spread to organs or generalize to the whole plant. Necrosis or necrotic spots on the leaves, at the tips of the stems or on the bark may occur.
Organ perforations	The formation of local lesions on leaves as a result of infections may be followed by falling dead tissue leaving perforations (Screenings: sieve sheets). These perforations can also result from a sudden cause such as hail
Wilting	The wilting comes from an alteration of the conductive system (xylem) by root or vascular parasites. It can be reversible or irreversible
Rots	Rots result from the Decomposition of tissues, following an enzymatic alteration of pectins, cells die, and tissues become the site of colonization by microorganisms (bacteria).

2.5.3 Anatomical changes

Various anatomical changes can be observed in diseased plants, on twigs and stems (Tab. 5), on leaves (Tab. 6), on flowers (Tab. 7) and in growth (Tab. 8 and Tab. 9):

Table 5. Stem and Twig Abnormalities

Symptoms	Features and causes
Fasciation	It consists of an abnormal morphogenesis of the stems that flatten.
Blastomania (Witch's Broomstick)	It corresponds to an abundant proliferation of twigs with shortened internodes and small, often deformed leaves.
Woody nodules	Correspond to woody productions on the surface or inside trunks or branches; they result from folds of the cambium or the differentiation of an internal meristem under the action of a trauma or a parasite.
Cankers (cortical necrosis)	These are localized alterations of the bark of woody plants.
Soft wood	Shaft stems may have a stiffness defect due to a lack of lignification.
Swelling	Stems and twigs may have swollen areas.

Table 6. Leaf Anomalies

Symptoms	Features and causes
Polyphyllie	Consists of a subdivision of the blade of normally simple leaves, an increase in the number of leaflets in compound leaves, or an abnormal increase in the total number of leaves; it is linked to physiological or parasitic disorders.
Enations	Tissue growths can form at the leaf veins, usually as a result of a viral infection.
Miscellaneous anomalies	As a result of parasitic infections or trauma, the leaves may be **thread-like** (blade reduction), **fan-shaped, thick,** curled downwards (Epinasty) or

Table 7. Flower abnormalities

Symptoms	Features and causes
Virescence	The floral parts remain green.
Chloranthia or Phyllody	Transformation of flowers into foliose structures.

Table 8. Growth Anomalies

Symptoms	Features and causes
Dwarfism or **Atrophy**	Reduction in the size of the plant or its organs
Hypertrophy and **Gigantism**	Abnormal growth of certain organs or of the whole plant, following an increase in the size of the cells **(**hypertrophy**),** or following an abnormal multiplication of cells (hyperplasia).

Table 9. Pathological growths

Symptoms	Features and causes
Tumors	Pathological growths with indefinite development, and which may be of parasitic or non-parasitic origin (result of the grafting of certain incompatible species).
Wales	Pathological growths with a defined development, and which can be caused in plants by insects, fungi or bacteria.

2.5.4 Abnormal production of substances

Different types of substances can be produced in diseased plants (Table 9).

2.5.5 Alterations in metabolism

The metabolism of diseased plants can also record various alterations (Table 10).

2.5.6 Internal anomalies

Table 10 shows some of the internal abnormalities observed in diseased plants

Table 10: Some substances produced in diseased plants

Symptoms	Features and causes
Exsudations	The exudation of water or sap from a leaf surface is a normal phenomenon. However, there are cases where its abundance is pathological (bacteria-laden exudates on

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Gummosis	Exudation of an amber-yellow substance that solidifies quickly. Gommosis can appear in some healthy plants, but in the case of abnormally abundant production, it is an indication of pathological disorders.
Resinosus	Symptoms peculiar to conifers, and the Overabundant secretion is a sign of internal pathological disorders.
Latexose	Abnormal latex discharge in latiferous plants can characterize the final stage of certain pathological alterations.

Table 11. Examples of metabolic alterations observed in diseased plants

Symptoms	Features and causes
Alterations in phloemic functioning	The slowing down of the circulation of the processed sap leads to disturbances in the metabolism of carbohydrates, proteins, hormones as well as oxidation-reduction. The leaves concerned are thick, brittle, rich in starch and are generally affected by yellows and/or anthocyanosis.
Alteration of photosynthesis	The lack of light causes chlorosis accompanied by a lengthening of the internodes (etiolation).
Altered breathing	Excess water causes a deficit of oxygen in the soil (asphyxiation). The lack of O2 acts mainly at the root level, as the roots can be the site of anaerobic fermentation with the formation of toxic compounds (sulphides, alcohols).
Altération du métabolisme minéral	Deficiencies or excesses of major or minor mineral elements can cause color changes, root alterations, malformations of aerial organs, as well as changes in the growth and development of foliose organs, flowers and fruits.

Table 12. Internal abnormalities that may be observed in diseased plants

Symptoms	Features and causes
Macroscopic symptoms	When making a cut in a diseased organ, browning, necrosis or internal rot can be observed in the bark or conductive tissues. Internal symptoms may be also observed in roots, seeds, fruits, tubers...

	Thyllose: Thylls are vesicular expansions that form in the xylem from the living parenchymal cells adjacent to it. This symptom is often related to the dieback of the affected plants, following wilting caused by the toxins of a pathogen.
Microscopic symptoms	a polysaccharide that normally covers the inside of phloemic cells and can clog them in the case of certain diseases Excessive production of callose (Cals) can be found in the phloem of stems or tubers of plants infected with certain viruses.
	Inclusions in cells: In the case of some viral diseases, examination under the microscope reveals the presence of various inclusions. The structure of these inclusions can guide the identification of the viruses involved.
	Cell structures in conductive tissues: Microscopic observation through preparations and sections can reveal the existence of bacteria or other parasites in the phloem.

It should be noted **that the same symptom can be induced by different causes:** yellowing can be due to non-parasitic causes (excess water, iron deficiency, lack of light, herbicide,) or parasitic causes (virus, fungus, etc.).

On the other hand, **the same cause can cause very different symptoms**, depending on the variety of the host, the stage and time of infection, the biotic and abiotic conditions of the environment, and the time of observation.

3 Chapter III/ Plant pathogenic fungi

3.1 Reminders about the biology of fungi

These lower plants, eukaryotic, non-chlorophyll (heterotrophic), parasitic, saprophytic or in symbiosis, feed by absorption; unicellular, plasmodian or filamentous; the latter, not partitioned (in the lower fungi) or partitioned (in the higher fungi); absence of real cells or tissues, asexual or sexual reproduction or in several fungi both: propagation ensured by the conidia, the spore, the mycelium or all three; fruiting bodies asexual or sexual.

- ❖ Thallus (the body) in the form of plasmode, its behavior is similar to that of the amoeba. These plasmodia are a protoplasmic mass without clear walls. Fruiting bodies with protective membranes – peridia. ……. Class Myxomycetes.
- ❖ Filamentous thallus, these filaments, also known as hyphae, are partitioned or non-partitioned:

1. (A) Hyphae not septate, rarely septa appear at the base of the reproductive hyphae, presence or absence of flagellate cells in the lower fungal biocycle
2. (B) Flagellate cells present, flagellum 1 or 2, smooth or mastigonemy; in an anterior, posterior or lateral position.
3. (C) Cell with 1 single flagellum; flagellum smooth or mastigonemous, and inserted in anterior or posterior position.

    - **Flagellum 1, posteriorly and smooth. …………… Class Chytridiomycetes.**
    - **Flagellum 1, anterior and mastigonemous........ class Hyphochytridiomycetes.**
    - ○ (BB) Flagellate cells absent, sexual reproduction by the way of cystogamia (gametical copulation), from which results a sexual spore "zygospore" from which the sporangium is produced.... Class Zygomycetes.
    - ○ (AA) Hyphae partitionate, flagellate cells absent. Normally defined number of sexual spores.

- Sexual spores with a defined number, in so-called "ascus" sacs. Asci enclosed in 3 kinds of fruiting bodies 1- Cleistothecis, 2- Perithecia, 3- Apothecia. ………………………………………………….……… class Ascomycetes.

- Sexual spores normally 2 to 4, carried via sterigma on the so-called basidia sacs. ………………………………………………… Calasse Basidiomycetes.
- Sexual reproduction unknown, multiplication (reproduction) carried out by conidia borne directly by hyphae or by different structures formed by hyphae. ………………………………………..…………. Class Deuteromycetes.

3.2 Systematic

The most important groups of fungi are

3.2.1 Lower mushrooms

- Deuteromycetes
- Oomycetes
- Zygomycetes

3.2.2 The groups of higher fungi

- Ascomycota
- Basidiomycota

3.3 The main plant pathogenic fungi

3.3.1 Place of soil fungi

Soil is considered as a living environment, and is the site of a wide variety of interactions between many microorganisms such as viruses, bacteria, fungi and nematodes. The intensification of crops and the reduction of rotations have led to an increase in the number of fungi in the soil and consequently their pathogenic actions.

Soil fungi are fungi that live in the soil or on the surface of the soil, i.e. on plant remains and debris. These fungi cause attacks on the roots, these fungi have been classified into two groups by **Garett**,

1st group: these are the fungi called the soil normal or which are capable of living in a saprophytic state and they are preserved in the absence of the host plant. Example: Rhizoctonia; Pythium; Phytophtora and Cylindrocarpon sp. These fungi have a pest period and a storage period.

There are fungi that cannot live without the host plant and cannot be preserved in the soil:

Example: - Phymatotrichum

- Phomopsis

2nd group: these are fungi that do not keep in the soil unless there is a host plant.

Zones of activity of fungi in the soil:

There are many fungi that are harmful depending on the depth of the soil there are different types of fungi.

1. Surface fungi that destroy seeds and seedlings and cause considerable damage to the crowns and stem bases of plants such as Phytophthora; Fusarium; the Rhizoctona.
2. At a depth of 30 cm there are other fungi that attack roots, bulbs and tubers such as Rhizoctonia and Fusarium. This wilting agent (Fusarium) is found in the deepest parts that can reach a depth of 1 m and attacks the roots of plants and rises into the vascular tissues of plants, e.g. Fusarium oxysporum.

1. Damping-off: causes necrosis of the crowns as well as root rot, which leads to the death of the plant. Damping-off agents are generally derived from the genus Pythium, which has a non-septate mycelium; It becomes very pathogenic under high temperatures and very high humidity (in the presence of very light rains). There are strains from temperate regions that develop at temperatures ranging from 10 to 15°C, and strains from tropical regions that develop at temperatures around 30°C, such as *Pythium debaryanum*. They cause very significant damage to cucurbits, legumes (peas and broad beans) causing a lack of seed emergence such as Rhizoctonia and *Sclerotinia sclerotiorum* which cause (damping-off and sometimes because of very deep sowing) on several crops, especially parsley and celery. *Stemphylium radicinum* and Alternaria which cause rot on carrots on its roots. Fusarium and *Cephalosporium gramineum* cause damping-off and failure to emerge on cereals. There are other fungi in storage areas that cause damping-off of seedlings on cereals and lack of emergence, such as penicillium and aspergillus, which reduce the germination value of seeds (damping-off). Fusarium *roseum* which causes the lack of emergence of cereals (necrosis of the seeds and colored red).

2. Phytophtoras live in the soil and are capable of causing root and crown rots on peppers and peppers as well as on potatoes and tomatoes on the host plant.
3. Septoria (present in the soil): cause pycnidia on Pythiaceae and plum rot on roots and yellowing of the aerial part of the seedlings.
4. *Helminthosporium gramineum* causes damage to, barley
5. *Helminthosporium avenae* causes damage to oats
6. Helminthosporium sativum causes damage to wheat and barley.

3.4 Damping-off damage in forest nurseries

Phytophthora, Pythium, Rhizoctonia and Fusarium, Botrytis are very common species in forest soils and are saprophytic, their parasitic actions from germination to the age of 2 months. They cause necrosis on young tissues, however, fusarium has very significant damage to plant roots, which causes the trees to gradually wilt.

3.5 Vascular diseases (tracheomycosis)

Some soil-dwelling fungi can cause vascular disease. These fungi enter through the roots either from wounds or after necrosis is provoking; The mycelial filament arrives at the level of the vessels and produces fruiting bodies that will be carried away by the sap and cause accumulations of fruiting bodies at the level of the vessels. These fungal diseases are usually caused by various parasitic ascomycete fungi that clog the vessels of the wood by colonizing the xylem tracheids, and the sap no longer rises, causing total or partial wilting of the infected plant. Pathogens include fungi of the genera *Fusarium* and *Verticillium*. These symptoms can be external and internal. These diseases are often known by names derived from pathogens (fusarium wilt, verticillium wilt) or characteristic symptoms (wilting).

3.5.1 External symptoms

Tracheomycoses result in yellowing and wilting of the stems and leaves.

3.5.2 Internal symptoms

After making a cross-section or longitudinal section; There is a brown discoloration at the level of the vessels

3.6 Date palm disease

Also called **Date palm bayoud** is a fungal disease, The term "bayoud" is derived from the Arabic, "white", in reference to the whitish discoloration of the palms affected by the disease, is a Tracheomycosis, or vascular fusarium wilt, whose pathogen is an ascomycete fungus, *Fusarium oxysporum* f.sp. *albedinis*, which affects date palms in North Africa.

The infection occurs through the roots, the pathogen being a soil fungus, and spreads through the xylem vessels to the terminal bud. It leads to a blockage of the circulation of the sap and consequently to the dieback of the palm tree.

Vascular disease on vegetable crops: Verticillium and Fusarium (telluric fungi that can develop in the absence of the host in saprophytic mode for a very long time), in the presence of a susceptible host and favourable environmental conditions of temperature and humidity, the fungus changes its lifestyle from saprophytic to parasite and generally causes tracheomycosis on vegetable crops by blocking their vascular tissues. Three species are very dangerous, including:

- Fusarium oxysporum
- Fusarium solani
- Fusarium roseum

On tomato crops, tracheomycosis can be caused by *Fusarium oxysporum* and *Fusarium lycopersici* (a fungus that only attacks tomatoes "specific to tomatoes"). *Fusarium melonis* that attacks melons, which are responsible for several cases of drying out in open fields and greenhouses. In general, the disease begins with yellowing of the leaves at the base of the plant, which then spreads to the upper leaves. These symptoms can appear on only one side of the stem or leaves, then they generalize to the entire stem where there is a pinkish longitudinal depression that appears at the collar and sometimes goes up to the top of the plant. There is a slowing of the growth of the spinatied plant (phenomenon of curvature of the leaves of a plant downwards due to differential growth of cells between the upper and lower surface of the petioles, in response to certain stresses), and the formation of bulges on the stem. The plant begins to wilt during the hot hours of the day, however, in the evening it regains its turgissence, but later the wilting becomes permanent.

Verticillium

Tracheomycosis agent presented by two species

Verticillium albo-atrum

Is a species of phytopathogenic ascomycete fungi of the family Plectosphaerellaceae, it does not form sclerotic necrosis, it is a species of cold regions and its growth is stopped at 30°C, it is preserved in the soil in the form of mycelial articles. This fungus causes symptoms of yellowing in its various host plants, known as verticillium wilt or verticillium wilt.

Verticillium dahliae

Very formidable in a Mediterranean climate, thanks to these sclerotia necrosis its preservation in the soil can reach 14 years; and develops well at 30°C, however its optimum virulence is between 18 – 24°C, which allows it to survive during the hottest summer periods. Unlike the strains of Fusarium oxysporum, it is capable of invading vessels of many species such as (eggplants, peppers, potatoes, melons, cucumbers) and causes very great damage to apricot trees and some weeds such as amaranth and black nightshade.

Symptoms: manifestation of black beaches with dull translucent and soft edges on the leaves, which turn yellow then necrotic and cover 1/3 of the leaf.

Internal symptoms: greyish (black) discolouration of wood

Other diseases affecting date palm in Algeria:

1. Streak disease caused by (*Diplodia phoenicum*) family Botryosphaeriaceae which is part of the Ascomycetes group.
2. Date palm heart disease (Rot) caused by (*Phytophthora palmivora*) of date palm the foliage dries out and becomes very brittle. The central bud dies.
3. Inflorescence rot by Mauginiella on date palm
4. Anthrax caused by Aspergillus niger

All of these diseases are caused by Fusarium sp. Albidini since 1932 causes bayoud in Morocco which is tracheomycosis caused by Fusarium albidini.

Fusarium oxysporum

Is a species of ascomycete fungus in the family Nectriaceae. As with all *Fusarium*, it is the asexual reproductive form of an ascomycete, but its teleomorph is unknown.

Fusarium oxysporum is a complex of terrestrial, ubiquitous, plant-parasitic species, including many *special forms* (f. sp.), which collectively infect more than 100 different hosts, causing significant economic losses in many cultivated plants such as banana, cotton, melon, tomato.

3.6.1 Symptoms

Leaden appearance of the palms which becomes whitish in colour generalising over all the palms. On the rachis we observe wet feathers with brownish streaks that progress from the bottom to the top and then become generalized. However, the roots take on a decaying reddish-brown color and few in number and represent the point of penetration of the parasite, the vessels present a brown color. When a palm tree is attacked, its death is obvious and takes place within varying time frames. This fungus is distributed in the soil in a very heterogeneous way and is preserved for a long time on plant debris. The number of germs found in the soil must exceed a certain threshold for it to cause fatal contamination.

When the pest enters the date palm, it progresses from the bottom to the top and can invade the rachis of the leaves and the shoots. The tree can take more than 7 years to die; on the other hand, it was not known how long the pathogen took between the attack of the roots and the appearance of symptoms, because a palm tree may appear healthy when it is already contaminated.

3.7 The situation of the Bayoud in Algeria

The disease was introduced from Morocco where all the palm groves were affected, however in Algeria, the most affected regions were those bordering Morocco.

3.7.1 Methods of control

3.7.1.1 Preventive controls

1. Avoid the transport of plant material
2. Irrigated with uncontaminated water
3. Do not plant Djebar in old orchards considered contaminated
4. Avoid intercropping, especially henna.
5. Disinfect the tools of the work.

3.7.1.2 Healing control

1. Apply systemic fungicides (products circulating with sap).
2. Disinfect the floor
3. Planting bayoud-resistant varieties, including Deglet Nour

3.7.1.3 Biological control

1. Fusarium is controlled biologically by antagonistic species.

3.8 Fruit tree diseases

3.8.1 Localization of diseases on plants

Each disease can affect different places from one tree species to another.

Example: pear septoria is limited to the leaves only; while pear scab attacks all aerial organs

Symptoms: Vary according to the period of attack and the organ attacked. E.g. black spots on the leaves and pustules and cankers on the twigs; Tracheomycosis attacks all the vessels in the wood of the tree and the symptoms can spread over the entire tree.

Causes of Fruit Tree Diseases

These causes can be physiological, the origin of which is unknown, or linked to the presence of a parasite. These diseases can be due to poor environmental conditions or to nutritional disorders that cause physiological disorders in the plant.

There are accidents that are due to physical conditions are injuries caused by pruning, animal bites, injuries caused by work instruments especially pruning as well as damage or injuries caused by frost.

Unfavourable soil conditions such as excess water or moisture, drought and soil conditions.

3.8.2 Physiological diseases

Some symptoms of diseases have been caused by deficiencies in trace elements; these deficiencies result from the absence of one or more chemical elements in the soil. The antagonistic action of another element which prevents the first element from being absorbed by the plant, the insolubilization or fixation of elements which cannot be absorbed by the plant.

3.8.3 Diseases related to the presence of parasites

Due to the presence of bacteria and viruses that promote the contamination of the plant by the fungus.

1. **Sudden dieback** that can be due to root asphyxiation, lack of water, fungi such as root rot, fusarium and verticillium wilt.

2. **Collar and root symptom**: due to root decay or rot, root rot, tumours and scabs on the crown and roots. Some bacterial diseases cause tumors on the roots or stems. There are physiological causes in the roots and necks.

3. **Symptoms on the trunk and branches**: appearance of dryness of very different origins and cankers of fungal origin; bacterial or physiological for example Bacterial **canker** is a disease that is often present in fruit trees such as chestnut, cherry, apple or plum trees. It is caused by a bacterium called *Pseudomonas syringae*. Monilias; causes cankers; *Taphrina cerasi* causes cankers on cherry trees

4. **Mould and drying** of fungal or bacterial origin.

- Des tavelures liées au développement de Venturia inaequalis
- Des cloques causées par Taphrina sur pêcher.
- Des nécroses foliaires sont des tâches arrondis sur les feuilles.
- Des criblures sur les feuilles par coreinium
- Des rouilles sur poirier ou cognassier
- Des feutrages blanc (poudreux) sur pommier et poirier.
- Des chloroses (feuilles jaunes) liée avec carence en fer.
- Des nécroses sur les bords des feuilles dû à une carence en potassium

1. Symptom on flowers

There may be a drying of the petals or even of the entire flower or of the floral bouquet, caused in particular by Monilia or Botrytis of the petals on whitish apple and pear trees following an attack of powdery mildew.

2. Symptom on fruit

Scabs have irregular blackish spots that cause cracking.

Rusts on pear and quince trees

Rots on plums in the form of a pouch in the case of Taphrina pruni which causes the deformation of young fruits and which contains a stone

Formation of cork on fruit: due to physiological diseases or parasites or linked to frost.

Note: A symptom can have a wide variety of origins

3.8.4 Classification of diseases

There are thousands of diseases in plants

3.8.4.1 Classification of diseases according to symptoms:

Each crop is susceptible to one or the other pathogen. Often, diseases are classified according to observable symptoms.

Example

1. Root rot
2. Cankers
3. Wilting
4. Anthracnose
5. Rust
6. Charcoal

3.8.4.2 Classification of diseases according to the organs affected

Example

1. Root diseases
2. Stem and crown diseases
3. Fruit diseases

3.8.4.3 Crop Classification of Diseases

1. Field crop diseases
2. Diseases of vegetable crops
3. Diseases of ornamental plants

Remark

From the point of view of pedagogical life, diseases are considered by Abiotic Disease; Infectious; non-infectious.

1. Physiological abiotic diseases due to lack of nutrients
2. Mineral toxicity
3. Lack or excess moisture at ground level
4. Low or rising temperature
5. Lack or excess light
6. Lack of oxygen
7. Air pollution
8. Acidity or alkalinity of the soil.

Fusarium wilt

1- Presence of toxins in the seeds.

*Fusarium wilt, which affects yields but also the sanitary quality of the harvest by the presence of toxins in the seeds

This endemic disease is caused by a complex of plant pathogenic fungal species.

1. "The Fusarium complex" with a broad host spectrum (Miedaner, 1996).
2. It includes the genera Microdochium and Fusarium, which include 19 species capable of inducing fusarium wilt.
3. Strains of the genus Microdochium are not toxigenic.
4. In contrast, Fusarium species are capable of producing a wide range of mycotoxins of the trichothecene family, the most common of which are Deoxynivalenol (DON) and Nivalenol (Niv) (Leonard and Bushnell, 2003).
5. The variability of this disease, in terms of its incidence and mycotoxin production.

Poses many problems in agriculture and agri-food.

In general, the relationships between disease levels observed in the field, mycotoxin concentrations at harvest and the presence of fungus in grain are complex and poorly understood.

Thus, the presence of fusarium-damaged ears would not always be linked to an abundant presence of toxins and, conversely, the absence of visible symptoms does not mean an absence of toxins in the seeds. This makes it difficult to assess the risk associated with the presence of toxins by simply observing the disease.

3.9 Main plant pathogenic fungi

3.9.1 Potato downy mildew (Laite blight)

Introduction

Potato downy mildew, *Phytophthora infestans*, belonging to the class of Oomycetes, order Peronosporales and the family Pythiaceae, is the main enemy of potato producers, was responsible for the great European famine of the 1840s which particularly hit Ireland and the Scottish region, this fungus attacks the **Leaves, stems, tubers and young plants**. It reduces the yield by up to 50% in the event of early attacks. It also has an impact on quality: influence on size, dry matter content, development of bacteria, poor storage in storage.

Life cycle of the fungus

The spores develop on the leaves, spreading throughout the crop when the temperature exceeds 10°C and the humidity level is 75%. Rain can carry the spores into the soil where they can infect young tubers. The spores can also be carried by the wind over long distances.

Overwintering occurs spores on infected tubers, especially those left on the ground after the previous year's harvest, or stored in piles, and are rapidly disseminated in hot, humid weather. This can have devastating effects by destroying entire crops.

Facteurs favorables

Factors favourable to downy mildew include:

1. Temperatures of around 10 – 20°C,
2. High humidity
3. Dense vegetation

Symptoms and damage

In the presence of a favorable temperature and a favorable humidity level, the fungus which appears in the potato plots in isolated outbreaks before spreading and becoming widespread throughout the plot. The first symptoms can be observed from March.

- The young shoots are covered with white down; they disappear quickly as well as the mother tuber.
- On the terminal clusters, the apical leaves turn brown, curl up and then dry out (Fig. 10).
- On the upper surface of the leaves, discolored spots of oily appearance then brown with a light green border appear (Fig. 10).
- On the underside of the leaves, a white down appears around the edge of the necrotic area.
- The stems have purplish-brown necrosis which may be covered with a corresponding fine white felting to the fruiting bodies of the fungus.

- At harvest or a few weeks later, the inside of the tubers has brown rust-coloured spots of diffuse shape with firm flesh (dry rot) (Fig. 10).

Figure 9: Potato tuber affected by late blight (Photo on Wikipidia)

Figure 10. Mildew symptom on leaf (Photo Wikipidia)

Control

In all cases, the fight must be preventive

1. Using Healthy Plants
2. Planting resistant varieties
3. Destruction of waste piles
4. Good ridging and fungicide protection ensured until haulm removal
5. There are many chemicals that are effective against downy mildew
    1. Copper products
    2. Contact fungicides
    3. Penetrating fungicides; diffusing or systemic

Note: the application of products must be reasoned according to the type of epidemic risk, the risk of resistance to certain fungicides and the sensitivity of the variety.

3.9.2 Alternaria in potatoes

Less well known than downy mildew, alternaria can cause yield losses, especially when the disease manifests itself early.

At least two species of the genus Alternaria can affect potatoes in France: *Alternaria solani* and *Alternaria alternata*.

Leaves

The disease usually attacks the foliage of the potato after flowering, starting with the lower leaf levels. It can cause early senescence of plants. Alternaria occurs on leaves as brown necrotic spots of varying size, with concentric rings on large spots (Fig. 11).

Figure 11. Alternaria in potatoes: symptoms on leaves

3.9.2.1 Symptoms

Tubers
During storage, depressed brown spots may appear on the tubers.

3.9.2.2 Enabling factors

The disease is favoured by **alternating dry and wet periods** and by **crop stress** (drought, insect attack, nutritional deficiency, etc.).

The intensity of the disease is not related to the pressure of the inoculum in each cycle, but to the **succession of close cycles**.

3.9.2.3 Means of control

Alternaria is a little-known disease to date, particularly with regard to its storage and contamination conditions.

Agronomic measures are essential in the fight against early blight:

1. Limit inoculum conservation by **removing crop debris**
2. **Choosing less susceptible varieties**
3. **Limit stress** (deficiencies, water stress)

Chemical control can counter an attack of alternaria from flowering.

3.9.2.4 Harmfulness

Generally, not very high; Yield losses can become significant in the event of a very early attack. They then reach 5 to 20% of the harvest, or even more than 50% in some cases.

3.9.3 powdery mildew

3.9.3.1 The causative agent of disease is *Erysiphe necator*

Is a microscopic filamentous fungus of the division of the Ascomycetes, an obligate parasite strictly subservient to the Vitaceae, essentially the genus Vitis. It is responsible for powdery mildew in the vine (called white), one of the major diseases of vineyards.

Native to eastern North America where it parasitized native vines, it was introduced to all parts of the world where European vines are grown.

Classification: Fungi, Ascomycota, Leotiomycetes, Leotiomycetidae, Erysiphales, Erysiphaceae.

- Synonyme : Uncinula necator (Schwein) Burrill, (1892)

3.9.3.2 Biology

Erysiphe necator is an obligate external parasite of the vitaceae, which develops in the form of mycelium on the surface of tissues. Figure 2 Primary contamination from forms of winter conservation can be of two types:

1. Mycelium overwintering in infected buds that colonizes the young growing twig as soon as it forms. This results in the presence of abundant white-grey mycelium at the base of the stem of the twig and leads to the symptom called "flag" (figure 3 These facies are frequently observed in southern vineyards, particularly on the Carignan grape variety (Montarry et *al*. 2009 and 2010).
2. Viable cleistothecia maintained on the bark of the vines. They expel their ascospores when climatic conditions are favorable, under the effect of rainfall (from about 2 mm) with a minimum temperature of around 10°C (Gadoury et al., 1988; 1990) (figure ....). In the Bordeaux vineyards, the ejection of ascospores can be spread over time, over a period of several months between March and June (Clerjeau, 1995; Jailloux et al., 1999). Ascospores infect the tissues of affected organs when they are sensitive and then produce a mycelium network.

3.9.3.3 Enabling factors

1. Climatic factors

Temperature plays a decisive role in the phase of infection by the spores and on the development of the mycelium. The optimum is between 20 and 25°C, the parasite can maintain itself between 6 and 35°C.

Rain, which is rather harmful to the parasite, affects the ejection of ascospores, the dispersal of spores and essentially the increase in humidity that it causes, an element that promotes the growth and sporulation of the fungus.

The wind favors the dissemination of spores but can disrupt the infection and the development of the disease by the drying effect it exerts on the ambient air in the vineyard.

Finally, direct light, and more particularly UV (B) radiation from the solar spectrum, is harmful to the parasite (Willocquet et al., 1996).

For all these reasons, the disease first manifests itself in a discreet way, mainly on the underside of the leaves, and prefers to develop in shaded areas inside the vegetation.

3.9.3.4 Plant sensitivity

The main grape varieties grown are sensitive to powdery mildew. The only sources of genetic resistance to powdery mildew are found in Vitis of American and Asian origin (Gee et al., 2088; Calonnec et al., 2013b).

In general, all herbaceous organs of the vine are susceptible to infection with powdery mildew, especially in their juvenile stage. The sensitivity of powdery mildew to host tissues and their ontogenic resistance, on leaves (Doster and Schnathorst, 1985) and on clusters (Ficke et al., 2002 and 2003, Gadoury et al., 2003), makes this pathogen particularly vulnerable to changes in plant development (e.g., position of sensitive tissues at key phases of the epidemic).

Rationale for protection

Powdery mildew is the disease that is generally well controlled by protection for the period of susceptibility of the bunches (until closure) and control programmes usually provide for the start of pre-flowering treatments (Collet, 1995; Speich et al., 2001).

Pre-flowering protection: allowing the prediction of primary contamination, it is illusory to want to apply fungicides preventively to these contaminating events. In addition, numerous experiments have shown that it is unnecessary to systematically protect vegetation from the initiation of the disease. Indeed, it is quite possible to tolerate a certain level of disease on the foliage without affecting the quality of protection of the bunches (Calonnec et al., 2004). In the vast majority of situations, a single pre-flowering treatment is sufficient. Nevertheless, in a context of strong parasite pressure (many primary foci) an early start of treatments (4-5 leaf stage) can bring a significant gain in efficiency. Visual detection of early symptoms or taking into account plot history. Indeed, plots regularly attacked on the bunches are indicative of situations favourable to the expression of the disease early in the season.

Flowering treatments remain essential, given the high receptivity

Young berries and the impact of contamination at this stage on harvest damage. These applications must be carried out with the utmost care and take into account the fungicide efficacy methods (Delière et *al*., 2010). As the closure approaches, the bunches are no longer receptive to powdery mildew contamination, but it is possible to note a certain progression of the already existing outbreaks until veraison. Treatments applied after this stage are therefore useless when the situation is healthy, but can bring a gain in effectiveness when a significant proportion of the bunch's present mild symptoms.

3.10 Some plant diseases in the El-Oued region

Early blight in tomato (***Alternaria solani***) – Deuteromycota -

Bayoud (***Fusarium oxysporum* sp)** – Deuteromycota -

late blight in potato (*Phytophthora infestans*) - Oomycetes -

Downy mildew in vine (***Plasmopara viticola***) **-** Oomycetes –

Botrytis bunch rot **in vine (*Botrytis cinerea*)** – Deuteromycota -

Powdery mildew (*Uncinula necator*) – Ascomycota -

Verticillium wilt of cucurbits (***Verticillium dahliae***) –Deuteromycota

Cucurbit rot (***Chaonophora cucurbitarum***) – Zygomycota –

Pomegranate rot (***Rhizopus stolonifer***) – Zygomycota -

Peach leaf curl (***Taphrina deformans***) – Ascomycota -

Silver leaves of citrus fruits (***Sterum purpureum***) – Basidiomycota -

Sieve leaves of the apricot tree (***Stigmina carpophila***) – Deuteromycota

Moniliosis on apricot trees (*Monilia laxa*) – Deuteromycota -

Moniliosis on plum tree (***Monilia fructigena***) – Deuteromycota -

Damping-off on wheat (***Pythium gramineum***) – Oomycetes -

Coals on wheat (***Ustilago tritici***) – Basidiomycota -

Brown rust on wheat (***Puccinia graminis***) – Basidiomycota -

Apple scab (***Venturia inaequalis***) – Ascomycota -

Downy mildew of cruciferous plants (***Peronospora parasitica***) – Oomycetes -

Rhizoctonia of the cruciferous (***Rhizoctonia solani***) – Deuteromycota -

Anthracnose on tomato (***Glomerella lycopersici***) – Ascomycota –

Pear canker (***Botryosphaeria quercuum***) – Basidiomycota –

Peach tree burns (***Nectria cinnabarina***) – Ascomycota –

Septoria on Hordeum (***Septoria nodorum***) (Imp.) – Deuteromycota -

Celery leaf spots 'Ombellifères' **(Cercospora apii)** – Deuteromycota .

4 Chapter IV/ Non-parasitic causes of plant diseases

4.1 Introduction

Climatic and edaphic conditions influence the entire life of a plant: by ensuring an environment favourable to its growth and development, or by subjecting it to biotic or abiotic alterogenic factors.

The concept of physiological diseases expresses metabolic disturbances, growth retardation or developmental abnormalities resulting from abiotic causes, which are not transmissible from one plant to another.

Non-parasitic (abiotic) causes that affect plants include:
- Climatic factors (variations in temperature, water, wind, light, etc.)
- Edaphic factors (physicochemical properties of the soil, nutrients, etc.)
- Factors related to human activities (pollutants, pesticides, size and manipulations excessive).

The term " stress " is often used to refer to alterations of abiotic origin in plants (water stress, salt stress, heat stress, etc.). Depending on the intensity of the stress, the duration of its action and the sensitivity of the plant species affected, stress can have two types of effects:

+ Direct and irreversible effects, which cause rapid damage, and the exposed plant can wither away in a few minutes (in the case of rapid freezing where the formation of ice crystals leads to the destruction of the cytoplasm and the rapid death of cells).

+ Indirect and reversible effects, not destructive in themselves, but whose prolonged action can lead to irreversible effects, causing significant damage or death of the plant (in the case of a rise in temperature, without causing direct effects on the exposed cells, can promote transpiration and indirectly cause water stress, which will be harmful to the cell and the plant as a whole.

4.2 Different types of abiotic stressors in plants

4.2.1 Climatic factors

4.2.1.1 Temperature

- *Excessive temperatures:* in the case of high temperatures, the symptoms observed are due to evapotranspiration exceeding the quantities of water supplied by the conducting system. The cytoplasm becomes dehydrated, the leaves lose their rigidity and wither, the chloroplasts are destroyed inducing chlorosis and necrosis.

As soon as the temperature reaches values that inhibit photosynthesis (> 35°C), the accumulation of reserves stops and the plant consumes more carbohydrates than it produces, resulting in a halt in growth.

In cereals, the effect of warm periods in the milky stage, results in ears containing small, wrinkled grains and in reduced numbers, this phenomenon is known as scalding, leading to the formation of scalded grains.

- *Low temperatures:* the effects of cold depend not only on the minimum intensity of the temperature, but also on the nature and duration of the cooling, as well as on the resistance or sensitivity of plant species to this type of stress.

Cooling where the temperature is 0 to 5°C leads to a reduction in metabolic activities and alters the pigments, which results in chlorosis, the formation of red anthocyanins, leaf curling, etc.

4.2.1.2 Frost

Some plant organs, such as seeds, spores and pollen, subjected to temperatures close to zero, survive because they are dehydrated. Organs that are normally hydrated are less resistant and suffer irreversible damage. This damage is due to the formation of ice crystals in the cell or in the intercellular spaces.

4.2.1.3 Water stress

- *Water deficit (drought)*

The water deficit results in dehydration and withering. The direct effect of drought is the dehydration of cells, which remains reversible up to a water limit. Beyond this hydration threshold, the cell will no longer be able to re-soak itself and the damage will be irreversible. Drought can be marked by a stunted growth of the aerial organs as well as the roots.

Effects of drought include protein disorganization, alteration of enzymes, decreased phosphorus content, increased respiration, and decreased photosynthesis and translocation of metabolites.

- Excess water (flooding)

Excess water creates anaerobic conditions that impair the metabolic functions of the roots and can cause wilting. During floods, the roots are placed in an asphyxiated environment that inhibits their growth. Plants can survive periods of anaerobic conditions up to 0.5% O_2; roots require 6 to 8% O_2 to grow normally. Below these values the leaves become chlorotic, growth stops, the formation of new roots stops, the stems dry out and the plant dies. Transpiration can decrease by 90%, which limits the absorption of water and mineral elements and leads to a decrease in photosynthesis.

4.2.2 Radiative factors

4.2.2.1 Light

In plants, light intervenes both by providing energy for photosynthesis, and in growth (photoperiodism) and development (floral induction, dormancy lifting, etc.). For light, three aspects must be taken into consideration: intensity, quality and periodicity.

- Light intensity: For each plant species, there is a minimum light intensity, called a " *light compensation point"*, necessary for photosynthesis and plant growth. This compensation point varies depending on whether they are shade species, or so-called sun species.

In the absence of light, or at intensities below the light compensation point, etiolation is observed, characterized by a decrease in photosynthesis, a decrease in weight due to depletion of reserves, and a considerable elongation of the internodes (due to excessive elongation of the cells), and the leaves become chlorotic.

If the intensity of the light is very high, photosynthesis is greatly reduced, because there is photo-oxidation of chlorophyll, a substance essential for photosynthesis. Symptoms on the leaves consist of brownish spots, sometimes accompanied by drying of flowers and fruits.

- Light quality: Within a vegetation canopy, each vegetation level is exposed to a different light both quantitatively and qualitatively: the lower levels receive low radiation and low in bioactive radiation, because of the absorption of the wavelengths favourable to photosynthesis (red and blue) by the foliage of the upper parts.

- Periodicity of light: The photoperiod or period of illumination can affect the development of the plant. Deviations from requirements can lead to abnormal growth, flowering inhibitions and yield losses.

4.2.2.2 Ionizing radiation

Ionizing radiation (nuclear energy) can cause chromosomal alterations, disruptions of cytological structures, loss of membrane permeability and various effects at the molecular level.

4.2.3 Edaphic and trophic factors

The soil is the normal medium for the supply of mineral substances and water to the plants, as well as the substrate for root growth. The ions from the soil are distributed, according to the quantities found in the plant tissues, into:

- **Major elements** (N, P, K, Ca, Mg, S), greater than 0.1% of dry weight.
- **Minor elements** (Fe, Zn, Mn, B, Cu, Mo, ...) that are found in small quantities.

If the concentration of these elements is in excess or deficit compared to the optimum, characteristic symptoms and growth abnormalities will be observed.

4.2.3.1 Soil salinity

It can be caused by an overall excess of salt or by an excess of a specific ion:

- Salinity due to sodium (Na+): In nature, most cases of salinity are due to sodium salts and especially NaCl. Halophytic plants, living in salty areas, accumulate significant amounts of salt in their tissues without being affected by this salt. On the other hand, glycophyte (sensitive) plants are eliminated from these areas and can have several damages, and sometimes even the death of the plant which can be due to:

1. A direct effect of salt: phytotoxicity
2. An indirect effect of salt: modification of osmotic pressure and nutritional imbalance.

A plant subjected to this type of stress suffers from osmotic dehydration (physiological dryness), which results in a loss of turgidity, stunted growth, leaf drop and yield drop. The excessive presence of Na+ ions in the soil inhibits the uptake of other ions, including K+.

- Salinity due to calcium (Ca++): Excess Ca++ ions increase the pH of the soil, and immobilize other ions. Based on their sensitivity to calcium salts, plants are classified into:

1. Calcifuge plants: not tolerant
2. Limestone plants: which solubilize or precipitate calcium salts.

4.2.3.2 Nutrient excesses or deficiencies and phytotoxicity of certain ions

Compounds taken up by plants from the soil are classified as essential, indifferent or toxic elements. Depending on its concentration, its mobility in the soil, and the presence or absence of other ions, a nutrient present in large quantities can have toxic effects.

Deficiency of one element leads to growth abnormalities, a direct consequence of its deficiency, its immobilization in an insoluble form, or the antagonistic effects of other compounds.

A- Excess ions: The phenomena of toxicity by excess differ according to the elements involved:

- **Zinc (Zn):** toxicity due to excess zinc results in a reduction in root growth and leaf development, with progressive chlorosis; symptoms are similar to those of Mn deficiency. Since Zn is an antagonist of Mn, its excess inhibits enzymes having Mn as a cofactor. The toxicity threshold (500-800 ppm) varies depending on the species.

- **Boron (B):** boron has a very low toxicity threshold (0.5 ppm in water when used in nutrient solutions). In addition to the foliar symptoms (marginal yellowing, brown necrotic spots at the apex and margins of the leaves) inducing yield drops, the main effect is on flowering, which is partially or totally inhibited.

- **Copper (Cu):** excessive Cu levels in soils inhibit root growth and reduce crop yields. The foliage has a chlorosis similar to that observed in Fe deficiency (the replacement of iron by copper inactivates certain enzymes). Excess Cu damages the plasmalemma.

- **Aluminium (Al):** as soon as the concentration of soluble Al in the soil exceeds 10 ppm, phytotoxicity occurs. In rice and cereals, there are small brown spots at the tips and margins of the leaves, short, twisted and discoloured roots.

- **Nickel (Ni):** nickel is toxic at low concentrations (40 ppm). The symptoms are comparable to those of Mn deficiency (internervial and marginal chlorosis of the leaves with small necrotic dots).

- **Cadmium (Cd):** in maize, cadmium has a phytotoxicity threshold of 5 ppm, with a sharp reduction in root growth, followed by a shortening of internodes and a decrease in biomass. In extreme cases (more than 25 ppm), the first leaves that have formed turn yellow, generalized chlorosis of the foliage sets in, followed by progressive withering.

B- Ion deficiencies: The deficiency of certain elements can be the cause of various plant growth abnormalities:

- **Nitrogen (N):** nitrogen needs are very high; the most generalized deficiency symptom consists of more or less intense chlorosis. The gradual disappearance of chlorophylls unmasks xanthophylls and carotenes, so that the leaves turn red or orange; the twigs, stems and sometimes even the bark are red. There is early defoliation, stunted growth, and thin, sparse foliage. Each species reacts in a particular way to nitrogen deficiency; in cereals, tillering is reduced, the stems are red, the grapes are small, of lower quality, with early ripening. In some species of fruit trees, flowering is reduced and the flower buds turn yellow.

- **Phosphorus (P):** phosphorus is used in the constitution of nucleic acids and phospholipids; as it is the essential constituent of energy-transporting cofactors (ATP, GTP, UTP,...). Deficiency symptoms consist of reduced stem and root growth, leaves are small, dark green, with tan highlights and fall off early; Flowering is delayed, reduced or inhibited. The fruits are rare, small in size and of poor quality; Their coloration is variable (with a dominance of green) and their flavor is acidic.

- **Potassium (K):** Potassium is involved in most metabolic processes (synthesis and transfer of carbohydrates; intervenes directly in the mechanisms of cellular permeability; mitosis requires potassium to take place normally, etc.).). Potassium is present in plant tissues at concentrations of 1 to 2% of dry matter. Its deficiency alters photosynthesis, increases respiration and alters chlorophyll synthesis. Internervial chlorosis, a reduction in the lignification of the walls, a fall of the fruits, can be observed.

- **Calcium (Ca):** constituting walls (in the form of calcium pectate in intercellular cement), calcium participates in the maintenance of cell structures, carbohydrate transport, cell permeability, and it is also a cofactor for certain enzymes, and plays a role in the assimilation of nitrates. In case of deficiency, the young leaves are twisted and the blade is chlorotic. Often Ca deficiency is associated with water stress inducing rapid damage.

- **Magnesium (Mg):** Magnesium is present in the chlorophyll molecule, and it is a cofactor in most phosphorylation reactions. Mg deficiency results in a halt in chlorophyll synthesis, chlorosis, sometimes accompanied by orange to red pigmentation, develops in the oldest leaves, then in the youngest. Only the veins remain green. The size of fruits and roots may be altered.

- **Boron (B):** Plants have very low boron requirements; however, its intervention is mandatory in the transport of carbohydrates. Deficiency of this element results in numerous metabolic disorders (disruption of the synthesis or distribution of growth substances, accumulation of sugars in the leaves, premature ageing of the cells, swelling and bursting of pollen tubes, etc.).

- **Iron (Fe):** Iron is a constituent of cytochromes, involved in redox reactions, as it is involved in the synthesis of chlorophylls. Iron deficiency results in chlorosis of the internervian spaces that begins with the youngest leaves; Sometimes chlorophyll synthesis is totally inhibited, the leaves are yellow or white and only the veins remain green. Marginal areas dry out and die, growth is stunted, stems are weakened, and the plant may wither.

- **Zinc (Zn):** zinc is involved in the synthesis of auxin and in the composition of many enzymes. Zn deficiency. Result in chlorosis of the internervian spaces of the leaf blade, a reduction in leaf size as well as in stem elongation (short internodes), often leaf drop is early and yield is greatly reduced.

- **Copper (Cu):** copper is present in many enzymes; it catalyzes electron transfers and certain phases of photosynthesis. Copper deficiency consists of a reduction in the size of the leaves and a blue-green coloration of the foliage. In cereals, there may be an alteration of the floral parts and an inhibition of grain production.

- **Molybdenum (Mo):** Molybdenum is the main constituent of two enzymes in nitrogen metabolism: nitrogenase and nitrate reductase. Mo deficiency is marked as N deficiency; there is a reduction in growth and flowering, and chlorosis of the leaves. In legumes, atmospheric nitrogen fixation is inhibited.

2.2.4. Atmospheric factors

Among the most dangerous agents present in the air of cities and industrial centres are: sulphur dioxide (SO_2), fluorinated compounds, nitrogen oxides, ozone, chlorine compounds, ammonia, dust (cement works), and many other agents that can have harmful and very destructive effects on plants.

5 Chapter V/ Parasitic diseases of plants

5.1 Introduction

Parasitic diseases of plants are caused by living agents. The term "parasitism" is generally used to refer to the relationship or association between organisms generally of different species and in which one partner (parasite) benefits from the other (the host).

Higher plants can be parasitized by different types of microorganisms: fungi, bacteria, viruses, nematodes, etc. and also by parasitic phanerogams.

5.2 Parasitism and the development of diseases

5.2.1 Parasitism and pathogenicity

To elucidate the meaning of " **parasitism** " and " **pathogenicity** ", Several basic concepts must be defined:

- The parasite (from the Greek: *para* = next to it, and *sitos* = food) is an organism that develops on / or in another organism (host) and obtains from the latter the nutrients it needs for its growth and multiplication.

- From the ecologist's point of view, the "attack" of a parasite is not only an aggression since the latter, by the very fact that it inhabits its host, most often has no "interest" in destroying this shelter. The fact that the parasite takes its food on the spot and causes a certain pathology, or even increases the risk of mortality, does not necessarily make it a "killer", but the competition that occurs between the two organisms for water and nutrients generally leads to a decrease in the growth of the host.

- The pathogen is a biological (living) agent capable of causing an infectious disease.

- In many cases, parasitism is related to pathogenicity: the ability of the parasite to penetrate and invade the host's tissues, usually leads to the development of the disease. However, in most diseases, the damage to the host plant cannot necessarily be related to nutrient uptake by the pathogen, but is attributed to toxic substances released by the pathogen or to reactions of the host plant.

As a result, the concepts of parasitism and pathogenicity can be defined as follows:

1. *Parasitism* = removal of nutrients from the host by the parasite.
2. *Pathogenicity* = interactions of the pathogen with one or more essential functions of the host plant (nutrient uptake + secretion of substances by the pathogen + host plant response).

5.2.2 Development of the disease

In all infectious diseases, there is a succession of distinct events that make up the disease cycle, which most often corresponds to the pathogen's development cycle. The development of a disease depends on three factors: the pathogen, the plant and the environment (Fig. 12):

-The plant must be susceptible or predisposed to developing an infection.

- The pathogen, must be virulent (i.e. biologically equipped to infect a plant).

- The interaction between the host plant and the pathogen must occur within a environment conducive to contamination.

The interaction of the three factors mentioned above can be illustrated in a diagram called the " *Triangle of Disease* " (Fig. 12 a).

Some plant pathologists have revealed that the time required for these three factors to interact, and which reflects the "*time required for infection*", is a parameter that must be taken into account in certain plant-pathogen interactions (e.g., spores of *Puccinia triticina*, agent of wheat brown rust, deposited on the leaves of a susceptible host variety, in conditions of humidity and temperature favorable to their growth, require a period of a few hours to germinate and form the structures of infection. This made it possible to add a fourth factor and to propose another diagram illustrated according to the "*Pyramid of Disease*" (Fig. 12 b).

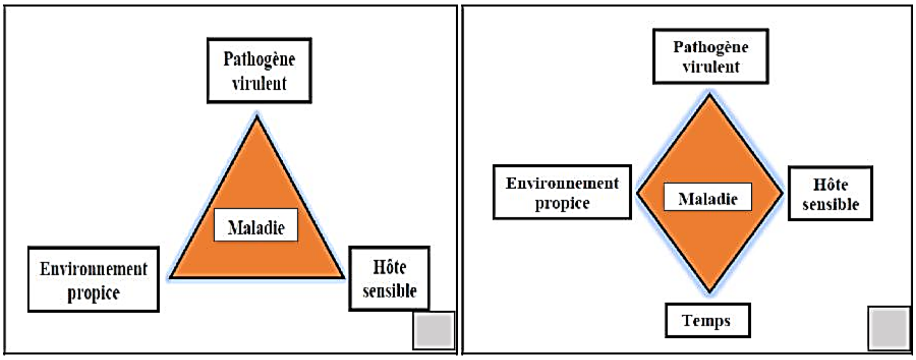

Figure 12. Factors favoring the development of a parasitic disease in plants:
a: " *Disease triangle* ", **b:** " *Disease pyramid* ".

5.2.2.1 Stages of development of a parasitic disease

When the conditions are right, the cycle of the disease goes through the phases Following:

a- L'inoculation (le contact)

Inoculation is the first step in the cycle of disease development parasitic, it corresponds to the contact between the pathogen and the host plant.

" **The inoculum** " which corresponds to "the whole pathogen " or " a part of the pathogen having the capacity to cause infection ", must be present and in sufficient quantity.

Depending on the nature of the pathogen, different types of inoculum can be distinguished:

- ***For fungi:*** the inoculum can be a fragment of mycelium, spores or sclerotia (masses of mycelium).
- ***For bacteria, mycoplasma:*** the inoculum can generally be the whole individual.
- ***For viruses:*** the inoculum can be the whole virus or its nucleic acid.
- ***For nematodes:*** the inoculum can be an adult individual, larvae or eggs of the nematode.
- ***For parasitic phanerogams:*** the inoculum can be formed from parts of the plant or seeds.

The inoculum is called a primary inoculum when it is stored in a dormant stage during the unfavourable season and causes the original infection called the primary infection. Inocula produced from the primary infection are known as secondary inocula and cause the secondary infections.

b- Penetration

The penetration of pathogens into the cells of host plants can

Be done in different ways:

- **Direct penetration**: by physical means, where the pathogen "by force" degrades the cell walls of the host and destroys the cuticle, or by biochemical means, which operates by the release of enzymes that break down plant tissues (pectinases, cutinases, cellulases, hemicellulases, etc.).
- **Penetration through natural openings** (stomata, lenticels, hydathodes, nectarthodes, sites of emergence of new roots).
- **Penetration through wounds**.

A pathogen can have different modes of penetration, for example bacteria penetrate through natural openings or through wounds (Fig. 13). Fungi can enter the cells of their hosts, directly, through natural openings or through wounds (Fig. 14). For nematodes, penetration occurs directly or through natural openings (Fig. 15).

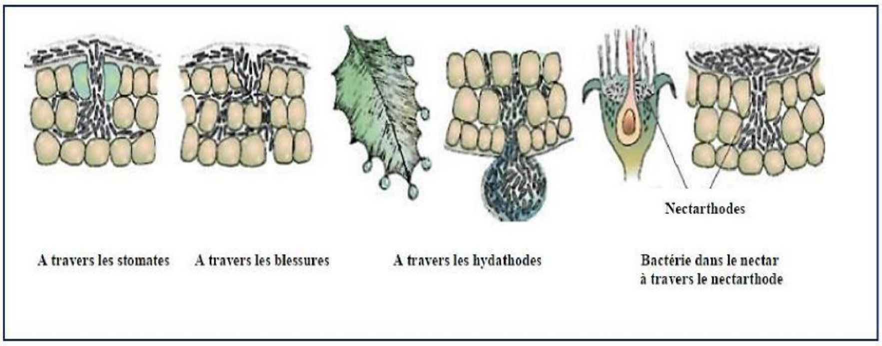

Figure 13. Modes of Bacterial Penetration and Invasion of Host Plants (Adapted from Agrios 2005)

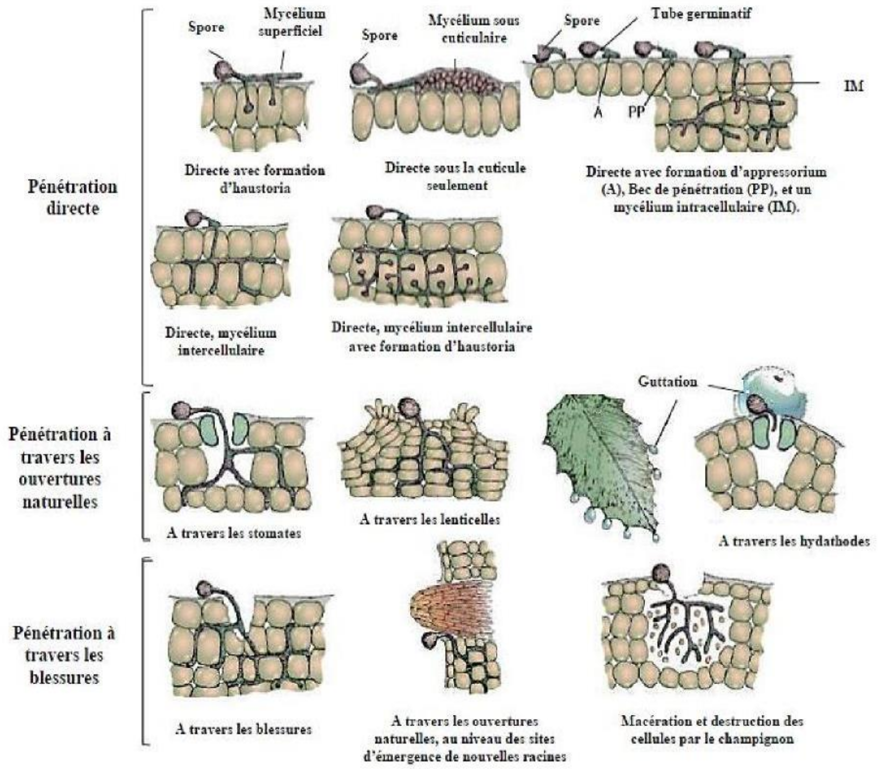

Figure 14. Modes of Fungi Penetration and Invasion of Host Plants (Adapted from Agrios 2005)

1. Infection

It is the process by which pathogens come into contact with the cells and tissues of the host plant to draw their food. During infection, the pathogen multiplies and continues to grow; this is called an invasion. It is during this phase that symptoms appear on the plant. The period between inoculation and the onset of symptoms is the incubation period. This period varies depending on the nature of the pathogen, the host plant and its stage of development, and environmental factors, including temperature.

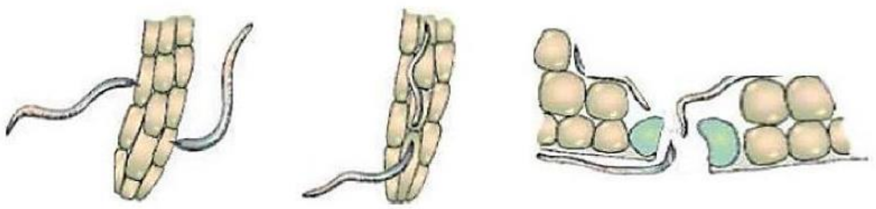

Figure 15. Modes of Nematode Penetration and Invasion of Host Plants (Adapted from Agrios 2005).

1. The growth and multiplication of pathogens

Higher plant parasitic fungi, in general, invade and infect host tissues through their growth and development within cells from an initial point of inoculation. Most of these pathogens, which produce small spots, large areas of infection, or general necrosis, continue to develop until all the tissues of the host have invaded, the infection has become widespread and the plant has died.

> **Modes of propagation:** Plant pathogens reproduce in several ways:

- Fungi reproduce by sexual or asexual spores.
- Parasitic plants of higher plants reproduce like host plants, by seeds and seeds or vegetative.
- Bacteria, mycoplasmas and protozoa, reproduce by cell division (1 individual gives 2 individuals, 2 individuals give 4 individuals).
- Viruses and viroids multiply by cells (code copied).
- Nematodes reproduce through the formation of eggs.

> **Multiplication rate:** The multiplication rate varies considerably with the nature of the pathogen:

- ***For fungi:*** thousands or hundreds of thousands of spores can be produced per Cm2 of infected tissue. Each sporophore can produce thousands of spores.

- ***For bacteria:*** the number of bacteria can double after 20 to 30 minutes, as long as the environmental conditions (more particularly, the temperature) remain favorable, and the host is susceptible.

- ***For viruses and viroids*** : a few hours after infection or detection of the first viral particles, a host cell can contain 100,000 to 10,000,000 viral particles.
- ***For nematodes:*** a female can lay 300 to 600 eggs, among which 50% are also females, and each will give birth to 300 to 600 individuals/generation, depending on the susceptibility of the host, the climate and the cycle of the pathogen. Nematodes can give up to a dozen generations per year.
- ***For parasitic phanerogams:*** the number of seeds formed can be considerable, especially for plants producing small seeds.

e- The dissemination of pathogens

The spread or dispersal of pathogens can take place depending on the several modes (Fig. 16):

- ***Airborne dissemination:*** occurs mainly in fungi or parasitic higher plants where spores or seeds projected a few millimeters from their fruiting orifice can travel hundreds of kilometers with the wind (cereal rusts for example).

- ***Waterborne dissemination:*** Water also plays an important role in the spread of pathogens. Bacteria, nematodes, spores, or sclerotia of fungi present in the soil can be spread by rainwater or irrigation water. On the other hand, bacterial and fungal spores in the air can be transported in rainwater droplets. However, the distance of diffusion by water is not as large as for diffusion by wind (air). However, for this mode of dissemination, the germination of the transported spores is immediate (favourable humidity).

- ***Spread by insects, nematodes and other vectors:*** pathogens can also be spread by:

1. Insects, and more specifically, aphids, are the most important vectors of dissemination for viruses and mycoplasmas (through their transition from a diseased plant to a healthy plant).
2. Bacteria can be carried by nematodes and other animals.
3. Some pathogens adhere to the animals' legs and are spread by them.
4. Bacteria and nematodes can be transported with soil particles.

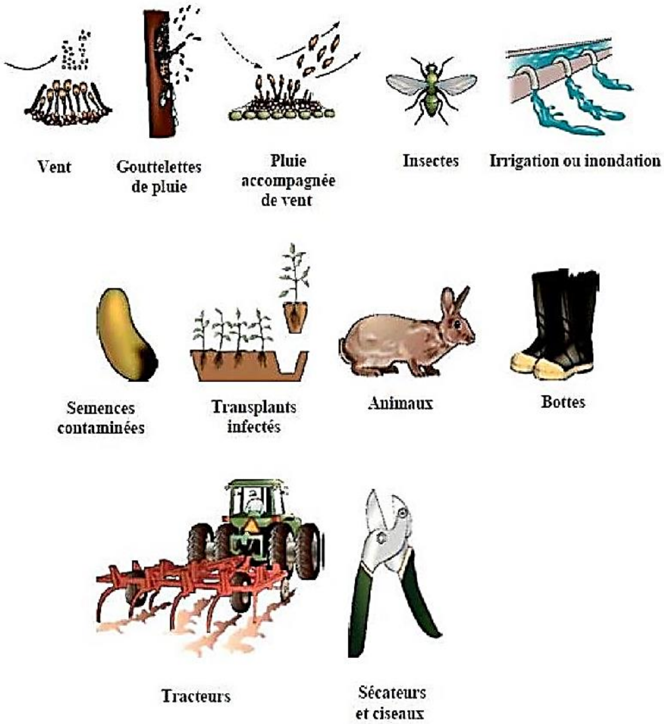

Figure 16. Modes of dissemination of bacteria and fungi (Adapted from Agrios, 2005)

5.2.2.2 Concept of epidemiology

Epidemiology is the branch of plant pathology that studies the spatial and temporal spread of diseases within a plant population.

A phytopathological epidemic encompasses the series of events that follow one another in a plant population invaded by a pathogen: the supply of the inoculum, the contact between the pathogen and the host plant, penetration, infection and the formation of a new inoculum and its dispersal.

Epidemic development implies that this sequence is repeated several times during successive cycles, producing an increasing quantity of disease and inoculum as much as the surrounding conditions, particularly climatic conditions, remain favorable and that the host population remains receptive.

5.3 Parameters to be measured for disease estimation

For the estimation of a disease, three parameters can be taken into consideration:

1. Incidence **:** Incidence is often used to measure the extent of the disease in a field or region.
2. Intensity **:** the evaluation of disease intensities is carried out by quantifying the symptoms or the number of lesions present; it is also called: severity of the disease.

3. Loss: Yield is often used to measure losses caused by a given disease.

5.4 Main groups of plant parasitic diseases

5.4.1 Fungal diseases

5.4.1.1 Characteristics of plant pathogenic fungi

A- Morphology and cytology of phytopathogenic fungi: Like all fungal species, phytopathogenic fungi are thallophytes, non-chlorophyll eukaryotes; the vegetative apparatus (thallus or mycelium) can be partitioned: formed of septate hyphae (Fig. 17), or non-partitioned: formed of siphons (Fig. 17). Cells possess the general characteristics of eukaryotes (Fig. 18). The cell wall contains 80 to 90% polysaccharides associated mainly with proteins and lipids, and chitin is the most important carbohydrate constituent of cell walls (with the exception of phycomycetes, where it is absent). These walls frequently have a dark color due to melanin compounds derived from phenolic amino acids that play a role in infection.

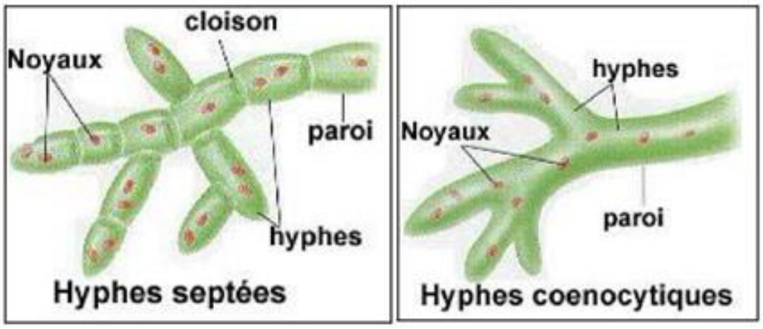

Figure 17. Structure of fungal thalli

B- Lifestyle and nutritional needs: fungi absorb organic and mineral substances in a dissolved state, which they draw from the cells of their hosts; and regardless of their lifestyle (saprophytes, parasites or symbionts) they need:

- Water, mineral salts (PO43-, NO3) and trace elements (Fe, Cu, etc.).
- A source of organic carbon.
- Mineral nitrogen.

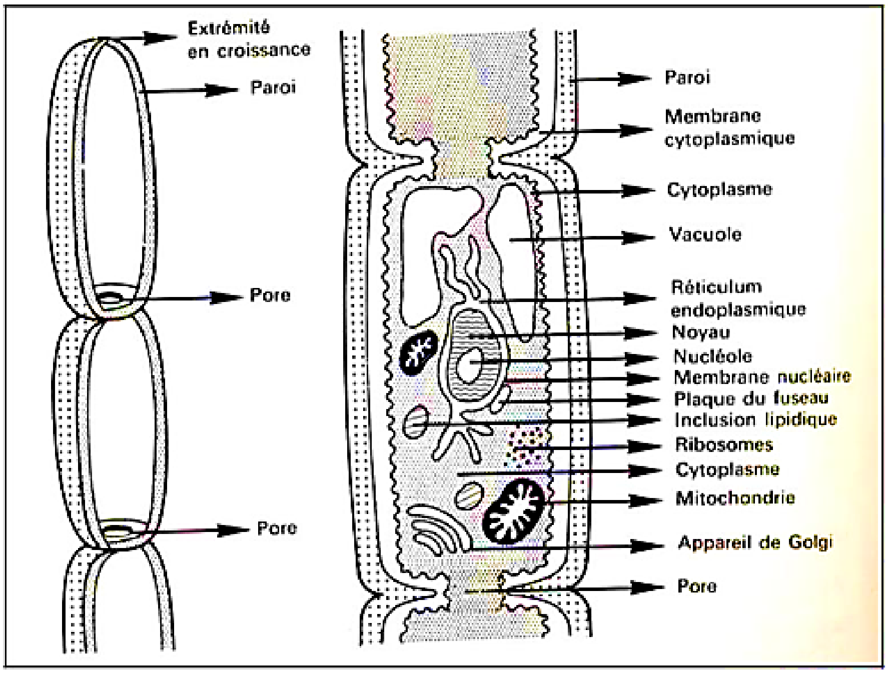

Figure 18. Cytological characteristics of fungi

In the plant kingdom, all taxa can be parasitized by fungi; depending on their degree of parasitism, phytopathogenic fungi can be: facultative saprophytes, obligate or facultative parasites (parasites during one part of their life cycle and saprophytic during the other part). They can adopt a biotrophic, necrotrophic or hemi biotrophic **lifestyle:**

- **Biotrophic fungi (Obligate parasites):** require a living organism to complete their life cycle. It is not in the biological interest of these fungi to cause the death of their host plant, nor to trigger defense reactions. This category of pathogens includes fungi belonging to the orders Pucciniales (rust agents: Fig. 19), Ustilaginales (anthrax agents: Fig. 20) or Erysiphales (powdery mildew agents : Fig. 21).

Figure 19. Symptoms of brown rust (*Puccinia triticina*) on wheat leaf
https://www.bayer-agri.fr/cultures/rouille-brune-10-a-40-de-pertes-possibles-en-ble 1277/

Figure 20. Symptoms of barley hulk smut caused by *Ustilago nuda*

https://www.bayer-agri.fr/cultures/charbon-nu-vehicule-par-lembryon-de-la-semence 684/

Figure 21. Symptoms of powdery mildew (*Blumeria graminis*) on wheat leaf
https://www.agro.basf.fr/fr/cultures/ble/maladies du ble/oidium du ble.html

- **Necrotrophic fungi:** actively cause necrosis of host cells and grow on necrotic tissues. *Botrytis cinerea*, responsible for grey mould in more than 1400 plant species, is the necrotrophic fungus with the greatest impact on crops (Fig. 22).

Figure 22. Symptoms of *Botrytis cinerea*, agent of tomato grey mould

(a) : sur feuilles : https://www.syngenta.es/cultivos/tomate/enfermedades/podredumbre-gris
(b) : sur fruit : https://www.interempresas.net/Horticola/Articulos/98801-Hongos-saprofitos-como-herramientas-de-control-biologico-de-Botrytis-cinerea-en-tomate.html

- **Hemibiotrophic fungi:** require a living host for their vegetative growth, then end up causing the death of this host in order to reproduce on its dead tissues. This strategy is intermediate between biotrophy and necrotrophy. This category includes: *Fusarium graminearum*, a fungus pathogenic to wheat (Fig. 23), *Fusarium oxysporum*, which infects about a hundred species of vegetable crops, *Zymoseptoria tritici*, the agent of Septoria in wheat, and *Colletotrichum* spp, whose host spectrum includes almost all cultivated plants (Fig. 24).

Figure 23. Symptoms of *Fusarium graminearum* on wheat
https://bladmineerders.nl/parasites/fungi/ascomycota/pezizomycotina/sordariomycetes/hypocreales/fusarium/fusarium-graminearum/

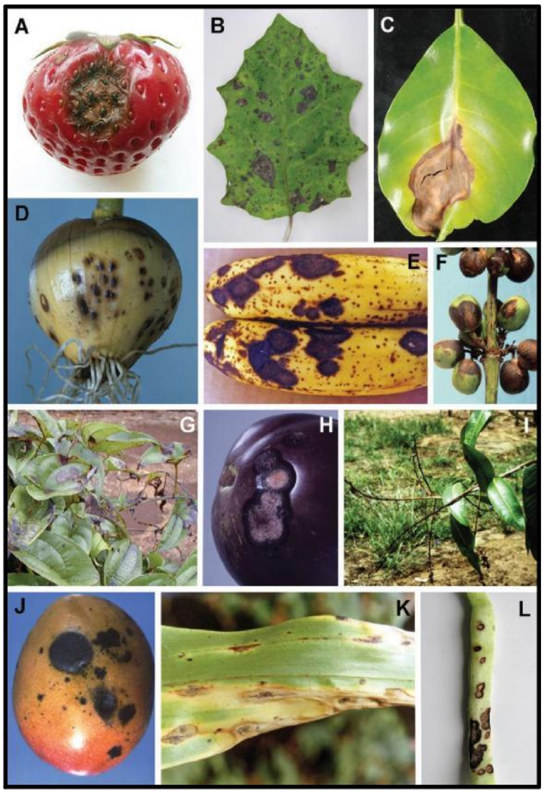

Figure 24. Symptoms caused by *Colletotrichum* spp. on different plant species (Cannon *et al*. 2012)

Some plant pathogens are polyphagous: colonize hundreds of plant species (*Botrytis cinerea*), while others are specialized: infect a few related species, or species of the same family

(*Phytophthora infestans* for nightshades). Sometimes fungal species include " specialized forms " whose parasitism is specific to a single plant species: *Erysiphe graminis* , the causative agent of powdery mildew in cereals, is a single fungal species whose different isolates are capable of infecting more than 100 plant species belonging to 34 genera of grasses, and an isolate that infects wheat (*E. graminis* f.sp. *tritici*), does not infect barley and vice versa; and within the specialized forms one can find "races" or "biotypes", each of which attacks only certain cultivars of a plant species. Table 13 shows some traits related to parasitism in fungi.

Table 13. Parasitism Traits in Fungi

Character	**Optional parasitism**	**Mandatory parasitism**
Routes of Entry	Injury	Stomata, intact epidermis
Infected tissues	Senescent tissues	No restrictions
Mycelium	Pas d'haustoria	Haustoria presence
Host spectrum	Large	Restricted

C- Reproduction: Most fungi have two reproductive modalities: asexual (vegetative) reproduction and sexual reproduction. Most often, the sexual reproductive organs (spores) ensure the conservation of plant pathogenic fungi during the period of vegetation cessation and are the sources of primary crop infection. The asexual forms emit propagules that ensure the secondary spread of diseases (epidemics).

5.4.1.2 Main genera of plant pathogenic fungi

Table 14 summarizes the main genera of fungi and their characteristic symptoms.

Table 14. Main genera of plant pathogenic fungi and their characteristic symptoms

Classes	**Genres**	**Diseases (symptoms)**
Plasmodiophoromycètes	- *Plasmodiophora* (Fig. 25) - *Polymyxa* - *Spongospora*	Infect the root hairs of plants and Can transmit plant-parasitic viruses: *Polymyxa graminis* is a vector of the barley yellow mosaic virus (BYDV). Contamination of crops occurs via zoospores (irrigation, soil transport or use of contaminated tools).
	- *Pythium*	Parasite of seedlings in moist soils, agents of damping-off

Oomycètes (Phycomycètes)	- *Phytophthora* (Fig. 26)	Have a very wide host spectrum, some are responsible for damping-off and rot others, colonize the foliage (mildew).
	- *Peronospora* - *Plasmopara*	Obligate parasites , with mycelium intercellular, agent of mildew.
Zygomycetes	- Mucor	Mucorales are essentially saprophytes that usually develop on fruit.
Ascomycetes and Deuteromycetes	- *Erysiphe* (Fig. 27)	Agents of "powdery mildew", affect all plant species and develop mainly on leaves, young shoots, flower buds and fruits: white powder deposits on the affected organs.
	- *Septoria / Zymoseptoria* (Fig. 28) -*Cercospora* - *Helminthosporium* - *Ascochyta* - *Cladosporium*	Cause leaf spots (chlorosis and necrosis) to appear on the foliage, and are agents of septoria, anthracnosesand helminthosprioses.
	- *Claviceps* (Fig. 29)	The species *C. purpurea*, the agent of ergot in grasses and cereals (rye), produces alkaloids that are toxic to humans.
	- *Sclerotinia*	Agents of rot of injured or senescent organs.
	- *Venturia* (Fig. 30)	Develop on leaves and fruits and cause black spot to form superficial, and can also be the origin of cortical alterations (chancres). They are agents of pear scab (*V.*
		pirina) and apple (*V. inaequalis*).

	- *Ceratocystis* - *Fusarium* - *Verticillium*	Responsible for vascular diseases and generally cause wilting of the organs leading to the death of plants: the circulation of sap is slowed down following a blocking of the conducting vessels by the mycelium or fungal spores, or by the formation of thylls (globular protrusions inside the vessels (thylloses).
Ba	- *Urocystis*	Production of black masses on leaves.
	- *Tilletia* (Fig. 31)	Agents of "cavities", produce black masses in the floral organs. In cereals infected with *Tilletia caries*, the grain is deformed and filled with black spores (one grain can contain 9 thousand spores).
	- *Ustilago*	Agents of "coals", *U. nuda* causes the naked smut of cereals (the ear turns into a powdery black mass).
	- *Rhizoctonia* - *Sclerotium* - *Armillaria*	Attack the roots and base of plant stems.
	- *Puccinia* (Fig. 32) - *Uromyces* - *Hemileia*	Rusting agents, mainly attack leaves and stems and cause the appearance of pustules (uredosores) containing the spores (uredospores). Rusts usually have a dioecious cycle (develop on two hosts).

Figure 25. Symptoms of *Plasmodiophora brassicae* on a cruciferous plant
https://www.naturepl.com/stock-photo-clubroot-plasmodiophora-brassicae-diseased-and-distorted-cabbage-nature-image01631306.html

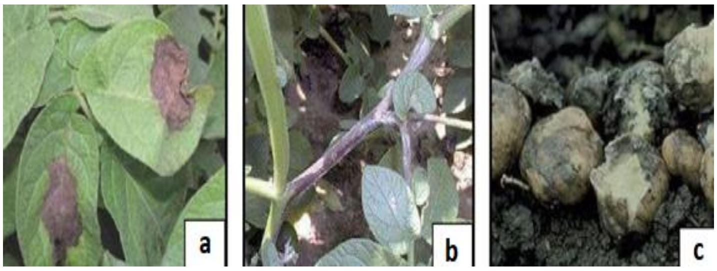

Figure 26. Symptoms of potato downy mildew (*Phytophthora infestans*):
A : on leaves, **B** : on stems, **C** : on tubers
https://www.bayer-agri.fr/cultures/mildiou-la-principale-maladie-des-pommes-de-terre 1068/

Figure 27. Symptoms of *Erysiphe pisi* agent of pea powdery mildew
https://www.toppr.com/ask/question/powdery-mildew-of-pea-is-caused-by/

Figure 28. Symptoms of *Zymoseptoria tritici* on wheat
https://www.agro.basf.ch/fr/Services/Pest-Guide/Septorioses-foliaires.html

Figure 29. Symptoms caused by *Claviceps purpurea* agent of ergot in rye on cereal
https://www.reussir.fr/grandes-cultures/lergot-signe-un-retour-sous-haute-surveillance

Figure 30. Symptoms of apple scab caused by *Venturia inaequalis*
https://www.koppert.fr/defis/maitrise-des-maladies/tavelure-du-pommier/

Figure 31. Symptoms of common wheat bunt caused by *Tilletia tritici*
https://www.agrotopvsg.rs/saveti/psenica/glavnica-psenice-tilletia-caries_343.html

Figure 32. Symptoms of wheat stem rust caused by *Puccinia graminis* f.sp. *Tritici*
https://rusttracker.cimmyt.org/?page_id=7

5.4.2 Diseases caused by bacteria

5.4.2.1 Characteristics of plant pathogenic bacteria

Bacteria are microscopic, single-celled organisms whose dimensions are of the order of a micrometer. They are prokaryotes characterized by the absence of a membrane and are capable of carrying out complex metabolic reactions.

Bacteria are found in all types of biotopes found on earth. They can be isolated from soil, fresh water, air, plants, animals, etc. There are about 40 million bacterial cells in one gram of soil and 1 million bacterial cells in one milliliter of freshwater.

A. Morphology and structure

Plant pathogenic bacteria are rod-shaped cells (bacilli) with the exception of the genus *Streptomyces*, they are filamentous, ranging in size from 0.6 to 3.5 µm in length and 0.3 to 0.7 µm in width (10 to 20 times smaller than that of a typical plant cell). Two categories of elements enter the bacterial structure (Fig. 33):

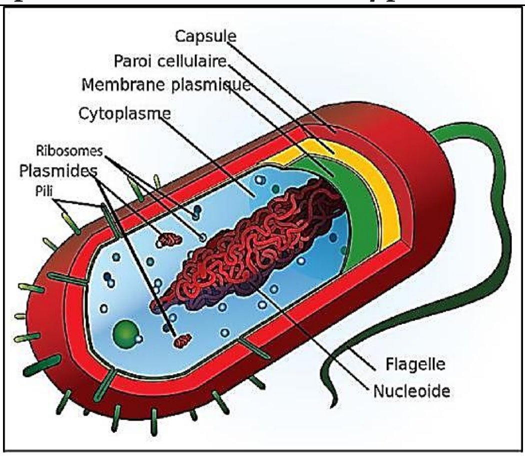

Figure 33. General structure of a bacterium
https ://www.antibiotique.eu/leur-fonctionnement.html

has. Mandatory constant elements

- Cytoplasm and cytoplasmic inclusions (ribosomes)
- The genome (carrier of the genetic heritage)
- The cytoplasmic membrane, composed mainly of lipids and proteins and contains several digestive and phosphorylation enzymes (acid phosphatase, lipases, nitrate reductase, proteases, etc.).
- The bacterial wall, rigid, permeable to mineral and organic solutions, its chemical composition varies according to the species and it plays a role in the recognition processes that determine the parasitic relationship.

b. Optional items

- The capsule: a gelatinous layer of varying thickness, composed of polysaccharides, enveloping the wall and has an important role in virulence.
- Flagella, motility structures of certain bacterial cells, composed of a pure protein (flagellin). The number and type of flagella insertion is characteristic of the different bacterial groups.
- Plasmids: free DNA fragments in the cytoplasm, carrying genetic information that can be transferred from one bacterial cell to another (antibiotic resistance genes).
- Pili: filamentous filaments or appendages, made up of a protein, pilin. Sexual pili condition gene transfer during bacterial conjugation, while common pili allow bacteria to adhere to interfaces and play a role in the virulence of bacteria.

1. Nutrition

The nutrition of bacteria is done by the exchange of mineral or organic elements with the

External environment: role of the bacterial wall and cytoplasmic membrane.

1. Respiration

The bacterial cell has membrane respiration (at the level of the membrane cytoplasmic). The respiratory type differs according to the genera (aerobic or anaerobic bacteria).

2. Reproduction

The reproduction of plant pathogenic bacteria occurs through an asexual process known as *binary fission* or *scissiparity*. The reproduction rate is fast under optimal conditions (temperature, pH, and composition of the medium). The growth curve contains several phases (Fig. 34):

- **Latency phase:** synthesis of enzymes adapted to the new substrate. Zero growth.
- **Exponential growth phase:** constant growth rate. Zero mortality, all cells are viable.
- **Slowing down phase:** exhaustion of the environment and accumulation of waste. Beginning of autolysis of bacteria.
- **Stationary phase:** As many cells that die as cells that multiply. Zero growth.
- **Decline phase:** Accumulation of toxic waste in the environment. Depletion of nutrient resources.

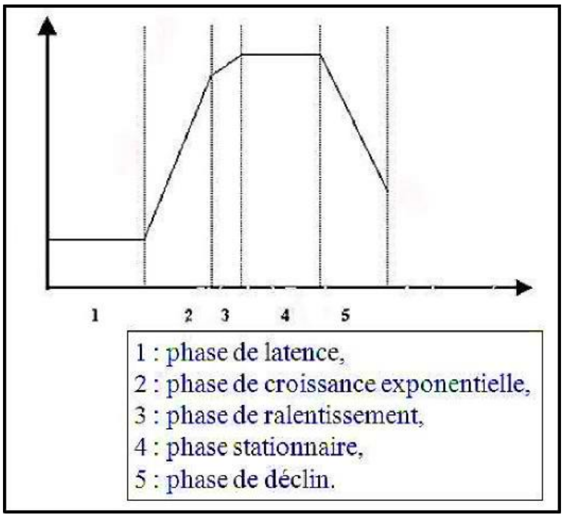

Figure 34. Bacterial growth curve
http://41.188.65.217/UNF3Smiroir/campus-numeriques/microbiologie/enseignement/microbiologie 4b/site/html/2.html

E- Biology and dissemination of phytopathogenic bacteria

Phytopathogenic bacteria can be:

1. Facultative or partially saprophytic parasites (*Agrobacterium tumefaciens, Pseudomonas solanacearum*, and others).
2. Bacteria with extracellular (meat) or intracellular localization.
3. Bacteria whose transmission is ensured by seeds and vegetative propagation organs (bulbs, tubers, cuttings).
4. Bacteria whose dissemination is ensured by various agents: water (irrigation, rain), wind, insects, man (tools and cultivation techniques).

5.4.2.2 Main genera of plant pathogenic bacteria

Table 15 summarizes the main genera of plant pathogens and their characteristic symptoms.

Table 15. Main genera of Plant Pathogenic Bacteria and their characteristic symptoms

Genres		Diseases (symptoms)
Corynebacterium (Gram +)		Cause various types of symptoms in plants such as galls, fasciations, gummosis or dieback (Fig. 35). Most plant pathogenic *Corynebacterium* can be transmitted by seed or insects and produce systemic infections.
Erwinia (Gram -) (03 groupes sont phytopathogènes)	*E. carotovora*	Have strong pectolytic activities and induce a degradation of tissue structure in infected plants leading to symptoms of wet rot, especially in the reserve organs.
	E. herbicola	Species that produce a yellow pigment and are associated with plants as non-pathogenic epiphytes or as weakness parasites. Some of them produce vascular infections and galls.
	E. amylovora	Cause dry necrosis and wilting in plants (Fig. 36); do not produce enzymes pectolytic or yellow pigments: "fire blight", bark canker, galls,

Xanthomonas (Gram -)	Five distinct species make up this group: *X. albilineans, X. ampelina, X. axonopodis, X. campestris and X. fragariae.* They are all plant pathogens. Symptoms appear on leaves, stems and fruits (necrosis, oil stains, gummoses, cankers, etc.). If the infection is transmitted by seed, the disease is systemic and the plant is destroyed before it reaches maturity (Fig. 37).
Pseudomonas (Gram -)	There are two groups of *Pseudomonas sp.* bacteria: - *Pseudomonas* known as "fluorescent" whose phytopathogenic species cause necrosis on leaves and stems, cankers, destruction of flowers, galles (*P. syringae* (Fig. 38), *P. viridiflava, P. marginalis*,..).
	- Pseudomonas called "non-fluorescent", they are leaf spot agents, some species are vascular parasites responsible for wilting, bulb rot in conservation (P. solanacearum, P. amygdali, P. andropogonis).
Agrobacterium (Gram -)	Some species cause the development of galls or tumors on the stems, roots and crown, others induce the proliferation of roots (Fig. 32).
Streptomyces (Gram +)	Several species of this genus are phytopathogenic and cause the formation of suberous pustules in the epidermis of the reserve organs found in the soil. (S. scabies : gall-like agent in potatoes) (Fig. 33).

Figure 35. Symptoms of bacterial canker caused by *Corynebacterium michiganense* on tomatoes (**a** : on leaves, **b** : on fruit)

https://u.osu.edu/diagnosticsshortcourse/2014/09/08/september-5-2014-day-5-more-pcr/

Figure 36. Symptoms of fire blight caused by *Erwinia amylovora* on pear trees

https://www.groworganic.com/blogs/articles/controlling-fire-blight-organically

Figure 37. Symptoms caused by *Xanthomonas vesicatoria* in tomatoes

https://www.pinterest.com/pin/368591550748421041/

Figure 38. Symptoms caused by the bacterium *Pseudomonas syringae* pv. *aptata* on melon

http://ephytia.inra.fr/fr/C/22562/Vigi-Semences-Pseudomonas-syringae-pv-aptata-melon

Figure 39. Symptoms caused by *Agrobacterium tumefaciens*

Figure 40. Symptoms caused by *Streptomyces scabies* bacteria in potatoes

https://spudsmart.com/common-scab-complexities/

https://www.naturespot.org.uk/species/agrobacterium-tumefaciens

5.4.3 Diseases caused by viruses

5.4.3.1 Characteristics of plant pathogenic viruses

Viruses are complex particles invisible under a photon microscope, and cannot be cultured on an artificial medium: they are obligate parasites that multiply only on living cells. They are made up of proteins and nucleic acid: these are nucleoproteins that cause disease.

Viruses attack all forms of plants and damage stems, leaves, flowers and fruits.

There are about 1,200 species of plant viruses, or "phytoviruses ", divided into about forty families. Diseases caused by viruses can have serious economic and environmental impacts.

A- Morphology of viruses

Viruses come in viral particles of various sizes and shapes:

1. Helical form: Tobacco mosaic virus, TMV (Fig. 41).
2. Icosahedral form: where the nucleic acid is curled up inside the capsid: cucumber mosaic virus (Fig. 42).
3. Complex structure: phage T (a head and a tail).

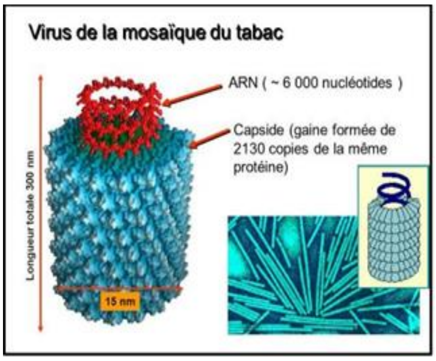

Figure 41. Morphology and structure tobacco mosaic virus (TMV)
https://slideplayer.fr/slide/3043163/

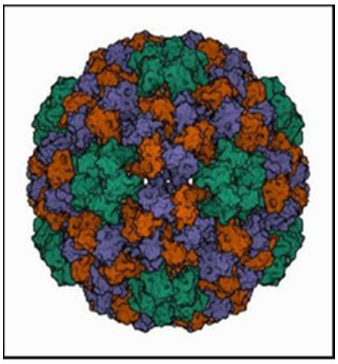

Figure 42. Morphology and structure cucumber mosaic virus
https://www.rcsb.org/structure/1f15

B- Structure des virus

- The viral particle is a nucleoprotein consisting essentially of a protein and of a nucleic acid. Two types of constituents characterize viral particles:

a- Essential components: exist in all viruses:

1. Nucleic acid: the nucleic acids of plant pathogenic viruses are all RNAs with a few exceptions. The viral particle has only one type of nucleic acid, which can be single-

stranded or double-stranded. It contains the genetic message and governs viral multiplication.

2. Proteins: their number is limited and they constitute the shell or capsid of the virus. The protein is considered to be the protective envelope of the nucleic acid.

b- Additional components: Some viruses have an additional envelope of the same nature as the plasma membrane.

C- Pathological characteristics

Plant viruses have three main characteristics that you should be aware of To fully understand their biology:

1. Plant viruses most often cause widespread diseases. They infect almost all organs of a plant: they multiply in the roots, stems or leaves. Only certain cell masses in the process of differentiation, meristems can be free of viruses.

2. Virus diseases are incurable in the field: a plant infected with a virus will remain infected for the rest of its life, whether it is annual or perennial.

3. Like all other viruses, plant viruses are obligate pests: they can only multiply in living plants or plant organs.

5.4.3.2 Biological functions and virus synthesis

A plant is only infected with a virus when it multiplies in the host cell. Following contact between the cytoplasm of the host cell and the virus, infection occurs in several stages (Fig. 43), which can be summarized as follows:

- **Step 01:** Penetration of the virus inside the plant.
- **Step 02:** decapsidation of the virus and dissociation of the capsid in the cytoplasm.
- **Step 03:** synthesis in the host cell of enzymes necessary for viral synthesis: RNA synthetases, RNA polymerases, serial copy of the viral genome and capsid proteins.
- **Step 04:** Self-assembly of the parts of the new virions.
- **Step 05:** Movement and spread of viruses to other plant cells Infected.

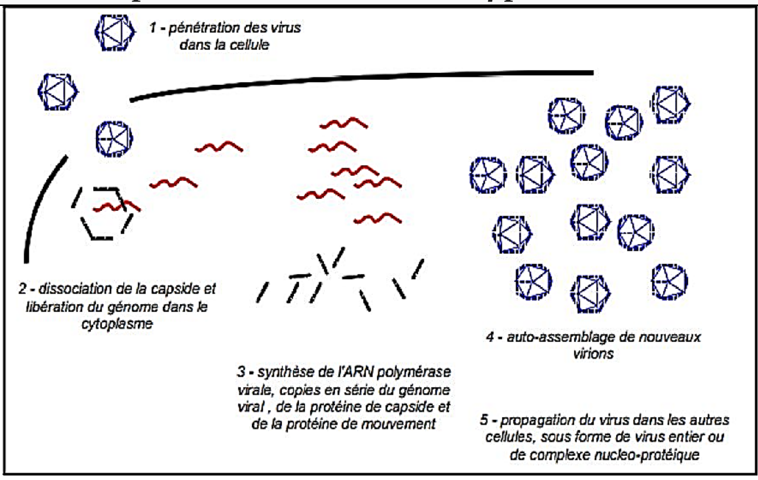

Figure 43. Mechanisms of plant virus infection
(*in* Casselyn, 2004)

5.4.3.3 Symptoms caused by plant viruses

The symptoms caused by viruses in plants can vary, depending on the virus, the Affected variety or species, the environment and the physiological state in which the plants are located:

1. Many viruses cause mosaic symptoms on the foliage, sometimes associated with deformities (blisters, threadlike or embossed appearance, reduction in size).
2. Other viral diseases cause yellowing of the foliage, which is often more pronounced on older leaves.
3. Some viruses induce more or less generalized necrosis on leaves, flowers, fruits or stems; These necroses sometimes lead to dieback of the plant.

5.4.3.4 Dissemination and transmission of viruses

Plant viruses have two main means of dissemination in the nature, a so-called vertical transmission and a so-called horizontal transmission:

A- Vertical transmission (without vectors): corresponds to the transmission of the virus to the offspring of an infected plant, it includes:

* **Transmission through vegetative propagating organs:** It is very common in vegetative propagated plants. All propagating organs (cuttings, grafts, tubers, bulbs, etc.) taken from a virus-infected mother plant will be infected, because viruses cause widespread diseases.

* **Transmission by seed and pollen**: the number of viruses that can be transmitted by pollen or seed from infected mother plants is very limited. A few rare viruses

of perennial plants can be transmitted by pollen. Some viruses can be transmitted by seed, such as *Tomato mosaic virus* (ToMV) or *Lettuce mosaic virus* (LMV).

* **Artificial inoculation:** is generally carried out by putting the inoculum in contact with wounds of the host.

* **Transmission by grafting:** all systemic viruses can be transmitted by grafting to a plant compatible with the virus host.

B- Horizontal transmission (with vectors): allows viruses to pass from one plant to another and involves 'intermediaries' which are called virus vectors. A virus vector must be able to take (acquire) the virus from a cell of a diseased plant and introduce (inoculate) it into a cell of a healthy plant. These vectors are very varied, some are aerial (insects, mites) while others move in the soil (nematodes, fungi):

* **Transmission by insects:** this is the most common route. The most important vectors are biting-sucking insects (aphids, whiteflies, leafhoppers, etc.). The aphid *Myzus persicae* alone carries about 50 different viruses.

***Transmission with other vectors:** nematodes and fungi (found in the soil) as well as parasitic phanerogams of higher plants (dodder) can also lead to the transmission of plant viruses.

5.4.3.5 Main genera of plant pathogenic viruses

Table 16 shows some groups of plant pathogenic viruses and their characteristic symptoms.

Table 16. Major Groups of Plant Pathogenic Viruses and their Characteristic Symptoms

Group	Virus type	Transmission	Symptoms
Tobamovirus	Tobacco mosaic virus (Fig. 44)	- Mechanics - Contact	Mosaic
Potexvirus	Potato virus X	- Mechanics - Contact	Mosaic
Carlavirus	Virus latent de l'œillet	- Mechanics - Contact	Mosaic
Potyvirus	Potato virus Y (Fig. 45).	-Mechanics -Aphids -Seed	Mosaic
Closterovirus	Beet yellows virus	- Mechanics - Aphids	Jaundice, necrosis of the

Tymovirus	Yellow Mosaic Virus of Turnips	- Mechanics - Beetles	Mosaic, Necrosis
Luteovirus	Barley Dwarf Yellows Virus (BYDV) (Fig. 46)	- Aphids	Hardening, yellowing and curling of the leaves
Tombusvirus	Tomato stunting virus	-Mechanics	Port érigé
Nepovirus	Tobacco Necrotic Rings Virus	- Mechanics - Nematodes - Seed -Pollen	Annular spots, mottling, necrosis.
Hordeivirus	Barley streaky mosaic virus	- Semence - Pollen	Streaks, necrosis
Tospovirus	Tomato tan spot virus (TSWV) (Fig. 37).	- Insects	Necrosis, leaf spots, concentric rings.
Cucumovirus	Cucumber mosaic virus	- Mechanics - Aphids	Mosaic, necrosis
Caulimovirus	Cauliflower mosaic virus	- Mechanics - Aphids	Mosaic
Rhabdovirus	Necrotic yellows of lettuce virus	- Mechanics - Aphids	Necrosis, yellowing,
Virus du nanisme chlorotique du	Chlorotic dwarfism virus of maize	- Mechanics - Aphids	Yellowing, dwarfism

Figure 44. Symptoms of tobacco mosaic virus (TMV) on a tobacco plant
https://www.drugtargetreview.com/news/55439/tobacco-mosaic-virus-creates-novel-malaria-vaccine-candidate/

Figure 45. Symptoms caused by potato virus Y on a tomato plant
https://www.iriisphytoprotection.qc.ca/Fiche/Virus?imageId=8434

Figure 46. Symptoms caused by barley yellow dwarf virus (BYDV)
https://www.agrimaroc.ma/jaunisse-nanisante-lorge/

Figure 47. Symptoms of Bronze Spot Virus on Potatoes (Feuilles)
http://plantdepommedeterre.org/index/virus-des-taches-bronzees-de-la-tomate-tswv
(Tubercules) http://plantdepommedeterre.org/index/virus-des-taches-bronzees-de-la-tomate-tswv

5.4.4 Phytophagous nematodes

5.4.4.1 Definition

Nematodes (Nemathelminthes) or "roundworms" are a zoological group of vermiform organisms. They are ubiquitous (all latitudes and climates) having colonized all types of environments: continental and oceanic waters (salt and fresh) and soils. Some of them have adapted to parasitic life in humans, animals and plants.

Nematodes are most often microscopic. They are found both as parasites and free-living organisms. Plant-parasitic nematodes (or phytoparasites) are very small, even microscopic. They have more than 4100 species, and are divided into 3 groups, which are separated into 4 different orders:

1. The Dorylaimida
2. The Triplonchida
3. Les Aphelenchida
4. The Tylenchida

5.4.4.2 Economic importance and damage

These pests have a very important economic impact on a global scale, as they attack field crops as well as vegetables, flowers and fruit crops.

The most damaging are the Heteroderidae, including nematodes of the genus *Globodera* spp., *Heterodera* spp. and *Meloidogyne* spp. In Europe, they are responsible for damage of up to 10% of cereal production and lead to harvest decreases of 20 to 30% in Mediterranean citrus orchards. The damage they cause in the United States represents 6 billion dollars annually. In tropical and warm temperate regions, which are very favourable to their development. In Australia, nematodes are responsible for 60% of wheat losses in infested plots.

In Algeria, the results of a survey carried out over 5 years (2007-2012) showed that more than 62% of cereal plots are infested by nematodes.

5.4.4.3 Nematode morphology and structure

Plant-parasitic nematodes are most commonly needle-shaped roundworms ranging in size from 0.25 to more than 1 mm, with some reaching 4 mm. Although generally tapered in shape from head to tail, nematodes exist with a very wide variability in shape and size. In some species, females lose their tapered shape as they grow, until they become enlarged, pear-shaped,

lemon, kidney or spherical. Like other animals, nematodes have circulatory, respiratory, and digestive systems (Figs. 48 and 49).

5.4.4.4 Nematode Nutrition

Plant-parasitic nematodes differ from other nematodes that feed on bacteria and fungi by the presence of a specialized structure: the stylet (Fig. 49). This stylet is used both to inject enzymes into plant cells and plant tissues and to extract their contents.

5.4.4.5 Reproduction of plant-parasitic nematodes

There are different modes of reproduction in plant-parasitic nematodes, and several Modes of reproduction can be found even within the same genus:

1. ***Amphimictic reproduction***: a mode of sexual reproduction that involves the fusion of a male gamete and a haploid female gamete.
2. ***Parthenogenetic reproduction:*** a mode of asexual reproduction, which does not require the intervention of the male's spermatozoa (no fertilization).

3. ***Hermaphroditism:*** a special case of bisexual reproduction. A hermaphrodite nematode is self-fertile, producing sperm and eggs in a single gonad. Sperm are first produced and stored to fertilize the gametes that are later produced.

5.4.4.6 Life history of nematodes

The development cycle of nematodes is typically divided into 6 stages: the egg stage, 4 juvenile stages and the adult stage. The length of each of these stages and the entire life cycle differs among species and depends on factors such as temperature, moisture content and the host plant. In favourable conditions, many species have very short development cycles with several generations per season. This can lead to very rapid population developments from only one (self-fertilization) or two individuals.

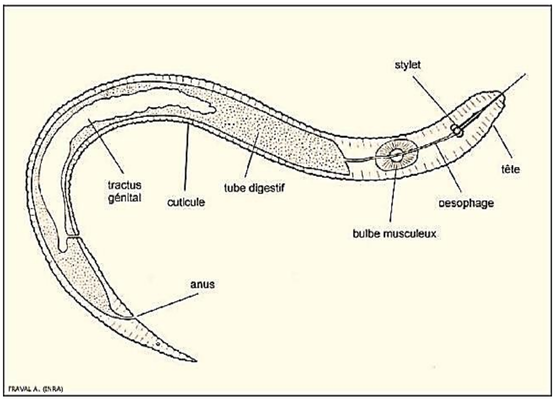

Figure 48. General anatomy of a parasitic nematode

(http://ephytia.inra.fr/fr/C/11096/Hypp-encyclopedie-en-protection-des-plantes-Nematodes-Nematoda)

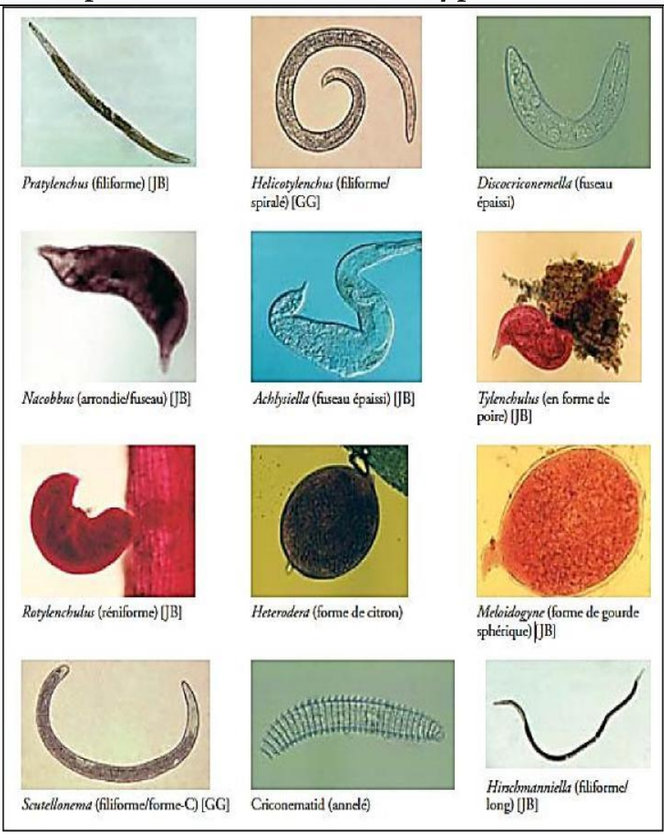

Figure 49. Various forms of nematodes, as seen through the microscope. (Adapted from Coyne *et al*., 2010)

Nematodes can survive adverse conditions such as the dry season or cold winters. Some species survive better at different stages, for example the species of the genus *Heterodera* survive best as eggs inside cysts, the genus *Ditylenchus* in the fourth juvenile instar, and the genus *Anguina* in the second juvenile stage.

5.4.4.7 Different types of plant-parasitic nematodes

Depending on their feeding site, plant-parasitic nematodes can be separated into two groups:

1. **Nematodes of the above-ground parts:** feed on the above-ground parts of the plants.
2. **Root nematodes:** feed on underground roots and tubers.

They can also be grouped according to their feeding behaviour and mobility into three main groups:

1. **Migratory endoparasites:** mobile nematodes that feed inside the root tissues of plants. In these nematodes, all stages are mobile except for the egg. Nematodes pass through plant tissues from cell to cell, or may leave plant tissues in search of new food sources.

2. **Sedentary endoparasites:** nematodes that, upon arrival at a feeding site, cease to be mobile and feed on this feeding site. They move through the soil in search of roots of a host plant, cross plant tissues to find a feeding site. Once the site is found, the juvenile settles permanently until the end of its development cycle as an adult female.

3. **Ectoparasites:** Ectoparasitic nematodes feed externally, on the surface of plant root tissues, usually on the root hairs or external cortical tissue of the roots.

5.4.4.8 Symptoms of Nematode Attacks

The symptoms of nematode attacks can be observed on the aerial parts such as on the underground parts.

> **Symptoms on the aerial parts**

Symptoms on the above-ground parts fall into two categories: those caused by above-ground nematodes that attack the foliage and those caused by root-attacking soil nematodes.

******Symptoms caused by nematodes of the aerial parts***

These are often specific symptoms associated with nematodes that are easy to diagnose. They include:

1. Gall formation, or abnormal swelling of grains (*Anguina*) or leaves (*Cynipanguina*),
1. Streaks on the leaf, bleaching and discolouration of the leaves (*Aphelenchoides*),
2. Thickening, cracking, and disorganized tissue growth (*Ditylenchus*)
3. Internal stem necrosis, association with a red ring (*Bursaphelenchus cocophilus*),
4. Necrosis of the inflorescence,
5. Chlorosis/browning of leaves (pine needles), possible tree death (*Bursaphelenchus xylophilus*).

* ***Symptoms caused by root nematodes***

Most of these symptoms can be mistaken for other problems like insufficient water supply or impaired mineral absorption. They include:

1. Chlorosis or any other abnormal coloration of the foliage,
2. Uneven and reduced growth,
3. Thin and sparse foliage,
4. Symptoms related to water stress (wilting of the plant, leaf curl),
5. Death of perennial or woody plants with few or no new leaves,
6. Reduction in fruit and seed size,
7. Poor harvests.

- **Symptoms on the underground parts**

Plant uprooting or clearing of roots is necessary to observe These symptoms, which include:

1. Gall formation,
2. Roots shortened, thickened, swollen at their ends,
3. Lesions on the roots,
4. Necrosis on the roots and tubers, rot and death of the roots,
5. Cracks on roots and tubers,
6. Presence of cysts or 'pearls' on the roots,
7. Deformed roots,
8. Altered root architecture.

5.4.4.9 Main genera of plant-parasitic nematodes

Table 17 lists some genera of plant pathogenic nematodes and their symptoms

Table 17. lists some genera of plant pathogenic nematodes

Characteristics.	Diseases (symptoms)
Anguina	Particularly attacks cereals: the species *A. tritici* causes wheat niello. Symptoms appear at heading (deformed leaves with stunting), rounded brown masses replace seeds and contain a large number of larvae that become active when the niello kernel is moistened. Niellofed seeds mixed with the seed spread the disease.
Ditylenchus	*Ditylenchus dipsaci* is a nematode that attacks several plant species. It is mainly found on the foliage, bulbs and seeds of onions (Fig. 50) and related plants

Meloidogyne	Gall agents, cause stunting and yellowing of the aerial apparatus of affected plants. Small galls form in the vicinity of the cap of the roots, each containing one or more females which produce a large number of eggs (Figs. 51 and 52).
Heterodera	Cyst agents. In the case of the species *H. avenae* , which attacks wheat, oats and rye, the roots of the affected plants have the appearance of a tuft resulting from excessive branching, there are the appearance of dark brown cysts attached to the roots: these are the female bodies transformed into sacs filled with many eggs.
Aphelenchoïdes	Cause abnormalities in the leaves and buds.
Pratylenchus	Agents of lesions and rots.

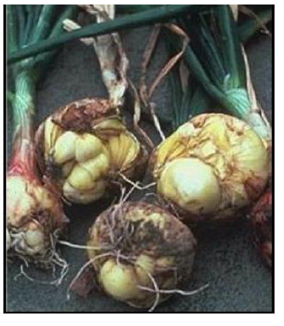

Figure 50. Symptoms of *Ditylenchus dipsaci* on onion bulbs
https://www.bio-enligne.com/lutte-biologique/554-nematode-tiges.html

Figure 51. Symptoms caused by *Meloidogyne graminicola* on a rice plant
http://nemaplex.ucdavis.edu/Taxadata/G076s7.aspx

Figure 52. Symptoms of root-knot nematodes (*Meloidogyne sp.*) on beet
https://www.agrifind.fr/alertes/betterave/betterave-nematode-galle/

5.4.5 Parasitic phanerogams of higher plants

Parasitic phanerogams are heterotrophic plants that live at the expense of other plants called "hosts". About 4000 species of plants are considered parasitic phanerogams. These species include: mistletoe**,** dodder, striga and.

Depending on their level of heterotrophy, parasitic phanerogams can be subdivided into two groups:

- chlorophyll hemiparasitic plants, partially parasitic, capable of photosynthesis;
- Holoparasitic plants that are completely devoid of photosynthetic pigments and therefore dependent on their host for carbonaceous substances, water and mineral salts.

Depending on the site of attachment to the host plant, two groups can also be distinguished:

- epiphytic parasitic plants implanted on the aerial parts of their hosts; - epirhizal parasitic plants, attached to the root system of the host plants.

Parasitism occurs through a "sucker" or "haustorium" which ensures the attachment of the parasitic plant to its host, and the transit of nutrients from the host to the parasite (Fig. 53).

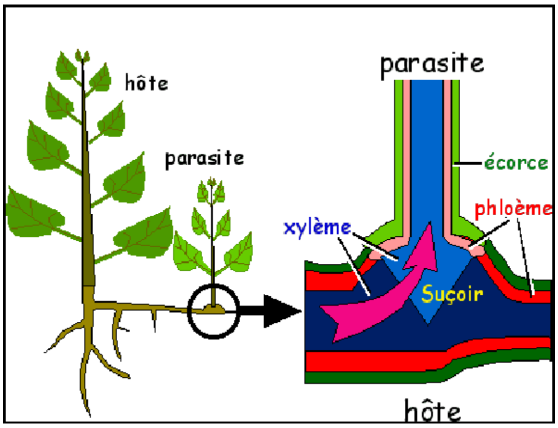

Figure 53. Epirhizal parasitic plant. The thick arrow indicates the diversion of the raw sap to the parasite.
https://www.futura-sciences.com/planete/dossiers/botanique-plantes-parasites-481/page/2/

5.4.5.1 Damage and damage to parasitic plants

Parasitic plants can cause significant damage to crops, exerting harmful effects on them through both competition and parasitism. Losses caused by these pests can be as high as 100% and lead to the dieback of parasitized trees or crops.

5.4.5.2 Biological characteristics of some parasitic phanerogams

- Mistletoe

Mistletoe (*Viscum album* L.) is a higher plant belonging to the Loranthaceae family. It grows on many trees, of which poplars and apple trees are the most susceptible.

Mistletoe is a hemiparasitic chlorophyll plant, the aerial part, composed of branched articles, forms a ball of elongated and evergreen leaves (Fig. 54). Living on the stems or branches of trees, it forms endophytic suckers that insert themselves through the bark of the branches and draw from them water and soluble mineral matter that it cannot draw directly from the soil.

The white, fleshy fruits (Fig. 55) are disseminated by birds, and the young, slimy, adherent seeds germinate on the bark of another tree, developing an appressorium.

Depending on their host specificity, three subspecies are differentiated:

- the deciduous mistletoe: *Viscum album album,*
- le gui du Pin : *Viscum album austriacum,*
- Fir mistletoe: *Viscum album abietis*.

Figure 54. Tree parasitized by mistletoe
http://www.snv.jussieu.fr/bmedia/arbres/gui.htm

Figure 55. Mistletoe Berries

https://www.plantes.ca/feuillage/famille/viscum.html

- The orobanche

are parasitic plants that graft themselves onto the roots of crops, depriving them of all food. They cause considerable losses on legume crops, sunflowers, tobacco, etc. This parasitic plant belongs to the Orobanchaceae family, of which there are 4 main species:

1. *O. crenata* (Fig. 56) mainly attacks broad beans, lentils, peas and to a lesser extent chickpeas and green beans;
2. *O. aegyptiaca and O. ramosa* mainly attack tomatoes, tobacco, melons, potatoes and lentils;
3. *O. cernua and O. cumana* mainly infest sunflowers, tobacco, eggplants and tomatoes;
4. *O. foetida* parasitizes alfalfa and fava bean crops.

These plants are holoparasitic, they cause the plants to wilt. Crops lose vigour and flowers drop which leads to yield losses. can cause up to 100% losses in the most infested plots. The majority of species are annuals and reproduce through tiny seeds (0.2 to 0.3 mm).

Figure 56. Orobanche *crenata Forssk*
https://www.pharmanatur.com/Plantes%20parasites/Orobanche%20crenata.htm

- The Striga

Striga are hemi-parasitic phanerogams, belonging to the Scrophulariaceae family, the damage caused to crops by these species is considerable and can reach 100%.

S. hermonthica (Fig. 57) is an annual species, parasitic of Poaceae (wild sorghum, maize, millet, upland rice, sugarcane and Poaceae). It is propagated by seed. A plant can produce 10,000 to 50,000 seeds. It is an allogamous species, whose fertilization is ensured by insects, especially butterflies. The viability of seeds in the soil can be as long as 10 to 15 years. They are mainly spread by wind and runoff. At the time of dispersal, the seeds are dormant. Germination is triggered by substances (strigol) contained in the root exudates of host plants, and then the radicle attaches to the host root by the haustorium. *S. hermonthica* then develops as a parasite by feeding on the raw sap of the host. Once it emerges, it develops roots and becomes hemiparasitic.

Figure 57. Flowers of *Striga hermonthica*
https://commons.wikimedia.org/wiki/File:Striga hermonthica flowers.jpg

- **Dodder**

They are epiphytic holoparasitic plants, belonging to the convolvulaceae family, they are leafless, and whose stems wrap around the plants in which they insert lollipops to feed. The flowers are grouped in glomeruli.

The species *Cuscuta epithymum* (Fig. 58) attacks a large number of plants. The very slender stem is often reddish. The flowers are white, yellowish, pinkish or lilac.

Figure 58. *Cuscuta epithymum*
https://maflorefc.pagesperso-orange.fr/Cuscutaceae/especes/cuscuta_epithymum.htm

The dodder has adaptations that allow it to parasitize a large number of host species, each dodder plant produces a very large number of seeds (between 2000 and 3000). In addition, when a seed has germinated in the ground, the tip of the young stem makes a rotational movement that increases its chances of encountering a host plant and clinging to it. The dodder stem then emits suckers into the host stem, and branches out of its apical end, allowing it to potentially encounter new hosts.

5.5 Pathogen variability

All pathogens are capable of producing variants that are capable of evolving or producing new capabilities for their growth. These capacities are developed to give the pathogen the ability to infect as many hosts as possible (increased virulence, or production of new races), especially in the event of the appearance of new resistant host varieties.

5.5.1 Physiological specialization of pathogens

For the same host, varieties do not react in the same way to the pathogen. Varieties can be classified according to their resistance or susceptibility. However, it should be noted that for the same variety, the classification varies according to the region and the year. This variability is due to the pathogen, and within each species of the pathogen there are so-called physiological races distinct from each other by their particular parasitic abilities with regard to the varieties of the host used.

5.5.1.1 Concept of "physiological race"

Physiological race is a population collection of the pathogen with similar pathogenicity capabilities. The identification of physiological breeds is done by the use of so-called "differential" varieties which make it possible to distinguish the different races of the parasite, however, sometimes, a variety that was resistant to a race becomes susceptible to it, this is due to another form of specialization of the pathogen: this is the biotype.

5.5.1.2 The "biotype"

The biotype is a population of individuals with identical hereditary traits. Each physiological breed is composed of one or more biotypes. The appearance of new breeds in the pathogen depends on several conditions (presence of resistant varieties of the host, obligate parasitism, sexual reproduction and the inability to complete the life cycle for the pathogen).

The variability of pathogens can be caused by genetic phenomena (mutation, hybridization and sexual recombination).

5.6 Dynamics and conservation of pathogen inoculum

In contrast to plant parasitic bacteria, which lack any particular forms of preservation, many plant pathogenic fungi have developed specialized structures that are resistant to unfavorable environmental factors. Some form sclerotia whose germination produces mycelium or sexual fruiting bodies; others form rhizomorphs that develop from an infected site and are capable of colonizing new hosts or substrates.

Sexual or asexual spores are also forming of inoculum conservation in unfavorable environmental conditions. Example: Phycomycete oospores and Fusarium oxysporum chlamydospores *can* survive in a latent state for long periods of time in soils in the absence of host plants.

Some plant pathogenic fungi can attack several species of cultivated plants at the same time, each of which is a potential source of inoculum for the others (Table 18).

Table 18. Example of some polyphagous agents and their host spectrum

Pathogen	Illness	Number of host species
Cucumber mosaic virus	Mosaic	775 species belonging to 85 families
Slerotinia sclerotiorum	Rot	361 species belonging to 69 families
Botrytis cinerea	Grey rot	Several thousand

5.7 Environmental action on the development of parasitic diseases

The presence of the susceptible host, the virulent pathogen and the favorable environment are the essential factors for the development of an infectious disease in plants. However, in its environment, the plant is subject to two types of environment:

- Air environment: Air temperature and humidity, light, wind, rain, snow, ...
- Subsurface environment (soil): physio-chemical composition of the soil, soil pH, soil texture and structure.

Both types of environment have a direct influence on the plant and are of considerable importance for its physiology and development. As they have an accelerating or slowing down influence on the course of pathogen cycles.

5.7.1 Temperature

In some cases, temperature may be the main factor limiting the geographical spread of diseases, such as some rust agents (*Puccinia* sp.) where temperatures above 27°C can prevent disease establishment by affecting the viability of uredospores in sores. In hot regions, high daytime temperatures inhibit sporulation and fungal infection, on the other hand, in temperate zones, low temperatures can inhibit the infection and sporulation processes.

5.7.2 Humidity

Humidity has an effect especially during the early stages of infection, especially for plant pathogenic fungi, during the germination of fungal spores and the penetration of germ tubes. For the fungus *Phytophthora infestans*, the agent of late blight in potatoes and tomatoes, this pathogen requires the presence of a film of water to germinate and infect the host. Humidity also plays a role in the dispersal of spores.

On the other hand, a cool atmosphere can delay the maturity of the plant, and increase its susceptibility to certain diseases.

Similarly, water can be a transport vector for several genera of plant pathogenic bacteria, and facilitate their penetration into the leaves of the host.

5.7.3 Light

The most well-established effects for light are those of light intensity and its duration, concerning the physiology of plants. It has been noted that apple cultivars of soils resistant to downy mildew on long days are more susceptible to this disease on short days at the same temperature; which means that the decrease in day length stunts the development of the plant and increases its susceptibility to disease.

5.7.4 Host Plant Nutrition

A host plant that suffers from a nutrient deficiency can be a limiting factor for the development of pathogens and more particularly obligate pests, such as rusting agents. A plant that grows under ideal conditions is able to tolerate infection to a certain degree.

5.7.5 Soil pH

The fungus *Phymatotrichum omnivorum*, a root rot agent in cotton, which can infect multiple hosts, is less abundant in acidic soils, but is highly destructive to neutral or alkaline soils.

6 Chapter VI/ Modes of action of pathogens on plants

The process of infecting a plant with a pathogen begins with the establishment of contact between the two protagonists of the parasitic relationship. The inoculum can be brought to the level of healthy organs by various modes of transport (wind, rain, soil, cultural practices, etc.).

6.1 The Host-Parasite Interface

In plants, there are two zones: the hypogeal zone (root system, bulb, tubers, seeds sown, seedlings before emergence) and the epigeal zone (crown, stems, twigs, leaves, flowers and fruits). There is a great diversity among the mechanisms that bring germs (parts of the pathogen that can initiate an infection) into contact with the host or the host into contact with germs (in the case of roots growing in the soil):

- At the root level, the root tips represent the preferred area of infection by certain soil fungi belonging to the genera *Phytophthora* and *Rhizoctonia*. Root hairs are the specific site of attachment and penetration of symbiotic bacteria (*Rhizobium*), while the zoospores of some fungi (*Polymyxa*, *Plasmodiophora*) penetrate the cells of the root epidermis. Parasites introduced at the root level can either alter the entire root tissue or penetrate the xylem or phloem and reach the epigeal parts of the host without causing significant damage to the roots.

- The crown region is also an area subject to parasitic stresses, in addition to abiotic stresses (heat and water stress) and damage to this area results in damping-off, wilting, yellowing or dieback of aerial organs.

- In woody plants, the bark is an impermeable protective envelope, but it has openings (natural openings and wounds caused by different types of biotic and abiotic stresses: birds, insects, hail, high temperatures,) allowing the entry of pathogens.
- Aerial organs of plants, including foliose or floral organs, can become infected through the conductive tissue or from stems and twigs.

- Nectar can provide a food base for microorganisms that can later attack the floral organs, via the enzymatic activity of pathogen colonies.

- Fruit can be contaminated via wounds, peduncle or contaminated senescent sepals.

6.2 Interactions between parasite and host surface

6.2.1 Mushrooms

a- Fixation: In leaves, pathogen spores are generally observed to be rapidly attached to the host cuticle and resist washing of the host surface. In phycomycete spores, upon contact with the plant, the spore (without a wall) forms peripheral vesicles that spill their contents out of the cytoplasm forming a gangue (bulge) that adheres to the surface of the host.

For spores with a wall, it is during germination that the adhesive structures develop. Depending on the case, the latter form either at the place of emergence of the germ tube, or throughout it, or at the distal end. The adhesive material consists of a mucilage formed by polysaccharides or glycoproteins, which is secreted through the wall of the fungus.

In addition to binding by mucilage formation, in some cases adhesion can occur by molecular interaction (host lectins and parasite polysaccharides, enzyme-substrate reaction), this case is also encountered in bacteria.

b- Germination

Fungal spores placed in suitable conditions on the surface of the host germinate, germination begins with a swelling at the place from which the germ tube will emerge. This process corresponds to an active and localized synthesis of the molecules that make up the fungal wall using as energy sources reserve substances, including lipids, phospholipids, polysaccharides, and sometimes even soluble carbohydrates, present in the cytoplasm of spores.

After a few hours, the germ tube differentiates at its distal end, into a disc-shaped suction cup allowing attachment to the host's cuticle. The adhesive material is called: ***Appressorium*** **(**Fig. 48**).** Some appressoria are unicellular, polylobed and produce a wedge of penetration at each lobe, others are multicellular (*Rhizoctonia* sp., *Sclerotinia* sp.).

6.2.2 Bacteria

Unlike most plant pathogenic fungi, which have active mechanisms of host attachment, germination, and penetration into plant organs, bacteria generally behave as passive agents. They enter the plant mainly through natural openings or wounds. Some species can infect host plants from soil or from tools used for cropping.

6.2.3 Infectious molecules and mycoplasmas

They are most often introduced into healthy plants via Vectors. Some viruses are transmissible by simple contact between infected and healthy plants.

6.2.4 Parasitic phanerogams

The supply of parasitic or hemiparasitic phanerogamous propagules to a host can be done in different ways: transmission by birds and attachment to a twig via a viscous envelope in mistletoe, development with thigmotaxis at the stem level in dodder, establishment of root contacts with the host in, etc.

6.3 Modes of Penetration and Invasion of Host Cells

6.3.1 Mushrooms

Apart from special cases, all phytopathogenic fungi develop structures that allow them to penetrate under the cuticle of the leaves and exploit a food source. The depth of this penetration, the site of the trophic relationship and the methods of sampling of molecules essential to the development of the parasite are very variable; A distinction is made between:

- Piercing of the cuticle and sampling of nutrients: the case of the apple scab agent (*Venturia inaequalis*) in which the penetrating hyphae uses the walls of the epidermal cells as a food base, thanks to the action of pectinases.
- Establishment of a trophic relationship limited to the epidermal cells in which the fungus develops suckers: the case of powdery mildew.
- Piercing of the cuticle or passage through a stoma, and establishment of a trophic ratio with a first cell and then development of secondary intercellular hyphae that colonize other cells: the case of rust agents (*Puccinia* sp.) and mildew (*Phytophthora* sp., *Peronospora* sp., *Plasmopara* sp., etc.).

Many plant pathogenic fungi synthesize cutinase to break down the leaf cuticle. In addition to cutinases, cell walls, which also consist of pectic polysaccharides, cellulose, hemicellulose and lignin, can be degraded by several other enzymes produced by pathogens.

6.3.2 Bacteria

The penetration of bacteria into plants can be done via wounds, vectors or most often through natural openings (stomata). However, some bacteria (notably *Pseudomonas syringae* pv. *tomato*) produce cutinases capable of degrading cutin chains.

6.3.3 Pathogens transmitted by vectors or cultural practices

The methods of introduction of these pathogens into the host are closely linked to the behavior of the vector concerned or the cultural constraint provided (addition of grafts, cuttings or contaminated irrigation water, etc.).

6.4 Host-parasite recognition process

The phenomenon of plant-pest recognition is based on the interaction of pathogen molecules and host plant receptors. Glycoproteins (lectins) present in different plant organs, specifically bind the polysaccharide terminal sugars of the fungal wall and could play an important role in the interactions between microorganisms and plant cells.

6.5 Parasitic relationships

After the pathogen enters the host cells, a series of molecular interactions are triggered and two types of relationships can be established:

- ***A compatible relationship***: which corresponds to an active multiplication of the pathogen and a colonization of all or part of the host by the latter.
- ***An incompatible relationship***: which corresponds to an early cessation of the growth of the parasite.

6.5.1 Incompatibility in the Non-Host Relationship

It is the result of a pre-existing malmatch between the plant and the pathogen, which prevents the germination of spores or the penetration of the microorganism: presence of preformed toxic substances in the host (germination inhibitors), morphological (thick cuticle) or biochemical maladaptation (absence of molecules essential for the early stages of parasite development). In this type of relationship, the cessation of infection occurs before any trophic relationship with the plant is established.

6.5.2 Compatibility and incompatibility in the host relationship

After the penetration of the pathogen, a series of biochemical interactions begins and the mechanisms of resistance or susceptibility in the plant, virulence or avirulence in the pathogen are then determined. In the event of compatibility, pathogenesis continues by the passage of the pathogen from one cell to another in the tissues of the host plant, living at its expense, and the plant is described as " ***susceptible*** ". On the other hand, for an incompatible relationship, the infection process is stopped and the plant continues its normal development without major alterations caused by the pathogen and is qualified as " ***resistant***

a- Compatibility, Susceptibility

A high susceptibility of the plant to a disease can be characterized by Four main components:

- A large number of infections resulting from a certain amount of inoculum, which does not

  causes no significant damage to other plants
- Large lesions or lesions that expand more quickly
  - A short latency period (short time between infection and sporulation)

- Production of a large quantity of spores (cases of fungal disease) per unit area of a tissue or per lesion.

The susceptibility of a host plant varies with age and responds to the influence of environmental factors. In a compatible relationship, the pathogen can be described as " ***virulent*** " and/or " ***aggressive*** ".

b-Incompatibility, Resistance

A plant's resistance to a disease is related to its ability to prevent or limit the penetration or development of the pathogen when exposed to a sufficient amount of inoculum and favourable environmental conditions. The majority of resistance mechanisms are induced in the host plant after contact with the pathogen: *Induced resistance.*

Depending on the pathogen, the plant can be: Immune, highly or poorly resistant.

- Immunity: this is complete resistance against a disease. This is the highest level of resistance. It is due to morphological characteristics or biochemical properties of the plant's cells. It may be due to the absence in the pathogen of the enzymatic systems necessary for the degradation and/or use of the substances in the plant.

- Tolerance: it can be defined as the ability of a host plant to survive and give satisfactory yields in the presence of an infection that causes economic losses to other varieties of the same species.

Several studies have shown the existence of the "gene-for-gene" relationship in plants infected with pathogens: for each avirulence gene of the pathogen, there is a resistance gene in the host plant. There are two types of resistance:

- **Specific, vertical or perpendicular resistance:** this is resistance that manifests itself in the form of a hypersensitivity reaction leading to a blockage of the success of the infection, it is a monogenic type of resistance, controlled by a major gene, and it is only effective against certain breeds of the pathogen.

- **General, horizontal or lateral resistance:** this is a resistance that provides stable and long-lasting protection against several races of the pathogen. It is controlled by a polygenic system.

6.6 Concept of toxins

Several plant pathogens are capable of producing alterations at different levels of the plant and in areas more or less distant from the site of infection. These alterations caused by microorganisms "at a distance" are due to the production of substances by pathogens, called toxins.

Toxins are metabolic substances that are toxic to plants, produced by microorganisms and can have an important role in pathogenesis. Two categories of toxins can be defined on the basis of their role in pathogenesis:

- Toxins that intervene during the initiation of infection and the development of symptoms; these are primary determinants of the parasite's infectivity that determine the type of parasitic relationship (compatibility or incompatibility).
- Toxins that modify the intensity of symptoms (without being related to the compatibility or incompatibility of the parasitic relationship); these are secondary determinants of pathogenicity.

6.7 Role of Growth Hormones in the Host-Parasite Relationship

In plants, growth is controlled by a number of hormones called: growth regulators, which are produced by the plant and act at low concentrations. Among these regulators are:

- Growth promoters such as auxins, gibberellins and cytokinins.
- Growth inhibitors such as ethylene.

In a host-parasite relationship, the pathogen can produce the same growth promoters or inhibitors that the host plant produces, as it can produce substances that stimulate or retard the plant's production of growth regulators; as a result, the hormonal system of the host plant is very affected; growths, organ malformations, defoliation, and several other types of symptoms can be observed in infected plants. Among the growth hormones that play a major role in pathogenesis are:

- **Auxins:** Auxin (AIA) is continuously produced in young plant tissues and migrates to older tissues, but it is constantly destroyed by an enzyme (AIA oxidase). It is involved in cell elongation, activates respiration and protein synthesis, etc.

An increase in auxin levels has been observed in plants infected with fungi, bacteria, viruses and nematodes, and several pathogens decrease auxin levels in their hosts. *Phytophthora infestans, Ustilago maydis, Fusarium oxysporum* and other fungi, the nematode *Meloidogyne* sp. and many other plant pathogens not only cause an increase in the level of auxin in the host, but are themselves capable of producing auxin. The increase in auxin levels can be attributed totally or partially to a decrease in the degradation of this hormone by inhibition of the activity of AIA oxidase. *Pseudomonas solanacearum*, a wilting agent in nightshades, causes 100-fold increases in AIA levels in diseased plants compared to healthy plants. This increase affects cell permeability, increases respiration, and may be responsible for increased transpiration in infected plants.

- **Gibberellins**: gibberellins are phytohormones that can also be produced by several microorganisms, including fungi (*Gibberella fujikuroi*, which affects rice).

- **Cytokinins:** cytokinins are growth factors necessary for the growth and differentiation of cells, in addition to inhibiting the degradation of proteins and nucleic acids and thus causing an inhibition of senescence. Cytokinin levels increase in several species of plants infected with rusts, especially during the early phases of infection around sites of infection, and appear to have a role in defense for both the host (to repair damage caused by the pathogen) and the parasite (to keep infected tissues alive for as long as possible).

- **Ethylene:** ethylene is considered to be a real stress hormone, capable of acting locally or remotely, capable of activating the defense mechanisms of plant cells. It stimulates the synthesis of enzymes necessary for the synthesis of phytoalexins and glycoproteins, as it stimulates the synthesis and activity of chitinases and anti-proteases.

7 Chapter VII/ Effects of pathogens on plant physiology

7.1 Introduction

To meet their needs for energy and nutrients necessary for their development, several pathogens secrete enzymes and other metabolites that allow the degradation of cell membranes and even cytoplasmic constituents of the host plant; Some of them secrete toxins that disrupt the metabolism of host cells, others produce growth substances that impair the normal development and differentiation of host cells. Viruses synthesize nucleic acids and viral proteins from the nucleic acids and proteins of the host plant.

In all stages of pathogenesis, the pathogen forces the plant to alter its vital functions; These alterations are manifested in all infected cells and tissues. The lesions that have appeared become metabolic wells in which nutrients of all kinds disappear.

7.2 Action of pathogens on photosynthesis

Photosynthesis or chlorophyll assimilation consists of the formation of carbohydrates from carbon dioxide and water, thanks to the light energy captured by chlorophyll and the associated pigments, hence the classic formulation:

This equation shows that water, CO2, the presence of light and chlorophyll are necessary for photosynthesis. The products formed, O2 and sugars should not accumulate: O2 diffuses easily (photorespiration), on the other hand if the carbohydrates formed do not migrate from the assimilative cells, there is a "bottleneck" and there is a decrease in photosynthesis.

Plant pathologists report that photosynthesis is the major function with which pathogens can intervene, and necrotic and chlorotic zones usually appear in different host-parasite interactions following a decrease in photosynthesis by destruction of leaf tissues.

Several authors point out that in cereals infected with rusts, photosynthesis is usually reduced to 1/3 to 2/3 of that of uninfected leaves. However, in plants

$$6\,CO_2 + 6\,H_2O \xrightarrow[\text{Chlorophylle}]{\text{Lumière}} C_6H_{12}O_6 + 6\,O_2 \uparrow$$

Infected with obligate parasites (rusts, powdery mildew, etc.) a slight increase in photosynthesis may occur in the first few days after inoculation; this is probably due to the fact that this type of parasites maintain, in the first days of infection, the photosynthetic apparatus intact and functional in order to meet their continuous needs of metabolites necessary for their own synthesis processes; and the formation of the "green islands" or " green Island " around the centers of infection represents a site for the maintenance of photosynthetic activity, rather than a site for the increase of this activity.

The decrease in photosynthesis in infected tissues may be due to the degeneration of chloroplasts; however, it begins to decrease even before structural changes are detectable. Several factors can be involved:

- Reducing plant density
- The destruction of the photo assimilation system of the plant, the chloroplast, which has the following consequences:
    1. A decrease in the amount of chlorophylls, which is the main factor in photosynthesis.
    2. A decrease in the amount of ribulose 1,5-diphosphate carboxylase, the enzyme that catalyzes the first step of CO_2 fixation in photosynthesis, by decreasing the ribosomal RNA responsible for its synthesis, or by its degradation by the proteolytic enzymes produced by the pathogen, especially in the late stages of infection.
- Alteration of carbon (CO_2) assimilation by uncontrolled closure of the stomata.
- Changes in the assimilation of carbohydrates in reserves, the alteration of the translocation process by pathogens, transforms the sites of infection into storage areas and which contributes to a large part in the limitation of photosynthesis.

7.3 Effects of Pathogens on Host Plant Nutrition

7.3.1 Action of pathogens on the water status of the host plant

Almost all nutrients arrive at the plant cells in the form dissolved in water (raw sap), which shows that any interruption in the plant's water supply has an impact on the plant's nutritional process. In several species of infected plants, numerous studies have shown that the main cause of desiccation and death of the plants corresponded to a decrease in the ability of the roots to absorb water. This decrease was caused by the reduction in the transfer of organic solutes (products of photosynthesis) from the infected parts (leaves) to the roots (cases of leaf diseases), from which the growth of the plant is reduced.

In wheat infected with rusts, at an early stage of plant development, the ratio of root dry weight to air organ dry weight is greatly lowered. Root weight can be reduced by 80% or more. This reduction results in a greater sensitivity of the host to lack of water. This is why some breeders look for varieties with great root development.

On the other hand, soil-dwelling nematodes can feed entirely on the roots and thus cause the plant to stop absorbing water and nutrients.

Also, in most cases, the infection causes pathological loss of water through the membranes and degraded tissues of the plants either by mechanical or enzymatic action. A large part of the absorbed water will be lost through the lacerated epidermis at the level of the lesions.

In some leaf diseases, water loss may be due to uncontrolled stomatal opening that remain open after pustules have opened or the pathogen has developed on the leaves.

On the other hand, the agglutination of pathogens on plant leaves causes the stomata to close, which leads to a decrease in transpiration, thus inducing a decrease in the absorption capacity of the roots in the plants (this usually occurs in the early stages of infection).

7.3.2 Action of pathogens on water and nutrient translocation in the host plant

The water and mineral elements absorbed by the roots pass through the xylem vessels of the stem to the leaves where they are used for the synthesis of organic substances through photosynthesis. The synthesized organic substances are in turn transported and distributed to all the cells of the plant via the vessels of the phloem. It is therefore evident that the interaction of plant pathogens with the movements of water and organic substances causes metabolic alterations in the interaction areas and in the plant as a whole.

The use of radioactive elements (3H, 14C, 32P and 35S) has shown that both organic and inorganic substances accumulate in the sites of infection. Infected bean leaves by rusts, for example, import 40 times more photosynthesis than the leaves of healthy plants, and the movement towards the apex of the stem is reduced by 5 times, and towards the roots by 8 times in infected plants. In wheat stripe rust (*Puccinia striiformis*), the translocation of carbon-14C after a 3-hour period was reduced by approximately 99% in infected leaves. The fungus seems to create a real storage area.

Several studies have reported the accumulation of 32P, Ca2+, S, Na+, K+, Mg2+,... and have proven that these ions are incorporated into the mycelium of fungi and have a direct action in the induction and differentiation of infection structures; and the supply of nutrients in the form of non-organic ions to plants increases their susceptibility to disease.

7.4 Action of pathogens on carbohydrate biosynthesis, utilization and degradation

To meet their energy needs, pathogens exert a competitive action on the nutrients that arrive or are synthesized at the plant level. Work carried out on the barley dwarf yellows virus (BYDV) has shown that the content of soluble carbohydrates in infected leaves increases by 400 times, and infection centers become sinks in which large quantities of carbohydrates accumulate and disappear (sucrose, glucose, fructose, etc.).

Several studies have shown that *Puccinia graminis f.sp. tritici* is able to hydrolyze sucrose into glucose and fructose, because invertase, the enzyme responsible for this hydrolysis, increases sharply in infected tissues. The accumulated sugars will be converted into arabitol, mannitol, trehalose and glycogen, none of which is a constituent of the plant.

The alteration of photosynthesis and trophic processes of the plant has repercussions on all the physiological functions of the plant (protein synthesis, respiration, reproduction, etc.), which consequently leads to a deficiency in the yield and quality of the harvested product.

8 Chapter VIII/ Plant Defenses Against Pathogens

To defend themselves against pathogens, plants have different mechanisms: physical barriers to the penetration of pathogens, or biochemical reactions that produce substances that are toxic to pathogens.

8.1 Structural Defense

8.1.1 By pre-existing structures in the host plant

These structures exist in the plant before infection and include the structure of the epidermal cell walls, the quality of the cuticle, the size and location of the stomata and lenticels, etc. Some varieties of wheat, in which the stomata open late in the day, are resistant to stem rust, because the germ tubes of spores germinating during the wet period of the night dry out after the water evaporates before the stomata open. Similarly, in some cereal varieties, the thickening of cell walls by the existence of bands of sclerenchyma cells can stop the invasion of pathogens.

8.1.2 By infection-induced structures

- Histological structures

The plant can form layers of cambium as a defense reaction against fungi or bacteria (Fig. 59). The formation of these layers is stimulated by substances secreted by the pathogen. They block the invasion of other parts of the plant by the pathogen, and prevent the passage of toxic substances secreted by the pathogen to healthy parts of the plant, and the passage of nutrients to the pathogen.

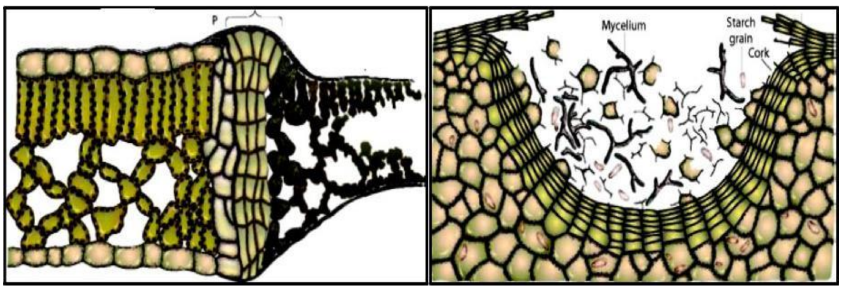

figure 59. Formation of histological barriers (protective tissue layers) between the healthy zone (ZS) and the infected zone (AZ)

(Adapted from Agrios, 2005)

Similarly, in some plants, abscission layers can form between healthy and infected surfaces of the plant (Fig. 60), resulting in the separation of the infected area from the rest of the plant (e.g. at the leaf level).

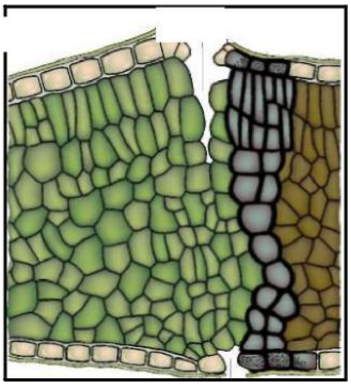

Figure 60. Formation of abscission layers (AC) between the healthy zone (ZS) and the infected zone (AZ) (Adapted from Agrios, 2005)

- Cellular and cytoplasmic structures

This type of defense consists of the formation of appositions (papillae) induced by the pathogen (fungus) at the level of the first plant cells it encounters.

 Papillae: The papilla is an anatomical change that forms in plants in contact with fungi and consists of the formation of deposits between the wall and membrane of the host cell that is in contact with the parasite (Fig. 61). It is usually preceded by an aggregation of the cytoplasm of the plant cell. It can be induced by metabolites of the fungus, or by alteration of the cell walls of the plant. They are made up of polyphenols, callose, proteins (thionines), pectic matter, enzymes and soluble and insoluble elements: Ca2+, Mg2+, Si, lignin, glucose, etc. lignin is responsible for the resistance of the papillae to pathogen enzymes (it makes the cell walls more resistant to mechanical pressure forces, limits the diffusion of toxins and enzymes from the pathogen to the host cells, and prevents the passage of water and nutrients from the host to the pathogen), This mechanism is associated with the activation of enzymes such as phenylalanine ammonia-lyase, peroxidases, tyrosine ammonia-lyase, etc.

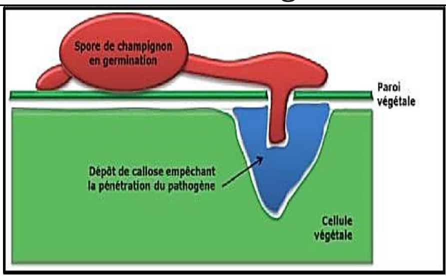

Figure 61. Schematic representation of a pathogenic fungus, whose attempt to penetrate fails thanks to a deposit of callose at the level of the plant wall.
https://blog.vegenov.com/2014/01/plantes-defense-zig-zag/

Necrotic reaction: Hypersensitive reaction (HR)

Hypersensitivity is an early necrotic reaction that occurs in resistant plants upon infection with fungal, bacterial or viral pathogens. This reaction corresponds to an incompatible relationship and generally takes place by inducing the synthesis of peroxide ions (O2-). The molecules inducing the hypersensitive reaction are usually polysaccharides. Once the inducer (parasitic molecule) is attached to a corresponding receptor (host molecule), a signal is transmitted from the membranes to the nucleus of the host cell, and a necrotic zone is formed, corresponding to a slowing or complete cessation of the growth of the hyphae in the cells of this zone (Fig. 62). This leads to the activation of genes in neighboring cells leading to the synthesis of phytoalexins and the lignification of the walls. In compatible strains, the induction of hypersensitivity is blocked by soluble glucans emitted by the pathogen and which inhibit the formation of ions (O2-).

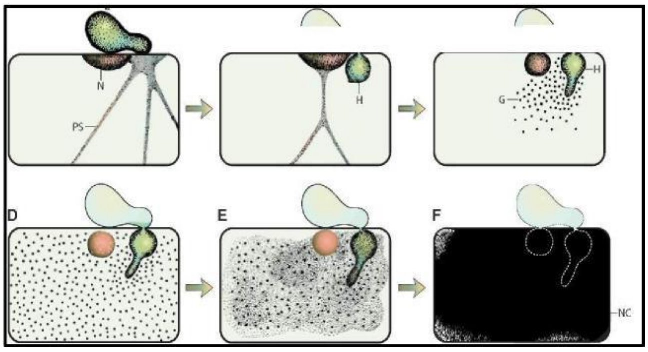

Figure 62. Developmental stages of the necrotic defense reaction in a potato variety that is highly resistant to *Phytophthora infestans*.
(Adapted from Agrios, 2005)

8.2 Biochemical Defense

8.2.1 Pre-existing biochemical defense

In some resistant plants, the concentration of certain substances is observed at the sites where pathogens penetrate (stomata, lenticels) such as phenolic compounds that are toxic to different pathogens. Similarly, species that for some reason do not produce the nutrients necessary for the development of certain pests may be resistant to these pathogens.

8.2.2 Pathogen-Induced Biochemical Defense

This type of defense consists of a series of biochemical reactions often associated with the production of toxic substances around the site of infection.

1. Phenolic compounds

Several studies reveal the accumulation of phenolic compounds in the tissues of plants injured or infected by pathogens. These compounds (chlorogenic acid, caffeic acid, scopoletin, etc.) accumulate in large quantities after infection, in resistant varieties. Phenolic compounds and their oxidation products cause the hypersensitivity reaction of plants. Similarly, these compounds can be oxidized by polyphenoloxidase to quinones, which are more toxic to microorganisms than the original phenols.

1. Peroxidases

Peroxidases accumulate in tissues showing a hypersensitive response. In addition to their role as antimicrobials, these compounds are involved as messengers in the induction of the expression of genes encoding the synthesis of proteins related to pathogenesis, and their presence is essential for the deposition of molecules such as sugars, lignin, lipids and proteins in cell walls.

2. Phytoalexins

Phytoalexins are molecules whose synthesis is induced in plants in response to various irritation factors (fungi, bacteria, viruses, UV rays, jelly, salts, etc.) and which have an inhibitory power against microorganisms. Molecules that induce the synthesis of phytoalexins are referred to as " elicitors "..

Phytoalexins are synthesized in living cells adjacent to infected cells and they are thought to diffuse to dead cells where they accumulate. Each plant species has its own specific phytoalexins: pisatin in peas, phaseolin and phaseolidin in beans, glyceollin in soybeans, etc

9 Chapter IX / Methods of Pathogen Studies

9.1 Pathogens of (olive tuberculosis)

9.1.1 Biology, symptoms and organic control

Olive tuberculosis is a bacterial disease caused by *Pseudomonas savastanoi*

Agent causal: *Pseudomonas syringae* ssp. *savastanoi* pv. *oleae*.

The spread of the bacterium responsible for tuberculosis in olive trees is mainly carried out by vectors such as insects contaminated by the pathogen. They recover the disease when they settle on fresh wounds on the tree, possibly caused by natural phenomena (wind, hail, etc.), or by human intervention during the various cultural tasks (grafting, pruning, picking, etc.).

After penetration of *Pseudomonas savastanoi*, there is generally an incubation period of 1 to 3 months, depending on the climate. The optimal climatic conditions for the development of the olive tuberculosis bacterium are between 25 and 30°C, and a relative humidity of more than 80%. During periods of heat and drought in summer, and during the winter season, olive tuberculosis bacteria take refuge inside the galls, where nearly 90% of the parasites will be able to survive and resume their activity the following year.

9.1.2 Symptoms of Tuberculosis of Olive Trees

The bacterium *Pseudomonas savastanoi* causes the appearance of very characteristic typical tumors **on the vegetative organs of the olive tree, leaves and twigs** . On the fruits (olives), these cracked growths are not observed.

The points of infection of olive tuberculosis are dark areas that can exude viscous material.

1. Biological control measures against tuberculosis in olive trees

As with most bacterial diseases, prophylactic methods remain the main part of the arsenal available to fight the pathogen biologically. The risk of olive tree infestation with tuberculosis can be potentially reduced by ensuring that:

a. Prune diseased branches and twigs.

b. Avoid injury during harvest.

c. Avoid pruning olive trees during rain and dew.

d. Prune the trees attacked last and disinfect the pruning tools.

Practical work I

9.2 Isolation; Identification; Conidia Characterization, Culture and Enumeration (P.W. I)

9.2.1 Preparation and enumeration of a Fusarium conidia suspension

The handling consists of making a suspension of spores of a mold: Fusarium. The spores are called conidia and have an elongated, spindle-shaped appearance. An enumeration in agar medium is then carried out after an estimation of the concentration of conidia in the Malassez cell. 1.1. Equipment – Fusarium culture on Sabouraud agar – 120 mL of Sabouraud agar + supercooled chloramphenicol – 6 empty sterile petri dishes – 1 tube of 10 mL of sterile physiological water – 1 mL straw or graduated pipettes of 1 mL – available: P1000 and tubes of physiological water 5 mL, 9 mL and 10 mL – Malassez cell 1.2. Preparation of Fusarium Conidia Suspension F Place 10 mL of sterile physiological water on the surface of the Fusarium culture on Sabouraud agar. Soak the mycelium very gently with a sterile rake. Leave in contact for about ten minutes, stirring occasionally. Recover a few mL of the suspension in a hemolysis tube. Carry out the count of conidia in Malassez cells; count at least 200 conidia. (show a microscopic field to the examiner). Evaluate the concentration of conidia per mL of suspension F (Document 1 available: grid of the Malassez cell). 1.3. Enumeration of conidia in agar medium Carry out the necessary decimal dilutions of the F suspension for enumeration in agar medium (have the choice of dilutions checked by the examiner). A number between 15 and 150 is aimed for central dilution. The medium used is Sabouraud + chloramphenicol agar. Make 2 per dilution, without double coat. Incubate for 24 to 48 hours at 30°C.

Report Present the result of the count in Malassez cells and the calculation of the concentration of conidia per mL of suspension F. Justify the choice of dilutions tested.

1.1. Give the result of the count in the conidia suspension (use technical sheet 2). 1.2. Determine the 95% confidence interval of the result. 1.3. Compare (arbitrarily) this result with the result of the cell count of Malassez 2. Identification of a contaminant the cups of the so-called "assimilation" test series (GLU to PAC) seeded with the AUX MEDIUM bulb. Here is the composition of this medium: – ammonium sulphate 2 g – agar 1.5 g – mineral base 82.8 mg – amino acids 250 mg – vitamins 35.9 mg – phosphate buffer 0.04M pH = 7.1 qsp 1000 ml 2.1. Observe the composition of the medium medium. a) How can this environment be qualified? b) What is the role of ammonium sulphate? (c) How the assimilation tests are read; express in one sentence what "GLU+" means, for example. d) What is the role of amino acids and vitamins?

Justify their presence at very low concentrations. e) The cupules of the assimilation tests are inoculated with a very low inoculum (see API 20NE data sheet). What for? f) The API 20NE gallery finally includes 2 "GLU" tests. A classic test, GLU (under oil) and an assimilation test. Compare the meaning of these two tests. What relationship can be written between these two tests? 2.2. Read the seeded media. Identify the strain using the tables (document 2) and the probabilistic method (API 20NE index and APILAB software available). Discuss possible tests against.

1. Characteristics of the Malassez cell (P.W. II)

Volume total V tot = 1mm3 (soit 1µL)

100 rectangles of 20 small squares

Volume v of 1 rectangle = 0.01mm3

Slightly moisten the side plates and then adhere the slat by moving back and forth with your thumbs until resistance is perceived (iridescent fringe). Introduce the suspension, after homogenization, by placing the end of the pipette (or a cone) near the coverslip. The liquid must not reach the central channel. Let settle for about 10 minutes. Observe with x10 and then with x40. Check the homogeneous distribution of the cells. The number of cells should be between 10 and 100 per rectangle if possible. Dilute the suspension if this number is too high. Count on a number of rectangles corresponding to about 200 cells (Figure 63)

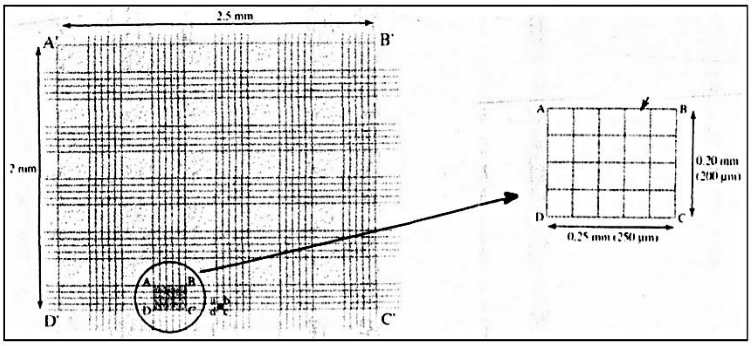

Figure 63. Cellule de Malassez

9.2.2 Cell count

9.2.2.1 Principle

Cell count is the determination of the number of cells contained in a specific volume of liquid medium. The result of the count is expressed in cell concentration, i.e. in **the number of cells per liter**.

Cell counting is performed directly by counting under a microscope, using a special counting slide (or counting cell).

9.2.2.2 Cell Count Technique

1-Prior dilution

When the cell suspension is too concentrated, it is necessary to perform a prior dilution. Indeed, when the suspension is too concentrated (large number of cells per unit volume), it is difficult to count the cells.

2-Using the Numeral Cell

a-Presentation of the counting cells

There are two main types of count cells:

-Thoma's cell.

-Malassez cell (the most common).

A numeral cell is an object slide in which a **counting chamber of known volume** is hollowed. It is a thick glass slide, with channels and a grid (figure 64):

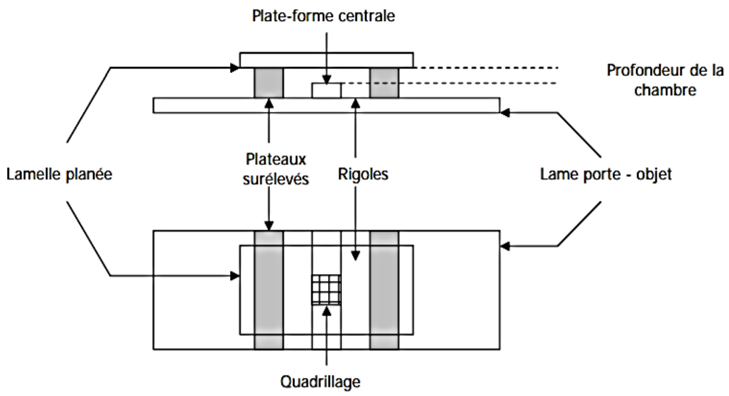

Figure 64. counting chamber of known volume

The counting volume is determined by:

- the surface of the grid engraved on the blade.
- the depth of the chamber.

b-The cell of Malassez

The Malassez cell has a specific grid with 100 rectangles (Figure 65):

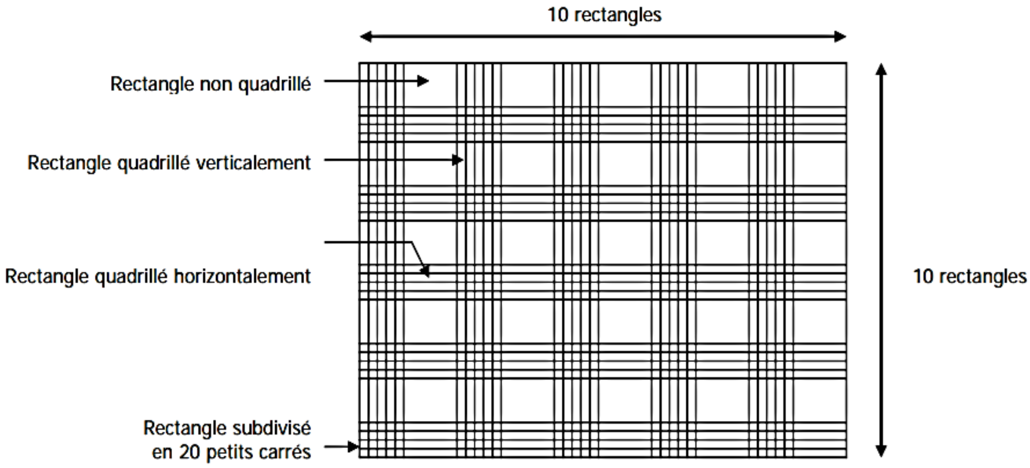

Figure 65. The Malassez cell

Among the 100 total rectangles, there are 25 rectangles that are divided into 20 small squares in order to facilitate counting.

→ the volume corresponding to the total grid is equal to 1 mm3 = 10-6 dm3

→ each rectangle corresponds to a volume 100 times smaller, i.e. 0.01 mm3 = 10-8 dm3

c-Filling the counting cell

• Moisten the two side plates. Make the slat adhere perfectly to the side plates: to do this, place the slat on these plates, then using the thumbs placed on the slat, exert pressure on the slat while moving back and forth until a resistance is perceived.

• Place the counting cell on a flat surface. Homogenize the cell suspension, and remove it using a Pasteur pipette. Fill the counting chamber by capillary action, placing the tip of the pipette slightly inclined near the coverslip on the central gridded platform.

→ The filling must be done **in one go, without air bubbles**, and without causing the liquid to overflow into the gullies. Let the cells settle on the grid for a few minutes, then proceed to the count.

• After use, the object blade and the planing lamella are immersed in a bleach bath for 5 minutes, then rinsed with distilled water and wiped with paper (without rubbing, especially at the grid).

3-Numeral

• Observe with the x10 objective to identify the position of the grid, and check the homogeneity of the distribution of the cells to be counted (if the distribution is poor, start again).

• Then observe with the x40 objective to carry out the count (1 rectangle per field).

• Count the cells contained in 4, 10, 20 or all of the 100 rectangles in the grid. **Note**: for cells overlapping the grid lines, count only those that overlap 2 edges of the rectangle out of 4 (in practice, we choose to take into account the cells overlapping the upper horizontal line, and the straight vertical line) (Figure 66).

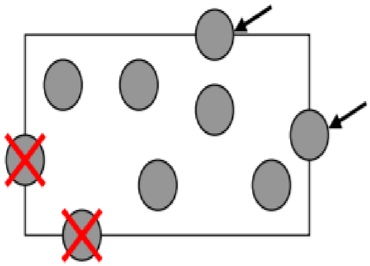

Figure 66. numbering on the triangle = 7 cells

4-Calculation of the cell concentration

After the manipulation, the cell concentration of the cell suspension studied is calculated. Are:

-n: number of cells counted.

-V: Counting volume.

-f: dilution factor.

-N: number of cells per liter.

If we have n cells in V liters, then we have N cells in one liter:

$$N \times V = n \times 1 \longrightarrow \boxed{N = n / V}$$

If the solution had been diluted: N = (n / V) x f

III-Manipulation

We count 2 samples:

- a suspension of brewer's yeast (Saccharomyces cerevisiae).
- a diluted suspension of bovine red blood cells.

Carry out each count by counting on 10 rectangles (choose these rectangles at the four corners of the grid).

Account

• Recall the main characteristics of the Malassez cell (appearance, number of rectangles, total counting volume, counting volume for a rectangle, etc.)

• Submit a table of results for each count:

Example:

Rectangle	Number of cells counted	Counting volume in (dm^3)
1		
2		
3		
….		

	Total counted number =	Total Counting Volume =

• Calculate the cellular concentration of the yeast suspension. Render the results in number of cells per dm3 of suspension.

• Calculate the cellular concentration of red blood cells in the dilute red blood cell suspension. Render the result in number of red blood cells per dm3 of suspension.

Knowing that this red blood cell suspension was obtained by diluting the blood tested 300 times, deduce the cellular concentration of red blood cells in pure **blood**. Render the result in number of red blood cells per dm3 of blood.

1. Spore Count and Dilution Techniques (P.W. III)

The plan

Introduction

1. **Purpose of the P.W.**
2. **Material and (technical) method used**
3. **Results of the experiment**
4. **Interpretation of the results**

Conclusion

9.2.3 Introduction

Infections in different species differ from one species to another, depending on the number of spores. Because for each species it would take a specific number for it to be able to carry out the infection or in other words for us to have an optimal infection.

In our experiment we will show that to obtain an optimal infection, the concentration of a spore solution varies from one species to another.

Whereas it would take 10 spores for a species like *Ascochyta chrysanthemi* (Figure 67).

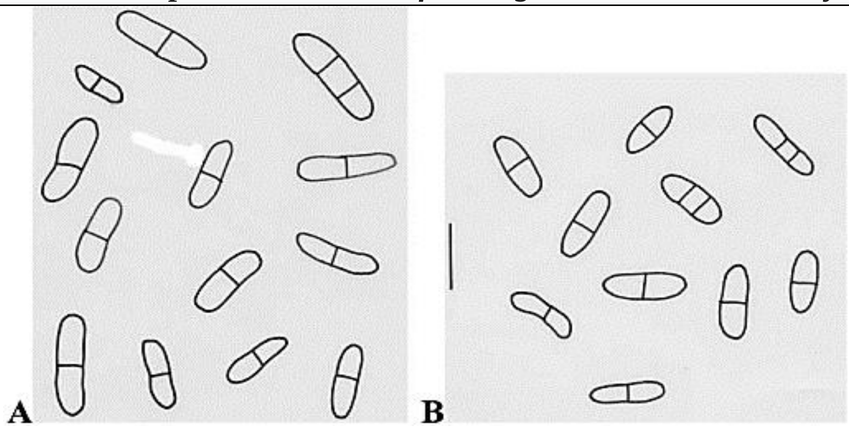

Figure 67. Conidia of *Ascochyta chrysanthemi*

On the other hand, it would take 5000 spores to obtain the same effect with *Ascochyta pisi*, .

Photographer: Bruce Watt

Organization: University of Maine

Descriptor: Asexual Spore

Description: Conidia.

Image type: Laboratory

Host: lilac (*Syringa* spp.)

9.2.4 The goal of the P.W.

It is the use of a cell bounded by a grid to count spores per ml of water at the microscope.

By this technique (method) we can determine the number of spores per any unit of water we want to use.

9.2.5 Equipment and techniques used

1. An optical microscope
2. A MALASSEZ cell: this is a cell delimited by a grid whose volume of each rectangle is defined by the depth of the grid striations.
3. The grid varies from cell to cell, but the number of spores is defined by the volume of each cell.
4. So, for the type of hematists:

   There are many types of cells, but in our case, we only use the MALASSEZ cell. The following diagram shows the grid of this cell.
5. The spores of *Ascochyta pisi*, a small part of the colony of this fungus, are used in a test tube + 8ml of distilled water. By mixing the contents using a vibration (vibrator).

6. We put a drop on the MALASSEZ cell, we add a lamella on it.
7. We look at it microscopically, to count the spores in each square.
8. After counting all the spores that are in the squares, we determine the total number of spores that are in the squares (at the level of the whole cell). Then, we calculate the volume of water that is under the lamellae and that is limited by the grid of the cell. We calculate the number of spores by this volume of water which will allow us to determine the number of spores per 8ml of water.

9.2.6 Results of the experiment

After counting the number of spores that are under 25 squares

1. In 9 squares → 48 spores

25 squares → X spores

$\Rightarrow x = \frac{25\ x\ 48}{9} = 134\ spores\ in\ 25$ squares

And to calculate the volume of water

134 spores → 0.25 mm^3

X spores → 1 mm^3

$\Rightarrow X = \frac{134}{0.25} = 536$ spores/mm^3

Therefore, 536 → 10^{-3}ml

X → 1 ML

$\Rightarrow X = \frac{536\ x\ 1}{10^{-3}} = 536\ x\ 10^3$ spores/ ml.

Therefore, par 8 ml of distilled water, we have: 8 x 536 x 10^3 = 4288 x 10^3.

9.2.7 Conclusion

This examination allows us to count the number of spores by a quantity of solution allows us to know the concentration of a solution in spores, thus, allowing us to calculate the number of spores that can infect a plant or pathogen a plant.

Practical work IV

9.3 Mushroom cultivation (Kokh's principle) (P.W. IV)

This is the basis of all pathological diseases to prove pathogenesis:

It is a process to prove pathogenesis:

1. Isolate fungi on a medium and put it on an artificial culture medium (Figure 68).

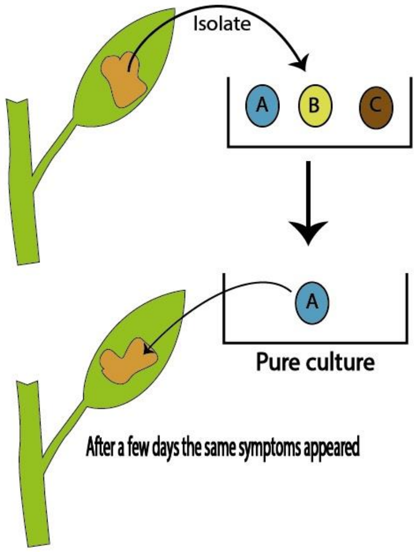

Figure 68. Showing the technique of mushroom isolate and culture

1. It was known that the pathogen is of the colony (A):
   Cause →Symptoms→Isolate the cause → inoculate a healthy organ → produce the same symptoms→ Isolate and observe under a microscope.

The pathogenic fungus infiltrates plant tissues (either inside cells or between cells) and infiltrates through the secretion of certain types of enzymes. This contact of the fungus' mycelium with the host's cells facilitates the feeding of the fungus with the help of haustoria (a special branch of a fungal hyphae, adapted to the absorption of food, and which often penetrates the cells of the living host), by means of osmosis and absorption (Figure 69).

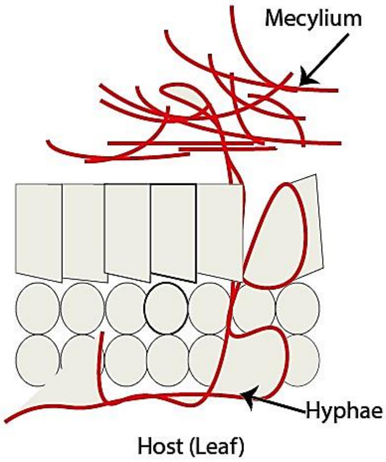

Figure 69. Showing the infiltration of hyphae of a mycelium inside the tissues of the host

The formation of a germinal filament indicates the beginning of the fungus life. This germinal filament is born from a propagule.

Propagules have various morphological forms:

Example

1. Spores
2. Conidia
3. Sporangia

These are propagules that facilitate the production of a specialized organ that facilitates the formation of a new mycelial filament; These propagules are formed sexually or asexually. (Propagule = seed).

Reproduction

To facilitate a great power of dissemination, fungi have many means of propagation (dissemination of propagules over a large area).

1. Vegetative reproduction (asexual): by simple cutting of mycelium, the new thallus can form another mycelium. This mycelium can produce asexual spreading organs (spores) (Figure 70).

The conidia are a propagule usually produced by the mycelium, when the conidia fall on a surface, it produces a germinal filament.

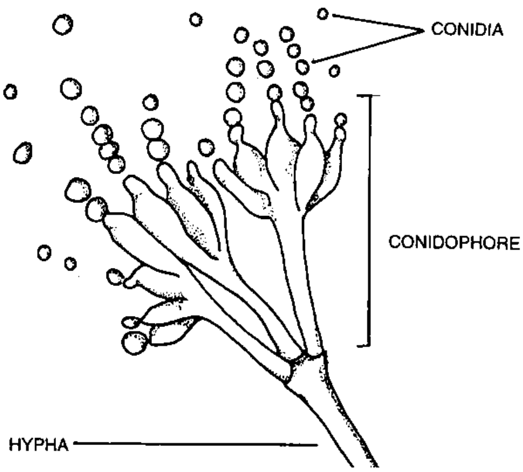

Figure 70. Asexual reproduction

2. Sexual reproduction: this is a propagation by sexual route; in general, there is a conjugation of two filaments (the female organ is the archegonia and the male organ is the antheridia), a contact of the walls facilitates the fusion of two nuclei. In so-called heterothallic fungi, sexual reproduction is possible only by the fusion of the two genetically different individuals, but morphologically are identical. While for other species, even between their cells of the same thallus (Homothallic), the cells can meet and fuse the nuclei.

N.B.: there would have to be genetic compatibility.

Practical work V

9.4 Classification of mushrooms (P.W. V)

Teleomorph: the sexual reproductive stage (morph), typically a fruiting body.

Anamorph: an asexual reproductive stage (morph), often mold-like. When a single fungus produces multiple morphologically distinct anamorphs, these are called **synanamorphs**.

Holomorph: a qualifier that designates both stages at the same time. (the whole fungus, including anamorphs and teleomorph).

Origin and challenges of this classification:

Fungi have been classified for several centuries mainly on the basis of the physical characteristics of their reproductive organs (stem, cap, etc.) which are relatively stable during evolution and in a population (while the shape, size and color of the mycelium can be more variable).

But many fungi reproduce only asexually. These species, which are difficult to classify, are most often Ascomycetes and Basidiomycetes. Some species rarely reproduce sexually or are only known in an asexually reproducing form without it being possible to know whether the sexual form still exists or has existed (in the case of a recent mutation for example). Pathologists often have the opportunity to observe only one of the two possible forms of reproduction. In addition, the two stages and/or forms of reproduction offer a morphologically very different appearance; The same fungus may have been described under two different names. It is genetic analysis that can guarantee that it is indeed one and the same species.

In the same fungal colony, the two forms of reproduction, sexual and asexual, can coexist, in which case we speak of a holomorph.

The terms Teleomorph, Anamorph and Holomorph can therefore describe 3 different states of the same fungus in the process of reproduction. They usually apply to parts of the life cycle of Phylum Ascomycota fungi; Basidiomycota.

Article No. 59 of the International Code of Botanical Nomenclature allows Mycologists to give two different names to the same mushroom to respectively describe:

1. Its asexual (anamorphic) reproductive state
2. Its state of sexual reproduction (Teleomorph)

When the two scientific names already exist for the two states (Anamorph and teleomorph) of the same fungus, the rule is that the mixed form (Holomorph) takes the name of the teleomorph.

For practical reasons, fungi for which no **teleomorph** is yet known have been classified in a phylum artificially created for them (**Deuteromycota**), formerly also referred to as **Fungi imperfecti** (Imperfect fungus).

Sclerotia: is the form of winter preservation of certain mushrooms. It is formed of compact mycelium. Often a pigmented layer (Cortex) can be distinguished surrounding a pseudo parenchyma (medulla) containing nutrient reserves. When this differentiated structure does not exist, it is rather referred to as pseudo sclerotia. Fungi belonging to very different families can have a sclerotia phase produces pseudo sclerotia, for example:

1. *Sclerotinia sclerotiorum*
2. *Botrytis cinerea*
3. *Claviceps purpurea*
4. *Sclerotium rolfsii*

Germination: at the end of winter, the sclerotia germinates, either by producing mycelium or spores. For this reactivation to be possible, the temperature and humidity must be favorable, but other conditions may be necessary, such as a signal from the host plant of the parasite or vernalization (a period of cold suffered by the plant or seed) is necessary to move the plant from the vegetative stage to the reproductive stage, so to germinate and then flower. (Some laboratories have greenhouses or pits equipped for "controlled vernalization"

Vernalization and stratification: are two different notions, although often confused.

Vernalization: is the biological phenomenon, while stratification is a technical process for breaking dormancy. Cold lamination is a process intended to artificially imitate vernalization.

Practical work VI

9.5 Observation and characterization and classification of the Brown Rhizoctonia (*Rhizoctonia solani*) (P.W. VI)

Brown rhizoctonia, also known as "black rhizoctonia", "tuber pox" or rotting agent, is a fungal disease that affects various cultivated plants including beetroot, potatoes, as well as carrots, chicory, lettuce, endive, etc. and which is caused by a basidiomycete fungus, Rhizoctonia solani Kühn. This cosmopolitan fungus, whose teleomorph is *Thanatephorus cucumeris*, has a wide range of host plants. It is one of the causes of damping-off. On potato crops, damage is characterized by lack of emergence, delayed tuberization, yield declines and depreciation of the value of the crop in the event of a high presence of sclerotia on the tubers.

9.5.1 Classification

Kingdom: Fungi

Division: Basidiomycota

Class: Basidiomycetes

Subclass: Agaricomycetidae

Order: Cantharellales

Family: Ceratobasidiaceae

Genre: Rhizoctonia

Nom binomial : Rhizoctonia solani Kühn, 1858

Characteristics of the fungus and life cycle

Rhizoctonia solani is in fact the asexual (also known as imperfect) stage of the class Basidiomycetes, the order Homenomycetales and the family Corticiaceae.

Rhizoctonia solani is a hydrophilic and thermophilic fungus. Below 9°C, no infection can occur. On the other hand, at 20°C, the incubation time is only 3 days and at this time, the spread of the infection is very fast. It is mainly a summer or warm-season mushroom (June to October) (Figure 71). *Rhizoctonia solani* is preferentially located in the upper layers of the soil (in the first two cm). In the soil, it can be kept for several years in the absence of plants or favourable conditions. This preservation is done in the form of sclerotia, intertwined clusters of mycelia, hard and dark in color.

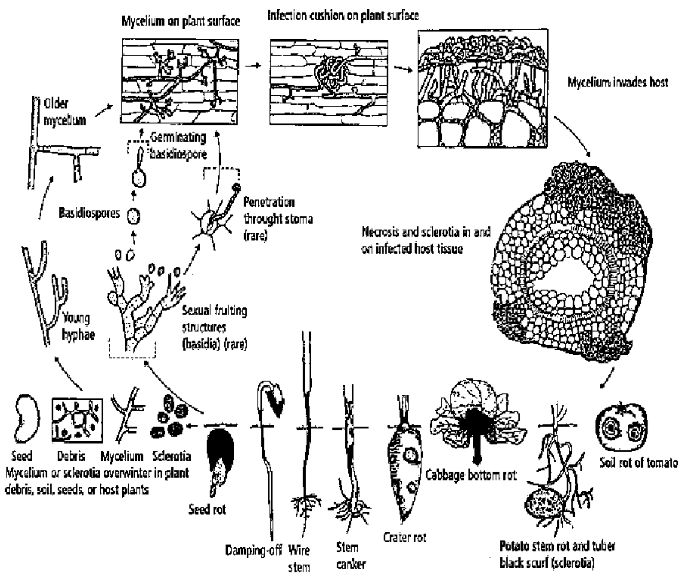

Figure 71. Disease cycle of R. solani (Source: Agrios, G.N.1997.Plant pathology, 4th edition. San Diego: Academic Press.)

9.5.2 Symptoms

It mainly attacks seedling crops and young transplanted plants. The attack is at the collar. The disease progresses in successive spots. At the level of the roots and leaf petioles at the interface of the soil, small dry brown to red necroses develop. Gradually, the browning spreads. This rot is the cause of plant toppling and dieback. The attack can then progress towards the tuber. In the attacked areas a shiny grey-brown mycelium develops. As a result of the movement of the plant, the root system can often be accompanied by those of other fungi such as *Nectria radicicola* and *Botrytis cinerea*. These fungi produce various enzymes that allow them to turn brown as well. As for the air system, it will tend to behave as if it were affected by chlorosis. Attack by older plants can also occur. It degrades cellulose and lignin in plant tissues. It is by this means that rot develops.

9.5.3 Spread of Rhizoctonia solani

Since the production of asexual spores is zero, the risk of dissemination by water, drafts and insects is zero.

In fact, it is the plants themselves that are the most important source of contamination.

This pathogen is present on a very large number of host plants.

Therefore, any soil that is not decontaminated is considered potentially infested. Sclerotia can live for many years in a saprophytic state on plant debris. They germinate under the action of the root exudates emitted by the plant when climatic conditions are favorable.

With a very strong saprophytic capacity, the mycelium develops quickly in the soil to the plant it will infect.

The favorable conditions are:

1. Substrate pH greater than 5.8
2. Substrate temperature in the range of 15 to 35°C, with dry substrate

Practical work VII

9.6 Pathogenic fungal inoculation technique (P.W. VII)

Plan

Introduction

1. The goal of the P.W.
2. Techniques and equipment used
3. The results of the experiment
4. Interpreting the results

Conclusion

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