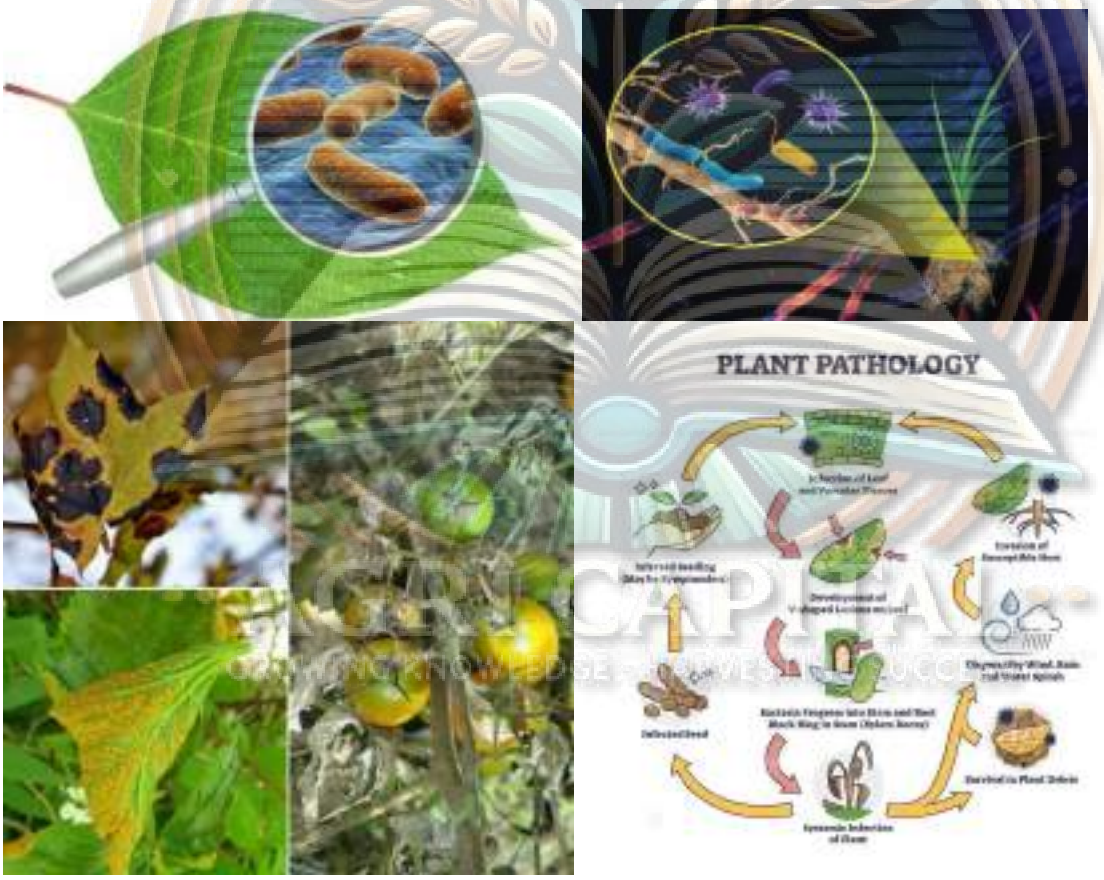
ACCORDING TO ICAR SIXTH DEANS' COMMITTEE

Fundamentals of Plant Pathology



SYLLABUS

UNIT NO.	UNIT NAME
1.	Introduction to Plant Pathology.
2.	History of plant pathology
3.	Concept of disease in plants.
4.	Causes of plant disease; Inanimate and animate causes
5.	Classification of plant disease
6.	Parasitism and pathogenesis.
7.	Development of disease in plants: Disease Triangle, Disease cycle
8.	Bacteria: Morphology, reproduction classification of phytopathogenic bacteria.
9.	Fungi and their morphology, reproduction and classification of fungi
10.	Other plant pathogens: Mollicutes; Flagellant protozoa; FVB; Green algae and parasitic higher plants; Viruses and viroid's, virus transmission
11.	Principles of Plant disease management: Disease management with chemicals, cultural and biological method of Integrated Disease Management (IDM), Host Plant Resistance

1. Introduction to Plant Pathology

Plant Pathology or Phytopathology: It is a science that deals with the study of diseases of plants, their development and control.

Phytopathology: Phyton = Plants, Pathos= Disease, logos= Science.

Plant disease: A malfunctioning process that is caused by continuous irritation which results in some suffering-producing symptoms.

The continuous irritation may be brought about by living and non-living factors (environmental) because of which the particular process in metabolic and catabolic activity of plant cells is disrupted leading to development of symptoms as a reaction to such suffering.

These may be brought about by utilizing host cell content, by death of tissue, excess production of enzymes, toxins, growth regulators, loss of nutrition and interference in translocation of food, minerals & water.

Diseases for plants have been known since ancient time.

Disease: is defined as a disturbance in the rhythmical equilibrium in the activities of host in respect of structure or physiology or both, leading to the death of a part or entire host, or reduce the economic value of the products.

OR

Disease: is a complex phenomenon, it is an interaction between the host, the pathogen and the environment.

OR

Disease: is malfunctioning process caused by continuous irritation, which results in some suffering producing symptoms.

Or

A structural abnormality or physiological disorder or both due to an organism or unfavorable conditions that may affect the plant or its parts or products or may reduce the economic value.

Pathogen is an entity usually a microorganism that can incite disease in susceptible plants. It is also referred to as incitant, causal agent or causal organism.

Plant Disease: (dis-ease ie., not at ease): It is the malfunctioning of host cells and tissue that results from continuous irritation by a pathogenic agent and leads to development of symptoms.

Symptoms: External or internal reactions or alterations of a plant as a result of disease.

Importance of plant pathogens:

1.Plant diseases caused by microorganisms are of paramount importance to humans because they damage plants and plant products on which human depend for food, clothing, furniture and housing.

2. Millions of people all over the world still depend on their own plant produce for their survival.
3. Plant diseases reduce the quality and quantity of plant produce. Eg.Wheat bunt caused by Tilletia sp.
4. Results in increased prices of products to consumer.
5. Results in severe pathological effects on humans and animals that eat plant products.
6. Destroy beauty of environment by damaging plants around home, park, streets and forests.
7. The pesticides used to control disease, pollute the water and environment.
8. Reduce crop yields.
9. Cause financial loss ie.,the money spent for plant protection c hemicals.
10.Changes agricultural pattern.
11.Influences the industries ie.,lack of raw material .
12.Some plant diseases even change food habits of human population.

Plant diseases are caused by biotic agents like fungi, bacteria, actinomycetes, phytoplasma, viruses, nematodes, flowering parasites or by abiotic agents like unfavorable environmental conditions or nutritional deficiencies.

Study of plant pathology includes the study of mycology, nematology, protozology, phycology, unfavorable environmental factors, nutritional deficiencies and flowering plant parasites.

Branches of Plant Pathology:

Microbiology: Study of Microorganisms
Mycology: Study of Fungi
Bacteriology: Study of Bacteria
Virology: Study of Viruses
Nematology: Study of Nematodes
Protozoology: Study of Protozoa
Phycology: Study of Algae

Objectives of Plant Pathology:

Plant Pathology or Phytopathology is one among the branches of Agricultural sciences that deals with cause, etiology, resulting the losses and management of plant diseases with following four major objectives.

i. Study the disease (s) / disorders caused by biotic and abiotic agents (s)
ii. Study the mechanism (s) of disease development by Plant Pathogens.
iii. Study the interaction between plant and pathogen in relation to overall environment.
iv. To develop suitable management strategies for managing the diseases and losses caused by them.

Economic importance of Plant diseases: ¬

The plant diseases are very important because they cause enormous losses to the cultivated crop. The losses due to plant diseases accounts around 26% in field, storage and transportation.

1. Impact of plant diseases on population: The late blight of potato is a famous example in history of plant pathology, the disease assumes epidemic proportion in Ireland in 1845 devastating the whole potato crop. The potato being the staple

food of people & because of non-availability of it, around 20 lakh people died due to starvation & migration of population to other lands including North American continent. ¬ Helminthosporium leaf spot of rice devasted rice crop in west Bengal in India during 1942-43 & thousands of people died because of hunger & migrated to other part of country.

2. Change in Agri Pattern: The diseases like coffee rust in Ceylon had changed the economy of country & shifting to other plantation crop like tea. In 1885 there was epidemic of coffee rust in Ceylon which devasted the entire coffee, Due to the rust yield of coffee went down from 228 kg/ acre to 101 kg/acre by 1878 & because of which by 1893 the coffee export of Ceylon reduced by 93% thus making huge loss. The coffee rust became so Severe that Ceylon has to shift itself to cultivation of tea.

3. Food Poisoning: The poisoning of food due to plant disease is another evil. There is death of people & animal due to consumption of contaminated rye with ergot, which produces toxin fetal to human beings & animals. Also, production of aflatoxin by Aspergillus flavus in foodstuff is also fetal to human beings.

4. Impact on Industry: The certain agro industries are also affected due to supply of the diseased raw material. e.g. The disease red rot of sugarcane affects the sugar industries because of poor recovery of sugar from such infested material which in turn increases the cost of production.

5. Impact on science: The plant disease system had provided a great scope for expanding the areas of human knowledge regarding, Microorganism, their taxonomy, ecology,

physiology & biochemistry, genetic, molecular & cellular biology & managements practices for control of crop diseases.

6. Useful plant diseases: The man has commercially exploited the plant disease for economic gain & aesthetic value

HISTORY:

Mycology (Mycetology- Greek grammer): It is the Science which deals with study of fungi.

Term Mycology derived from 2 Greek words. Mykes= mushroom / fungus, logos= discourse or study.

Term Fungus is derived from a Latin word fungor = to flourish.

Study of fungi started with study of mushrooms because of their macroscopic size and brilliant color.

Mushrooms attracted the attention of ancient people,and they started studying them out of curiosity.

Old Romans had interest in mushrooms and named one of their city name as 'Mycenean'.

Mycology

1675 - Dutch worker Anton von Leeuwenhoek developed the first microscope.

1729 - Italian botanist P. A. Micheli proposed fungi comes from spores; father of Mycology.

1755 - French botanist Tillet published a paper on bunt or stinking smut of wheat; discovered bunt is a disease of wheat.

1807 - French scientist I. B. Prevost showed bunt of wheat is a fungus and showed evidence that a disease is caused by a microorganism.

Foundational Contributions (1821–1865):

- **1821:** *E. M. Fries* published *Systema Mycologicum*; known as the *Linnaeus of Mycology*.
- **1821:** *Robertson* (England) discovered sulfur's effectiveness against peach mildew.
- **1845:** *Irish Potato Famine* caused by *Phytophthora*

infestans, leading to mass starvation and migration.
- **1858:** *J. G. Kuhn* published the first plant pathology textbook, *The Diseases of Cultivated Crops*.
- **1861:** *Anton de Bary* (Germany) proved fungi cause diseases; identified *Phytophthora infestans* as the agent of potato late blight—*Father of Modern Plant Pathology*.
- **1865:** *Anton de Bary* discovered the heteroecious nature of wheat stem rust.

Key Discoveries (1869–1904):
- **1869:** *Coffee rust* outbreak in England led to a shift from coffee to tea cultivation.
- **1874:** *Robert Hartig* published *Important Diseases of Forest Trees*—*Father of Forest Pathology*.
- **1875–1912:** *Brefeld* pioneered artificial culture techniques for microorganisms.
- **1877–1878:** *M. S. Woronin* identified *Plasmodiophora brassicae* (clubroot of cabbage) and studied potato wart disease.
- **1881:** *H. M. Ward* studied coffee leaf rust—*Father of Tropical Plant Pathology*.
- **1885:** *Millardet* discovered Bordeaux mixture for controlling downy mildew in grapes.
- **1894:** *Eriksson* described physiologic races in *Puccinia graminis* (cereal rust fungus).
- **1904:** *R. H. Biffen* proved plant disease resistance can be inherited as a Mendelian trait.

Advancements in Disease Resistance and Physiology (1912–1957):
- **1912:** *H. Burgeff* described heterokaryosis in fungi.

- **1917:** *E. C. Stakman* demonstrated physiologic forms in wheat stem rust.
- **1918:** *E. J. Butler* published *Fungi and Disease in Plants—Father of Modern Plant Pathology in India*.
- **1929:** *Alexander Fleming* discovered *Penicillin* from *Penicillium notatum*.
- **1942:** *H. H. Flor* developed the gene-for-gene hypothesis in flax rust.
- **1943:** *Great Bengal Famine* caused by *Helminthosporium oryzae*.
- **1953:** *N. E. Borlaug* developed multiline wheat cultivars—paving the way for the Green Revolution.
- **1956–1957:** *J. G. Horsfall* published *Principles of Fungicidal Action*; *Stakman & Harrar* wrote *Principles of Plant Pathology*.

Modern Plant Pathology Developments (1963–1972):

- **1963:** *J. E. Van der Plank* introduced vertical and horizontal resistance concepts.
- **1966:** *Van Schmeling & Marshall Kulka* discovered systemic fungicides (oxathiin compounds).
- **1970:** *S. D. Garrett* pioneered biological control of root diseases.
- **1972:** *G. Rangaswami* published *Diseases of Crop Plants in India*.

Plant Bacteriology:

Early Discoveries (1683–1882):

- **1683:** *Anton von Leeuwenhoek* was the first to observe bacteria using a simple microscope.
- **1876:**
  - *Louis Pasteur* and *Robert Koch* proved that anthrax in cattle is caused by a specific bacterium.

  - *Robert Koch* established *Koch's Postulates*—criteria to prove the causal relationship between microbes and diseases.
  - Koch and Pasteur disproved the *theory of spontaneous generation* and proposed the *germ theory* of disease.
- **1882:** *T. J. Burrill* (USA) proved that *fire blight* of apple and pear is caused by a bacterium (*Erwinia amylovora*).

Establishing Bacteria as Plant Pathogens (1901–1952):

- **1901–1920:** *E. F. Smith* (USA) provided final proof that bacteria can cause plant diseases (*Father of Phytobacteriology*).
  - He researched *bacterial wilt* in cucurbits and *crown gall disease*.
  - *Chilton* and team showed that *crown gall bacterium* transforms plant cells into tumor cells via plasmid transfer.
- **1910:** *C. O. Jensen* related *crown gall disease* in plants to cancer in animals.
- **1952:**
  - *J. Lederberg* coined the term *plasmid*.
  - *S. A. Waksman* won the Nobel Prize for discovering *streptomycin* (an antibiotic from *Streptomyces*).
  - *Zinder* and *Lederberg* discovered *transduction* in bacteria (gene transfer via bacteriophages).

Advancements in Bacterial Research (1962–1980):

- **1962:** *H. Stolp* discovered *Bdellovibrios*, bacteria that prey on other bacteria.
- **1972:**
  - *P. B. New* and *A. Kerr* achieved biological control of *Agrobacterium radiobacter* strain K.
  - *I. M. Windsor* and *L. M. Black* identified *phloem-*

inhabiting bacteria causing *clover club leaf disease*.

- **1974:** *I. Zanen* and colleagues demonstrated the role of the *Ti plasmid* in *Agrobacterium tumefaciens* (responsible for crown gall disease).
- **1980:** *D. W. Dye* introduced the term *pathovar* in plant pathogenic bacterial taxonomy, aiding in classification based on host range.

Plant Virology

Early Discoveries (1886–1898):

- **1886:** *Adolf Mayer* described *Tobacco Mosaic Disease* (*Mosaikkranheit*) and demonstrated its sap transmissibility.
- **1892:** *Dimitri Ivanowski* showed that the causal agent of tobacco mosaic could pass through a bacterial filter, suggesting it was smaller than bacteria.
- **1895:** *E. F. Smith* (USA) showed that *peach yellows* was a contagious disease.
- **1898:** *M. W. Beijerinck* (Netherlands), known as the *Founder of Virology*, proved that the tobacco mosaic agent was not a microorganism but an *infectious living fluid* (*contagium vivum fluidum*). He was the first to use the term *virus* (Latin for "poison").

Advancements in Virus Characterization (1929–1959):

- **1929:** *F. O. Holmes* introduced a method to measure virus concentration using local lesion assays on host plant leaves.
- **1935:** *W. M. Stanley* crystallized the Tobacco Mosaic Virus (TMV), proving viruses could exist as crystals. He won the *Nobel Prize* in 1946.
- **1936:** *F. C. Bawden* and *N. W. Pirie* discovered that viral crystals contain both *nucleic acids* and *proteins*.
- **1939:** *Kausche* and colleagues visualized TMV particles

for the first time using an *electron microscope*.

- **1956:** *Gierer* and *Schramm* demonstrated that the *nucleic acid* fraction of the virus is the actual infectious agent.
- **1959:** *Munday* successfully induced *mutations* in TMV.

Modern Discoveries (1966–1971):

- **1966:** *Kassanis* discovered *satellite viruses*—dependent on helper viruses for replication.
- **1971:** *T. O. Diener* discovered *viroids*—the smallest infectious agents, composed only of circular single-stranded RNA. He identified them as the cause of *potato spindle tuber disease*.

Phytoplasma

- **1967:**
    - *Doi et al.* (Japan) discovered *Mycoplasma-like organisms (MLOs)* in plants with *yellows-type* diseases, consistently found in the phloem.
    - *Ishiie et al.* observed that MLOs could temporarily disappear when plants were treated with *tetracycline antibiotics*, confirming their bacterial nature.

Spiroplasma

- **1972:** *Davies et al.* identified *Spiroplasma*, a motile, helical, wall-less microorganism associated with *corn stunt disease*. Unlike MLOs, Spiroplasmas can be cultured in the laboratory and were characterized as distinct plant pathogens.

Key Contributions of Scientists in Plant Pathology

1. **Pier Antonio Micheli (Italy) -** *Father of Mycology*

- Published *Nova Plantarum Genera* (1729) with 900 fungal descriptions (e.g., *Mucor*, *Aspergillus*).
- First to observe fungal spores and conduct spore germination tests.
- Described asci, ascospores, basidiospores, and cystidia in fungi.

2. **Mathieu Tillet (France)**
    - Studied *bunt disease* of wheat (1755); proved fungi's role in plant disease.
    - Showed infected seeds produced diseased plants; recommended seed treatment with salt and lime.
3. **Benedict Prevost (France)**
    - Proved *Tilletia caries* causes wheat bunt.
    - Recommended copper sulfate for seed treatment.
    - Published findings on plant diseases (1807).
4. **Christian Hendrik Persoon (South Africa)**
    - Published *Synopsis Methodica Fungorum* (1801) and *Mycologia Europica* (1822).
    - Named *Puccinia graminis* (wheat rust) in 1794.
5. **Elias Magnus Fries (Sweden)**
    - Authored *Systema Mycologicum*; introduced binomial nomenclature for fungi with Persoon.
6. **Pier Andrea Saccardo (Italy)**
    - Developed spore group system (1899) for fungal classification.
    - Wrote *Sylloge Fungorum* in 25 volumes.
7. **E. F. Smith (USA) -** *Father of Phytobacteriology*
    - Proved bacteria cause plant diseases (*crown gall*, *bacterial wilt*).
    - Authored *Bacterial Diseases of Plants* (1920).
8. **T. J. Burrill (USA)**
    - First to link bacteria (*Erwinia amylovora*) to plant disease (*fire blight* in apples and pears).

9. **M. K. Patel (India)**
    - Pioneered plant bacteriology in India (1948); identified ~40 plant bacterial diseases.
    - Established the post of *Plant Bacteriologist* at IARI (1955).
10. **M. W. Beijerinck (Netherlands)** - *Father of Virology*
    - Demonstrated *Tobacco Mosaic Virus* (TMV) is not a microorganism, coining *contagium vivum fluidum* (infectious fluid).
11. **W. M. Stanley (USA)**
    - Crystallized TMV (1935), proving viruses could exist as chemical entities.
    - Awarded Nobel Prize for work on viral structure.
12. **F. C. Bawden & N. W. Pirie (Britain)**
    - Purified TMV and identified it as a nucleoprotein (95% protein, 5% nucleic acid).
13. **Doi (Japan)**
    - Discovered *phytoplasmas* (1967) as causal agents of *aster yellows* and *mulberry dwarf*.
    - Demonstrated temporary elimination of phytoplasmas using tetracycline.
14. **T. O. Diener (USA)**
    - Discovered *viroids* as causal agents of *potato spindle tuber disease* (naked ssRNA).
15. **Howard Taylor Ricketts (USA)**
    - First identified *Rickettsia* (1916); linked it to plant diseases like *clover club leaf disease* (1972) and *Pierce's disease* (1973).
16. **Bové (France)**
    - Identified *spiroplasmas* as causal agents of *corn stunt disease* (1968).

Key Contributions of Indian Scientists in Plant Pathology

1. **M. K. Patel**
   - *Pioneer of Plant Bacteriology in India* (Started research in 1948).
   - Reported around 40 bacterial plant diseases.
   - Introduced the post of *Plant Bacteriologist* at the Indian Agricultural Research Institute (IARI) in 1955.
2. **B. B. Mundkur**
   - *Father of Indian Plant Pathology*.
   - Authored *Fungi and Plant Diseases* (1949), a comprehensive guide on fungal plant pathogens.
   - Contributed significantly to the study of rust fungi in India.
3. **R. L. Munjal**
   - Developed improved techniques for the mass multiplication of *Trichoderma* spp., used in biological control.
   - Contributed to seed health management and biocontrol of plant diseases.
4. **J. C. Edward**
   - Worked extensively on *rice blast disease* caused by *Pyricularia oryzae*.
   - Developed management strategies for fungal diseases in rice.
5. **K. C. Mehta**
   - Conducted pioneering research on *rust fungi* affecting cereal crops, especially wheat.
   - Studied the epidemiology and life cycles of rust pathogens under Indian conditions.
6. **T. S. Sadasivan**
   - Specialized in *soil-borne plant pathogens* and host-

pathogen interactions.
- Made significant contributions to understanding plant disease resistance mechanisms.

7. **S. N. Das Gupta**
   - Contributed to the study of *viral diseases* in plants.
   - Pioneered research on plant viruses affecting pulses and cereals in India.
8. **R. P. Singh**
   - Made significant advancements in *wheat rust resistance breeding*.
   - Contributed to the development of wheat varieties resistant to rust diseases in India.
9. **G. Rangaswami**
   - Authored textbooks on plant pathology, including *Diseases of Crop Plants in India*.
   - Contributed to the development of diagnostic techniques for plant pathogens.
10. **V. K. Gupta**
    - Contributed to biocontrol strategies using beneficial microbes.
    - Worked on microbial enzymes and their role in plant disease management.
11. **P. C. Jain**
    - Specialized in *integrated disease management* (IDM) strategies for horticultural crops.
    - Contributed to the development of eco-friendly plant disease control methods.
12. **P. N. Mathur**
    - Significant contributions in *nematology*, especially plant-parasitic nematodes and their management.
13. **R. S. Singh**
    - Authored important books like *Plant Diseases* and conducted extensive research on plant disease

epidemiology.

14. **H. S. Chaube**
    - Contributed to disease forecasting and management strategies for fungal and bacterial diseases in field crops.

15. **A. Mahadevan**
    - Specialized in the study of *plant pathology* and *phytopathogenic fungi*.
    - Contributed to understanding the biochemical aspects of plant disease resistance.

3. Concept of disease in plants

Concept of disease in plants:

Plant is healthy or normal when it can carry out its physiological functions to the best of its genetic potential. Any deviation from normal health is called disease. The kinds of cells or tissue that become affected determine the type of physiological function that will be:

For example: i) infection of roots which cause rotting and make them unable to absorb water and nutrients from the soil ii) Infection of xylem vessels, interferes with the translocation of water and minerals to the crown of the plant iii) Infection of the foliage as in case of leaf spots, blights, rusts, mildews, mosaics etc. interferes with photosynthesis.

What is a Disease

According to **Marshall Ward (1901)** disease represents a condition in which functions of the plant are not properly discharged. Disease is a harmful deviation from normal functioning of physiological processes. (**British Mycological Society, 1950**)

A complete definition of disease is given by **Stakman & Harrar (1957)** they defined disease as physiological disorder or structural abnormality that is deleterious to the plant or its part or product, that reduces the economic value of the plant e.g., wilt, potato blight, Loose smut of wheat, karnal bunt of wheat.

Horsfall & Diamond (1959) defined disease as a malfunctioning process that is caused by continuous irritation which results in some suffering producing symptoms.

A working **definition** of disease can be given in these words: Disease is manifestation of a condition wherein an animate or inanimate cause (including environment) interferes with one or more essential cell functions in the plant in such a manner that resulted plant losses to accepted appearance and productivity.

Disease

Disease –the process in which a pathogen interferes.

How Pathogens affect Plants

The pathogen brings about irritating processes through different but interrelated pathways. There are many ways in which plant disease pathogens can affect plants

– By utilizing host cell contents

–Causing cells death or by interfering with its metabolic processes through their enzymes, toxins etc.

– By weakening the host due to continuous loss of the nutrients.

– By interfering with the translocation of the food, minerals and water.

- They can suppress the chlorophyll content.
- They can reduce the leaf area.
- They can curb the movement of solutes and water through the stems.
- They sometimes reduce the water-absorbing capacity of the roots.
- They suppress the translocation of photosynthates away from the leaves.
- They sometimes promote wasteful use of the products of photosynthesis as in the formation of galls.

Importance of Plant Diseases: Plant diseases are important because of the loss they cause. The loss can be in field, during transportation or storage. In the history of mankind plant diseases have been encountered with a number of important events.

Late blight of potato-1841-51 (Irish famine) Coffee rust 1867-1870 (Srilanka)

Downy mildew of grapes (1880s) (France) Great Bengal Famine 1942 (India)

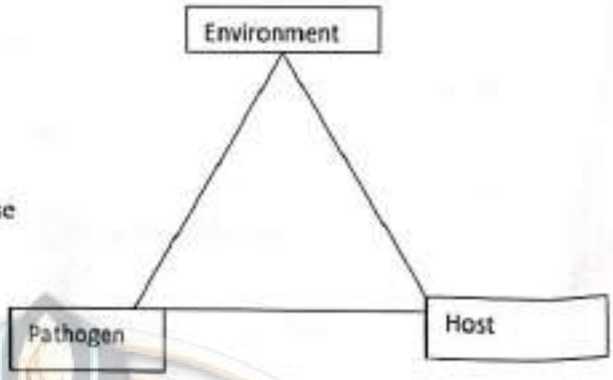
Bacterial Blight of Rice 1963 (Bihar) Southern corn leaf blight -1970 (USA)

Estimated annual losses

Worldwide		**India**	
Pest	**Net losses (%)**	**Pest**	**% of total losses**
Diseases	14.1	Diseases	26
Insects	10.2	Insects	20
Weeds	12.2	Weeds	33
Total av. looses	36.5	Rats	6
		Storage losses	7

In India, the total losses due to plant diseases is approx. 18% of our total produce accounting worth Rs 500 crores annually.

Disease Triangle: According to modern concept of plant disease, disease is a very complex phenomenon where in 3 components are involved. Disease is an interaction among the host, pathogen and environment.



Conditions for disease

Host should be susceptible

Pathogen should be virulent

Environment should be favourable for the disease

Disease tetrahedron: Actually disease is a result of interaction between host and pathogen under the influence of environment over a period of time and human activity.

Host Pathogen

Environment Time Human Activity

Classification of plant diseases: There are different basis of plant disease classification

1. Based on type of symptoms

– Blights – Rusts – Smuts – Rots – wilts

2. Based on type of crop

– Cereal diseases – Vegetable diseases – Horticultural crop diseases

3. Based on type of organ affected

– Fruit diseases – Root diseases

4. Based on cause: This is important criteria of disease classification as it tell about the causal agent

A. Infectious diseases; caused by Living organisms including fungi, bacteria, viruses and nematodes

B. Non-infectious Plant diseases caused by nonliving agents – including unbalanced soil fertility, toxic chemicals, air pollution, frost, drought, sunburn, wind and hail

Infectious Plant Disease are caused by:

Fungi Bacteria Viruses Viroids Virusoids

Protozoa Nematodes Algae and Parasitic higher Plants

Non-infectious diseases (due to abiotic factors)

Environmental stress/ excess

– Temperature e.g. high or low – Moisture e.g. excess- rotting or Stress-wilt/drying

– Air – Light e.g. etiolation

Nutritional imbalance

– Excess – Deficiency e.g. N deficiency, Zn deficiency (**khaira disease of rice**)

Disorder:

Abnormal physiological change due to non-parasitic agent or is a non-parasitic physiological malfunctioning due to either excess or deficiency in environmental factors or nutrients. e.g. Physiological wilt, sun scald, Nutrient deficiency)

Terminology

Parasite: An organism that lives on or in another organism and obtains food from the second organism

Pathogenicity- is the ability of a pathogen to cause the disease by interfering with one or more of the essential plant cell functions.

Important Terms in Plant Pathology

- **Immunity**: The state of being protected from a disease. For example, a plant resistant to a specific fungus will not get infected by it.

- **Immune**: A plant or organism that cannot be infected by a particular pathogen. Example: A plant resistant to a specific virus would be immune to that virus.

- **Immunization**: The process of making a plant immune to a disease. Example: Vaccinating crops to prevent fungal infections.

- **Infection**: When a pathogen (like bacteria, fungus, or virus) enters a plant and begins to live on it. Example: A fungus infecting a plant leaf.

- **Perpetuation**: The survival of a pathogen even when its main host isn't around. Example: Fungi can live in soil until they find a suitable plant to infect.

- **Incubation Period**: The time between a pathogen entering a plant and when symptoms of the disease appear. Example: After a plant is infected by a rust fungus, it may take several days before yellow spots appear on the leaves.

- **Polygenic Resistance**: Resistance to disease controlled by multiple genes. Example: A plant with many genes that work together to resist a virus.

- **Setae (Singular: Seta)**: Bristle-like structures found on some fungal fruiting bodies. Example: Setae on a fungus like *Sporotrichum*.

- **Antherozoid**: A motile male reproductive cell (like sperm in plants). Example: In mosses, an antherozoid is the male gamete that swims to the female gamete.

 Blastospores: A type of fungal spore that is created asexually by budding. Example: Yeast produces blastospores for reproduction.

 Parasite: An organism that lives on or in another organism (host) and benefits at the host's expense. Example: Mistletoe is a parasitic plant that attaches to trees.

 Saprophyte: An organism that feeds on dead organic matter. Example: Fungi like *Penicillium* decompose dead leaves.

 Facultative Parasite: An organism that can live as a parasite but usually lives on dead material. Example: Some fungi live as saprophytes but can parasitize plants when the opportunity arises.

 Facultative Saprophyte: An organism that is usually a parasite but can also live on decaying matter. Example: *Phytophthora* species.

 Obligate Parasite: A parasite that must live on a living host. Example: The rust fungus *Puccinia* only grows on living plants.
 Hyperparasite: A parasite that lives on another parasite. Example: A fungus that parasitizes an insect that is itself parasitic on plants.

 Homothallic: Fungi that have both male and female reproductive parts on the same individual. Example: Some fungi can self-fertilize.

 Heterothallic: Fungi that need two different individuals (with different sex organs) to reproduce. Example: *Neurospora* fungi.

 Holocarpic: A fungus where the entire body turns into a reproductive structure. Example: Some parasitic fungi like *Taphrina*.

 Eucarpic: A fungus whose body remains partly non-reproductive. Example: *Fusarium* fungi.

 Dikaryosis: A stage in fungal reproduction where two different nuclei exist in a single cell. Example: Common in basidiomycetes like mushrooms.

 Plasmogamy: The fusion of the cytoplasm from two cells. Example: In fungi, plasmogamy happens before karyogamy.

 Karyogamy: The fusion of two nuclei from different cells. Example: In fungi, karyogamy leads to sexual reproduction.

 Spore: A small, reproductive unit of fungi or plants that can grow into a new organism. Example: Spores from mushrooms that spread and grow in new areas.

 Haustoria: Specialized structures that fungi or parasitic plants use to absorb nutrients from their host. Example: *Rust* fungi have haustoria that penetrate plant cells to steal nutrients.
 Appressorium: A swollen structure at the end of a fungal hypha that helps it attach to and penetrate plant tissue. Example: In *Magnaporthe* (rice blast fungus), appressoria help infect rice plants.

 Alternate Host: A different plant species required by some pathogens to complete their life cycle. Example: The wheat rust fungus needs both wheat and barberry as hosts.

 Collateral Host: A plant from the same family as the primary host. Example: Wild grasses related to crops like rice that may host certain fungal diseases.

- **Anamorph**: The asexual stage in the life cycle of a fungus. Example: The conidia produced by *Aspergillus* are the anamorph.

- **Teleomorph**: The sexual stage in the life cycle of a fungus. Example: The sexual spores of *Neurospora*.

- **Signs**: Visible proof of a disease, such as fungal growth or bacterial ooze. Example: The black spores of a fungal infection are signs of disease.

- **Symptoms**: The plant's response to the disease, like wilting or yellowing leaves. Example: Yellowing leaves in a plant infected by a virus.

- **Chronic Symptoms**: Symptoms that appear slowly over time. Example: A plant that shows gradual leaf yellowing due to a viral infection.

- **Masked Symptoms**: Symptoms that only appear under certain conditions. Example: Virus symptoms that may not show until the plant is stressed by temperature or light changes.

- **Symptomless Carrier**: An infected plant that doesn't show symptoms but can spread disease. Example: An infected potato plant that doesn't show signs of the disease but can spread the pathogen to healthy plants.

- **Conjugation**: The fusion of two cells for reproduction. Example: In bacteria, conjugation allows the transfer of genetic material between cells.

- **Horizontal Resistance**: Partial resistance that works against many types of a pathogen. Example: A plant variety resistant to many strains of a specific fungal disease.

- **Vertical Resistance**: Complete resistance to some types of a pathogen but not others. Example: A plant variety resistant to one strain of a virus but susceptible to another strain.

- **Host**: A plant that is infected by a pathogen. Example: A tomato plant infected by a bacterial disease is the host.

- **Pathogen**: A microorganism that causes disease in plants. Example: *Xanthomonas* bacteria that cause leaf spot in crops.

- **Hypersensitivity**: An immune response where plant cells die to stop the spread of a pathogen. Example: When a plant shows rapid cell death to stop a fungal infection.

- **Inoculum**: The part of a pathogen that starts an infection. Example: Spores of a fungus that land on a plant leaf and infect it.
- **Propagule**: A part of an organism that can grow into a new individual. Example: Spores or seeds that can grow into new fungi or plants.

- **Resistance**: The ability of a plant to fight off or reduce the impact of a pathogen. Example: A resistant wheat variety that doesn't get infected by wheat rust.

- **Susceptibility**: When a plant has no natural defense against a disease. Example: A plant that easily gets infected by a specific virus.

- **Tolerance**: The ability of a plant to endure some disease without suffering severe damage. Example: Some crops can tolerate slight damage from pests but still produce a decent yield.

 Non-host Resistance: A plant that can't be infected because it's not the right kind of host for the pathogen. Example: Some plants that cannot host certain fungal diseases due to their structure or chemical makeup.

 Paraphysis: Non-reproductive hyphae found in some fungal fruiting bodies. Example: Found in the fruiting bodies of some fungi like *Agaricus*.

 Periphysis: Hair-like structures inside fungal fruiting bodies that protect reproductive structures. Example: Found in certain types of *Agaricomycetes*.

 Pathogenicity: The ability of a pathogen to cause disease. Example: The pathogenicity of *Puccinia* (a wheat rust fungus) allows it to infect wheat plants.

 Phytoalexin: Chemicals produced by plants to fight off pathogens. Example: Plants might produce phytoalexins to inhibit fungal growth when infected.

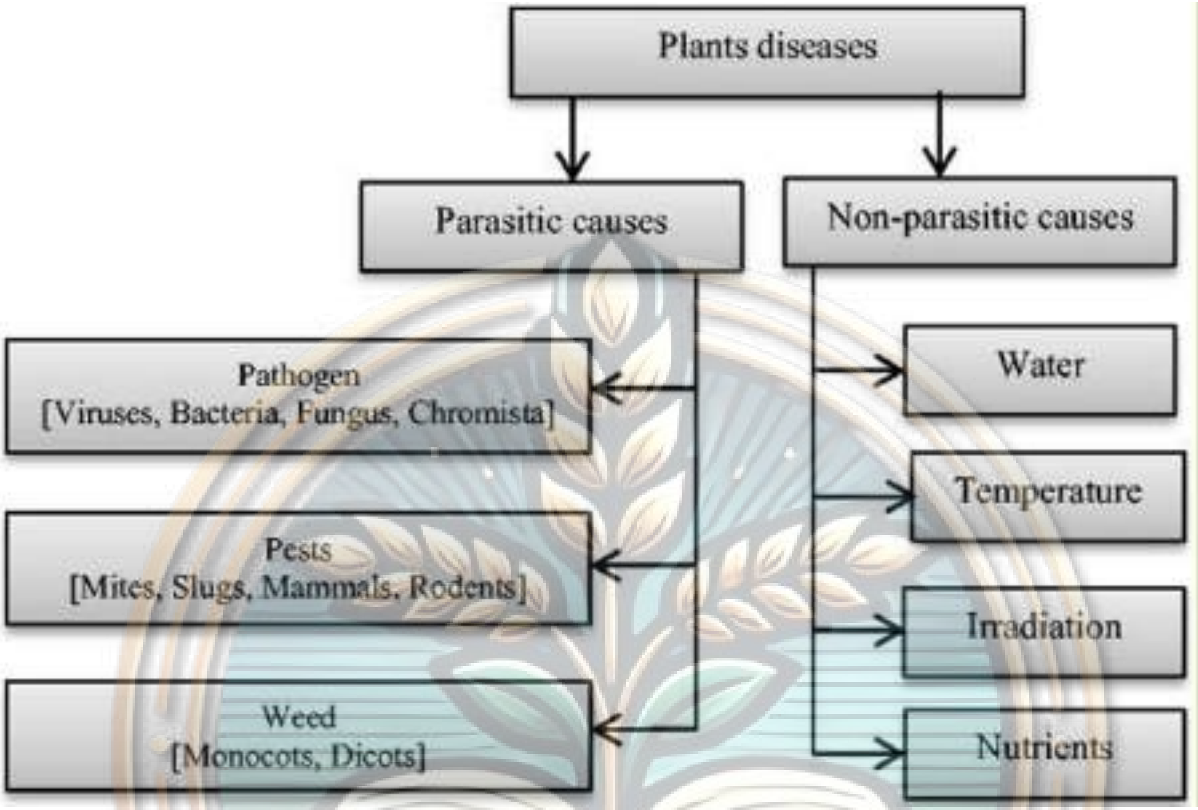
 L.D. 50 / I.C. 50: The concentration of a toxic substance that kills or inhibits 50% of the population. Example: A fungicide's L.D.50 might be the amount needed to kill half of the fungal spores.

 Anemochory: The spreading of plant pathogens by wind. Example: Spores of a fungus carried by the wind to new plants.

 Hydrochory: The spreading of plant pathogens by water. Example: Water carrying fungal spores from one plant to another.

 Entomochory: The spreading of plant pathogens by insects. Example: Aphids carrying viruses from one plant to another.

4. Causes of plant disease; Inanimate and animate causes



Causes of Plant Diseases

- Plant diseases are caused by a variety of pathogens.
- The word pathogen can be broadly defined as any agent or factor that incites 'pathos' or disease in an organism. Thus in strict sense, the pathogens do not necessarily belong to living or animate groups.

Abiotic (Inanimate) factors

- They include mainly the deficiency or excess of nutrients, light, moisture, aeration, abnormality in soil condition, atmospheric impurities etc. Examples are: Black tip of mango (due to SO2 toxicity), khaira disease of rice (due to Zn deficiency), whiptail of cauliflower (Mo deficiency), hollow and black heart of potato (due to excessive accumulations of CO2 in storage), bitter pit of apple (due to Ca deficiency).

The main inanimate causes include:

a) Environmental Stress

- **Temperature Extremes**: Both high and low temperatures can cause physiological damage to plants. Excessive heat can lead to heat stress, which impairs cellular function, disrupts enzyme activity, and can cause

cellular dehydration. Cold temperatures can lead to frost injury, causing cells to rupture due to ice formation inside plant tissues.
    - Example: Frost damage in tender crops like tomatoes.
- **Water Stress**: Insufficient or excessive water can result in diseases such as *drought stress*, which affects the plant's ability to photosynthesize, or *waterlogging*, which restricts root function and promotes fungal pathogens.
    - Example: Root rot caused by *Phytophthora* species under waterlogged conditions.
- **Nutrient Deficiencies or Toxicities**: Plants require specific nutrients for optimal growth. A lack of nutrients such as nitrogen, phosphorus, or potassium can lead to poor plant health, reducing its resistance to disease. Conversely, excess nutrients, particularly fertilizers, can lead to toxicities that affect plant metabolism.
    - Example: Nitrogen deficiency leading to stunted growth or phosphorous deficiency causing poor root development.

b) Chemical Injury

- **Herbicide Damage**: Incorrect application or overuse of herbicides can cause chemical damage to non-target plants. These herbicides often interfere with photosynthesis or disrupt cellular processes, leading to symptoms similar to those of disease.
    - Example: Herbicide drift causing leaf curling and necrosis in neighboring plants.
- **Air Pollution**: Pollutants such as sulfur dioxide (SO2), nitrogen oxides (NOx), and ozone (O3) can cause oxidative stress, leading to leaf burn, chlorosis (yellowing of leaves), and reduced growth.
    - Example: Ozone-induced leaf injury causing visible lesions on leaves.

c) Soil pH and Salinity

- **Soil pH**: Extreme pH values (either too high or too low) can affect nutrient availability, causing deficiencies or toxicities that weaken the plant and make it more susceptible to secondary infections.
    - Example: High soil pH (alkaline conditions) leading to iron chlorosis in plants like azaleas.
- **Salinity**: High salt concentrations in the soil can cause osmotic stress, making it difficult for plants to take up water, leading to dehydration and physiological disruptions.
    - Example: Salt stress leading to reduced growth and leaf desiccation in crops like rice.

Mesobiotic causes

- These are the disease incitants which are neither living nor non-living. They are considered to be on the threshold of life. They are:
- Viruses: They are infections agents made up of one type of nucleic acid (RNA or DNA) enclosed in a protein coat. Examples of viral diseases of plants are: potato leaf roll, leaf curl of tomato and chillies, and mosaic disease of many plants.
- Viroids: They are naked, infectious strands of nucleic acid. They cause diseases like potato spindle tuber, citrus exocortis, chrysanthemum stunt, cadang cadang of coconut palm, star crack of apple, etc.

Biotic (Animate) causes
This category includes the pathogens which are animate or living or cellular organisms. They are:

- Prokaryotes like bacteria which are unicellular prokaryotic microorganisms lacking true nucleus. Examples of diseases caused by true bacteria are: brown rot or wilt of potato, soft rot of potato and vegetables, , citrus canker, etc.

i) Phytoplasma are wall-less prokaryotes and cause diseases like peach X.
ii) Fastidious bacterium, Xylella fastidiosa causes almond leaf scorch, Pierce's disease of grapevine.

- Eukaryotes are the organisms with true nucleus.

i) Fungi: Potato wart, powdery mildew, rust, smuts, red rot of sugarcane (nearly 80% of plant diseases are caused by fungi).
ii) Straminopiles (Oomycetes): Downy mildews, late blight of potato, white rust of crucifers, damping off etc.
iii) Protozoa: Hart rot of coconut palm and phloem necrosis of coffee.
iv) Algae: Red rust of mango or papaya or litchi
v) Metazoan animals (Nematodes): Root knot of vegetables, ear cockle of wheat, citrus decline etc.
vi) Parasitic flowering plants (Phanerogamic plant parasites): Dodder, Striga, Orobranche, Loranthus, Phoradendron, etc.

Cause Type	Category	Example Organisms/Pathogens	Plant Diseases
Inanimate	Environmental Stress	Temperature extremes, water stress, soil pH, salinity	Heat stress, frost damage, drought, waterlogging
Inanimate	Chemical Injury	Herbicides, air pollution	Herbicide damage, ozone injury
Animate	Fungi	*Puccinia* (rust), *Alternaria* (blight)	Rusts, blights, mildew
Animate	Bacteria	*Xanthomonas* (bacterial blight), *Agrobacterium* (crown gall)	Bacterial wilt, bacterial blight
Animate	Viruses	*TMV, CMV, TSWV*	Mosaic diseases, leaf curl
Animate	Nematodes	*Meloidogyne* (root-knot nematodes)	Root-knot nematode disease
Animate	Insects/Mites	Aphids, whiteflies, spider mites	Virus transmission, leaf damage

5.Classification of plant disease

1.Based on plant part affected

- **Localized**, if they affect only specific organs or parts of the plants.

- **Systemic**, if entire plant is affected. or

They can be classified as root diseases, stem diseases, foliage/foliar diseases, etc.

2.Based on perpetuation and spread

- **Soil borne** -when the pathogen perpetuates through the agency of soil.
- **Seed borne** -when the pathogen perpetuates through seed (or any propagation material).
- **Air borne** -when they are disseminated by wind e.g. rusts and powdery mildews.

3. Based on the host plants affected

They can be classified as cereal crop diseases, forage crop diseases, flax diseases, millet diseases, plantation crop diseases, fruit crop diseases, vegetable crop diseases, flowering plant diseases, etc.

4.Classification of Animate Diseases in Relation to Their Occurrence

- **Endemic diseases** -which are more or less constantly present from year to year in a moderate to severe form in a particular geographical region, i.e. country, district or location.

- **Epidemic or epiphytotic diseases** - which occur widely but periodically particularly in a severe form. They might be occurring in the locality every year but assume severe form only on occasions due to the favourable environmental conditions occurring in some years.

- **Sporadic diseases** occur at irregular intervals and locations and in relatively few instances.

- **Pandemic diseases:** A disease may be endemic in one region and epidemic in another. When epiphytotics become prevalent through out a country, continent or the world, the disease may be termed as pandemic.

5. Classification Based on the Causative Agent
Plant diseases can be classified based on the biological or non-living entities that cause them. These agents are broadly categorized as **biotic** (living) or **abiotic** (non-living).
A. Biotic Causes (Living Organisms)
Biotic pathogens are living organisms that cause disease in plants. These pathogens include **fungi**, **bacteria**, **viruses**, **nematodes**, and **insects**.

1. **Fungal Pathogens**
   Fungi are one of the most common causes of plant diseases and typically reproduce through spores. They are often necrotrophic, causing tissue destruction.
   - **Examples**: *Puccinia* (rust fungi), *Alternaria* (leaf blight), *Fusarium* (root rot), *Phytophthora* (downy mildew).
   - **Mode of infection**: Fungal spores germinate on plant surfaces and enter the plant through natural openings or wounds. They spread within plant tissues, secreting enzymes that degrade cell walls and other plant components.
2. **Bacterial Pathogens**
   Bacteria are single-celled organisms that cause a variety of plant diseases. They can be either necrotrophic or biotrophic.
   - **Examples**: *Xanthomonas* (bacterial blight), *Pseudomonas* (canker), *Agrobacterium* (crown gall).
   - **Mode of infection**: Bacteria typically infect through natural plant openings like stomata or through wounds. They multiply in intercellular spaces and secrete toxins or enzymes that damage plant cells.
3. **Viral Pathogens**
   Viruses are obligate intracellular parasites that require a host plant for replication. They usually induce systemic infections.
   - **Examples**: *Tobacco mosaic virus (TMV)*, *Cucumber mosaic virus (CMV)*, *Tomato yellow leaf curl virus*.
   - **Mode of infection**: Viruses are transmitted via vectors such as aphids, whiteflies, or mechanically through plant-to-plant contact. They hijack the host's cellular machinery to replicate.
4. **Nematodes**
   Nematodes are microscopic, multicellular worms that infect plant roots. They are often parasitic, feeding on plant cells and disrupting water and nutrient uptake.
   - **Examples**: *Meloidogyne* (root-knot nematodes), *Pratylenchus* (lesion nematodes).
   - **Mode of infection**: Nematodes penetrate plant roots, feeding on root cells and forming galls or lesions, which affect plant nutrient and water uptake.

5. **Insects and Mites**
   Insects and mites are major vectors for pathogens or cause direct damage to plants. They often serve as intermediaries for viruses, bacteria, and fungi.
   - **Examples**: Aphids, whiteflies, thrips, spider mites.
   - **Mode of infection**: Insects feed on plant tissues and can spread pathogens during feeding activities.

B. Abiotic Causes (Non-living Factors)
Abiotic factors, also referred to as environmental or physiological factors, contribute to plant disease by causing stress or direct injury.

1. **Environmental Stress**
   These factors, such as extreme temperatures, drought, and waterlogging, can impair the plant's normal physiological functions.
   - **Examples**: Frost, heat stress, water stress, nutrient deficiencies.
   - **Pathogenic Mechanism**: Stress leads to metabolic disruption, cellular damage, and makes the plant more susceptible to secondary infections by pathogens.
2. **Chemical Injury**
   Chemical pollutants, herbicides, and fertilizer imbalances can cause direct damage to plant tissues.
   - **Examples**: Herbicide injury, nitrogen toxicity, ozone pollution.
   - **Pathogenic Mechanism**: These chemicals interfere with plant metabolic processes, resulting in symptoms like chlorosis, necrosis, and stunted growth.

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6. Classification Based on Symptoms
Plant diseases can also be classified based on the types of symptoms they cause in the host plant.

A. Necrotic Diseases
Necrotic diseases involve the death of plant tissue, causing visible lesions, wilting, or rot.

- **Examples**:
  - **Leaf spots**: Caused by fungal or bacterial pathogens such as *Alternaria* spp. and *Xanthomonas* spp.
  - **Blight**: Fungal diseases like *Phytophthora* blight cause rapid tissue necrosis, resulting in blackened leaves or stems.
  - **Rot**: Soft rot diseases, caused by *Erwinia* spp., lead to the decay of plant tissues.

B. Hypertrophic Diseases
Hypertrophic diseases involve abnormal tissue growth, leading to the formation of galls, swelling, or excessive growth.

- **Examples**:
  - **Crown gall**: Caused by *Agrobacterium tumefaciens*, where tumor-

like growths form at the crown or roots.
    - **Root-knot**: Caused by *Meloidogyne* nematodes, resulting in galls on roots.

C. Chlorotic Diseases

Chlorosis refers to yellowing of the plant tissues, typically due to nutrient deficiencies or viral infections.

- **Examples**:
    - **Nutrient deficiencies**: Iron or nitrogen deficiencies can cause yellowing of leaves.
    - **Viral infections**: *Cucumber mosaic virus* causes yellowing and stunted growth.

D. Deformative Diseases

These diseases cause deformities or abnormalities in plant structure, such as leaf curl or stunting.

- **Examples**:
    - **Leaf curl**: Caused by *Tomato yellow leaf curl virus*, leading to upward rolling of leaves.
    - **Stunting**: Viral infections or nematode infestations can result in reduced plant size and abnormal growth.

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7. Classification Based on Mode of Infection

Plant diseases can also be classified according to how the pathogen enters and spreads within the plant.

A. Direct Infection

In direct infection, the pathogen enters the plant and infects tissues directly through natural openings like stomata, lenticels, or wounds.

- **Examples**:
    - **Rust fungi**: *Puccinia* spp. infect through leaf stomata.
    - **Bacterial infections**: *Xanthomonas* spp. infect through natural openings or wounds.

B. Indirect Infection

In indirect infections, pathogens do not infect directly but instead require a vector, such as an insect or wind, to facilitate the infection process.

- **Examples**:
    - **Viral transmission**: *Cucumber mosaic virus* is transmitted by aphids.
    - **Fungal transmission**: *Phytophthora* spp. may be spread by water.

C. Systemic Infection

Systemic infections occur when the pathogen spreads throughout the plant's vascular system, causing systemic symptoms.

- **Examples**:
    - **Bacterial wilt**: Caused by *Ralstonia solanacearum*, which spreads through the xylem, causing wilting.

- **Viral infections**: *Tomato mosaic virus* spreads systemically, leading to widespread chlorosis and stunting.

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8. Classification Based on Disease Cycle

The disease cycle refers to the stages of the pathogen's life cycle, from infection to reproduction. Diseases are categorized into **monocyclic** and **polycyclic** based on how many generations of the pathogen are produced within a growing season.

A. Monocyclic Diseases

Monocyclic pathogens complete only one generation of infection per growing season. These diseases typically cause less severe damage because the inoculum does not increase significantly during the season.

- **Examples**:
  - **Apple scab**: Caused by *Venturia inaequalis*, with a single spore cycle per season.
  - **Late blight in potatoes**: *Phytophthora infestans* has a single generational cycle.

B. Polycyclic Diseases

Polycyclic pathogens can produce multiple generations of spores or other propagules in a single growing season, allowing for widespread disease development.

- **Examples**:
  - **Powdery mildew**: Caused by *Erysiphe* spp., which produces multiple generations throughout the season.
  - **Rust diseases**: *Puccinia* spp. cause repeated cycles of infection during the growing season.

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9. Classification Based on Pathogenic Mechanism

Pathogenic mechanisms refer to how pathogens cause disease in the host plant. This classification focuses on the manner in which pathogens feed and interact with plant cells.

A. Biotrophic Pathogens

Biotrophs depend on living plant tissues for their nutrition, often maintaining the host alive while feeding.

- **Examples**:
  - **Powdery mildew**: *Erysiphe* spp., which grow on the surface of plant leaves without killing the host cells.
  - **Rust fungi**: *Puccinia* spp., which extract nutrients without immediately killing the host plant.

B. Necrotrophic Pathogens

Necrotrophs kill host tissue and feed on the dead cells. These pathogens often produce enzymes or toxins that induce necrosis.

- **Examples**:

- **Botrytis blight**: *Botrytis cinerea*, which causes rapid tissue death.
- **Soft rot**: Caused by *Erwinia* spp., which infect and break down plant tissues.

C. Hemibiotrophic Pathogens

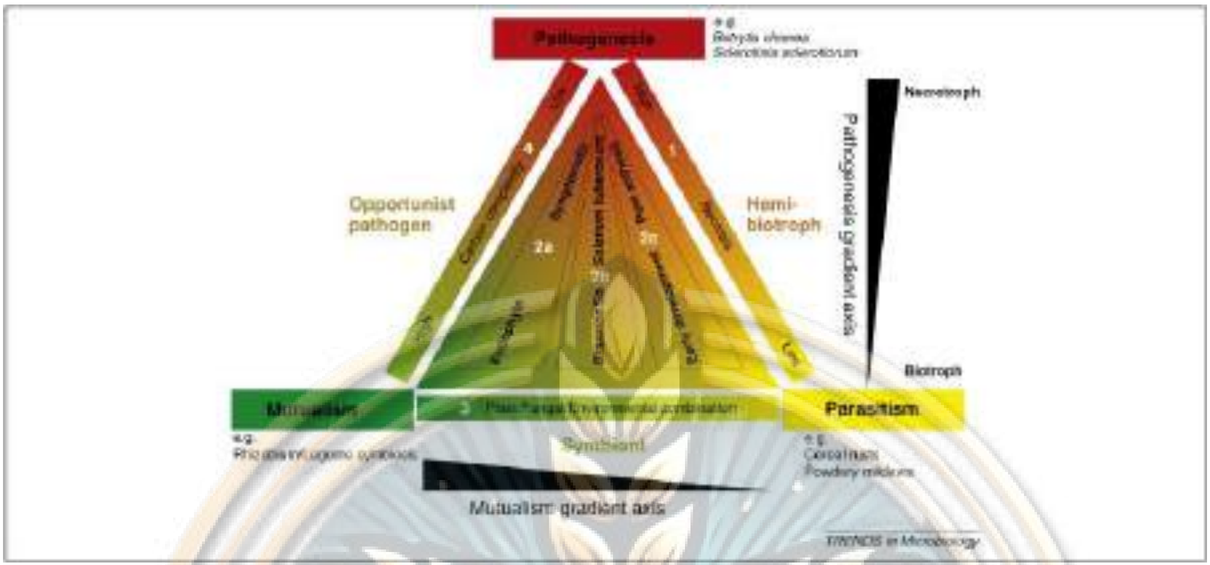
Hemibiotrophs begin as biotrophs but transition to necrotrophic feeding, causing tissue destruction later in the infection process.

- **Examples**:
  - **Phytophthora blight**: *Phytophthora* spp. initially cause minimal damage but later cause extensive necrosis.
  - **Downy mildew**: *Peronospora* spp. initially infect leaves without causing death but later produce necrosis.

10. **Based on Infection Process**

- **Infectious** -All the diseases caused by animate causes, viruses and viroids can be transmitted from infected host plants to the healthy plants and are called infectious
- .
- **Non-infectious**- Non-infectious diseases can not be transmitted to a healthy plant. Also referred as non-parasitic disorders or simply physiological disorders, and are incited by abiotic or inanimate causes like nutrient deficiency or excess or unfavorable weather conditions of soil and air or injurious mechanical influences.

6.Parasitism and Pathogenesis in Plants



Parasitism and **pathogenesis** are essential concepts in plant pathology. While they are related, they describe distinct processes in the interaction between a host plant and a pathogen.

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1. Parasitism in Plants

Parasitism refers to a symbiotic relationship between two organisms, where one organism (the parasite) benefits at the expense of the other (the host). In the context of plant diseases, parasitism occurs when a pathogen (parasite) invades a plant (host) and derives nourishment or other benefits from it, often causing harm to the plant.

A. Types of Parasitism

1. **Obligate Parasitism**:
   Obligately parasitic organisms are entirely dependent on the host for their survival and reproduction. They cannot complete their life cycle without the host plant. These parasites typically feed on living plant tissues, often leading to disease and death of the host.
   - **Examples**:
     - *Cuscuta* (dodder): A holoparasitic plant that attaches to its host and absorbs nutrients from the host vascular system.
     - *Orobanchaceae* family: Parasitic plants like *Striga*

(witchweed), which attach to the roots of cereal crops.

2. **Facultative Parasitism**:
   Facultative parasites can live independently or as parasites. Under favorable conditions, they act as saprophytes (decomposers) but can switch to parasitism when a suitable host is available.
   - **Examples**:
     - *Bipolaris* (a genus of fungi): Under certain conditions, they are saprotrophic (feed on dead matter), but under specific circumstances, they can become parasitic on living plants.
3. **Hemiparasitism**:
   These are partially parasitic organisms that can photosynthesize but depend on the host for water and nutrients. Hemiparasites often form connections with the host's vascular system to extract resources.
   - **Examples**:
     - *Viscum album* (mistletoe): A well-known hemiparasitic plant that parasitizes trees by tapping into their vascular system for nutrients and water while still performing photosynthesis.
4. **Hyperparasitism**:
   Hyperparasitism refers to a situation where one parasite infects another parasite. This type of interaction can occur when a secondary pathogen infects the primary pathogen (e.g., a parasitic fungus infecting another parasitic fungus).
   - **Examples**:
     - *Hirsutella* spp. infecting *Heterorhabditis* (a nematode parasite).

B. Mechanisms of Parasitism in Plants

- **Attachment and Penetration**: Parasites usually attach to host tissues through specialized structures like haustoria (in parasitic plants) or appressoria (in fungi). These structures allow the parasite to penetrate the plant's cell wall and access nutrients.
- **Nutrient Absorption**: Once attached, the parasite taps into the host's vascular system (xylem and phloem) to extract water,

minerals, and other nutrients, often interfering with the host's normal metabolic processes.

- **Host Manipulation**: Some parasites secrete chemicals or hormones that manipulate the host plant's growth or immune responses to facilitate parasitism.

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2. Pathogenesis in Plants

Pathogenesis refers to the mechanism by which a pathogen causes disease in a host plant. It involves a series of steps where the pathogen establishes itself in the host, grows, and leads to damage. Pathogenesis encompasses all processes by which disease symptoms are expressed in the plant due to pathogen invasion.

A. Stages of Pathogenesis

1. **Infection**:
   Infection is the first stage in pathogenesis, where the pathogen comes into contact with and penetrates the plant. It can occur through natural openings (stomata, lenticels), wounds, or directly through the epidermis.
   - **Examples**:
     - *Pseudomonas syringae* (bacterial pathogen) infects through stomata and wounds.
     - *Phytophthora infestans* (fungal pathogen) penetrates through leaf tissues by secreting enzymes.
2. **Colonization**:
   After the pathogen penetrates the plant, it begins to multiply and spread within the plant tissues. During this phase, the pathogen may secrete enzymes to degrade plant cell walls and release nutrients, facilitating its growth.
   - **Examples**:
     - **Fungal pathogens** like *Fusarium oxysporum* colonize the xylem, causing vascular wilt.
     - **Bacteria** like *Xanthomonas* spp. multiply intercellularly and produce toxins that inhibit host cell function.
3. **Symptom Expression**:
   Pathogenesis results in the production of disease symptoms, which may include wilting, chlorosis (yellowing of leaves),

necrosis (death of plant tissue), stunting, or gall formation. These symptoms are often a result of the pathogen's toxins, enzymes, and the host's immune responses to the infection.
   - **Examples**:
      - **Leaf spot diseases** caused by fungi like *Alternaria* result in necrotic lesions on leaves.
      - **Bacterial wilt**, caused by *Ralstonia solanacearum*, leads to wilting and collapse of the plant vascular system.

4. **Reproduction and Dissemination**:
   Once the pathogen has sufficiently colonized the plant, it reproduces and produces propagules (e.g., spores, seeds, or bacterial cells). These propagules are released into the environment and can infect new hosts.
   - **Examples**:
      - **Fungal spores** like *Conidia* are released from infected tissues to spread and infect new plants.
      - **Bacterial colonies** produce exudates that can contaminate irrigation water or be spread by wind, insects, or mechanical means.
5. **Pathogen Overwintering (Perpetuation)**:
   Some pathogens can survive in the absence of a host through specialized resting structures such as spores, cysts, or other forms of dormant stages. This allows the pathogen to persist in the environment until favorable conditions for infection arise again.
   - **Examples**:
      - **Fungal pathogens** such as *Puccinia* (rust fungi) produce teliospores, which survive in soil or plant debris over the winter.
      - **Bacterial pathogens** like *Erwinia* spp. form dormant cells in soil or on plant material.

B. Mechanisms of Pathogenesis

Pathogens employ various mechanisms to invade, colonize, and damage the host plant. These mechanisms include:

- **Enzyme Production**: Pathogens often secrete enzymes like cellulases, pectinases, and proteases that break down plant cell walls and tissues, facilitating pathogen entry and nutrient extraction.

- **Toxin Production**: Many pathogens release toxins that damage plant cells, inhibit plant immune responses, or disrupt plant metabolism.
- **Induction of Host Responses**: Pathogens may induce hypersensitive responses or systemic acquired resistance (SAR) in the plant, which can be beneficial to the plant in some cases but also be a part of disease progression.
- **Exploitation of Host Resources**: Some pathogens manipulate the host plant's metabolic processes, causing it to direct nutrients and energy toward supporting pathogen growth rather than normal plant functions.

C. Types of Pathogenic Interactions

1. **Biotrophic Pathogens**:
   Biotrophic pathogens are those that require living host cells to sustain their growth and reproduction. They do not immediately kill the plant cells but rather modify them to support their survival.
   - **Examples**:
     - **Rust fungi** (*Puccinia* spp.) require living plant cells for nutrient uptake.
     - **Bacterial pathogens** like *Xanthomonas* cause chronic infections without directly killing the plant cells.
2. **Necrotrophic Pathogens**:
   Necrotrophic pathogens kill plant tissues and feed on the dead cells. These pathogens are often more aggressive and cause rapid necrosis and decay of plant parts.
   - **Examples**:
     - **Botrytis cinerea** (gray mold), which kills plant tissues and thrives on decaying material.
     - **Fusarium spp.**, which causes vascular wilt by killing plant tissues, blocking water transport.
3. **Hemibiotrophic Pathogens**:

Hemibiotrophic pathogens begin by living as biotrophs (in a living host) but transition to necrotrophy, killing the plant cells as the infection progresses.

- **Examples**:
  - **Phytophthora infestans** (late blight of potatoes) starts by infecting living tissues but eventually kills plant cells as it spreads.

Development of Disease in Plants

The development of disease in plants is a complex process involving several stages, from the initial encounter between a pathogen and its host plant to the eventual symptom expression and spread of the disease. Plant disease development occurs when a pathogen interacts with a host under favorable environmental conditions. Understanding this process is essential for managing plant health and preventing disease outbreaks.

The development of a plant disease can be broken down into a series of stages, often described in terms of the **disease cycle** and influenced by the **disease triangle**.

1. Disease Triangle

The **Disease Triangle** is a fundamental concept in plant pathology that explains the conditions necessary for disease development in plants. The model suggests that three key factors must interact for a disease to occur:

1. **Pathogen (Infectious Agent)**
2. **Host (Susceptible Plant)**
3. **Environment (Favorable Conditions)**

The relationship between these three factors determines whether disease will develop or not. If one of the elements is absent or not conducive, the disease cannot develop.

A. Pathogen

The pathogen is the biological agent (e.g., fungus, bacteria, virus, nematode, or parasitic plant) that causes disease. The pathogen must have the ability to infect, colonize, and reproduce in the host plant.

- **Example**: *Phytophthora infestans*, the causal agent of potato late blight, is a pathogen that needs to be present for the disease to occur.

B. Host

The host is the plant that is susceptible to the pathogen. Not all plants are equally vulnerable to all pathogens. Host susceptibility depends on factors such as genetic resistance, age, and physiological condition.

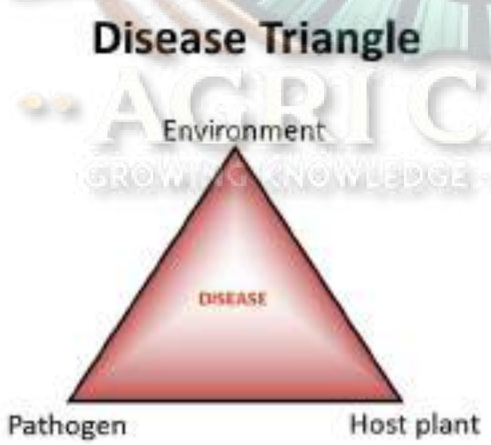
- **Example**: Potato plants are the host for *Phytophthora infestans*. Disease only develops if the potato is susceptible, as some varieties of potatoes are resistant to this pathogen.

C. Environment

Environmental conditions play a crucial role in disease development. Favorable conditions such as temperature, humidity, moisture, and light affect pathogen survival, spread, and infection process.

- **Example**: *Phytophthora infestans* thrives in cool, moist conditions, typically with temperatures between 15–22°C and high humidity. Without these favorable conditions, the disease cannot progress.

Diagram of Disease Triangle



In the Disease Triangle, all three factors must be present in a critical manner for disease to manifest. If any one of these factors is altered or absent, disease development is either prevented or controlled.

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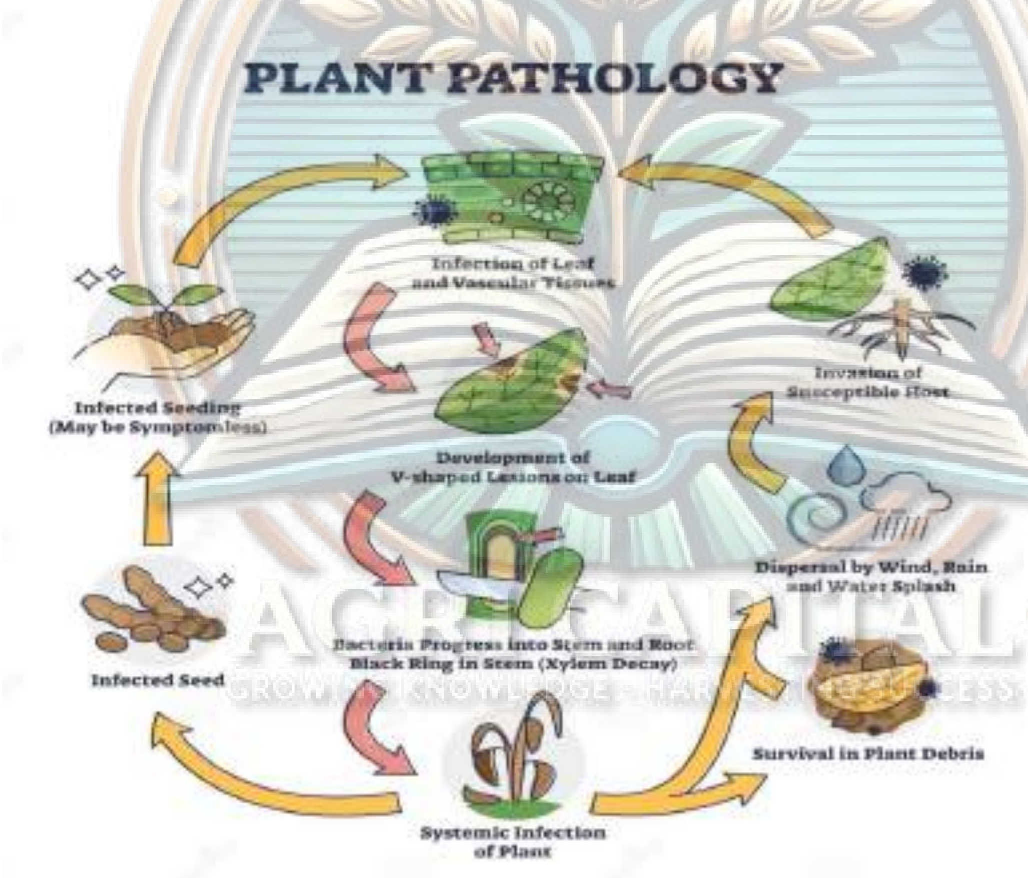
2. Disease Cycle

The **Disease Cycle** describes the process through which a plant disease develops, spreads, and perpetuates itself. It includes a series of stages that pathogens undergo to infect a host plant, reproduce, and continue the cycle. The exact stages can vary depending on the pathogen but generally involve the following key steps:



A. Inoculum (Primary Source of Infection)

The disease cycle begins with the presence of inoculum, which is the initial form of the pathogen that can initiate infection. The inoculum can be in the form of spores, bacteria, or viral particles, depending on the type of pathogen.

- **Example**:
  - In fungal diseases, the inoculum may be conidia, sporangia, or teliospores.
  - In bacterial diseases, the inoculum may be bacterial cells, often found in soil or plant residues.

B. Dispersal (Spread of Pathogen)

Once the inoculum is present, it must be dispersed to a susceptible host. Dispersal can occur via different means, including wind, water, insects, animals, or human activity.

- **Example**:
  - Wind disperses fungal spores like *Puccinia* (rust fungi) to distant plant hosts.
  - Water disperses *Phytophthora* spores during rain or irrigation.

C. Infection (Penetration and Colonization)

For the pathogen to establish an infection, it must successfully penetrate the host plant's defense barriers, including the cuticle, cell walls, and innate immune systems. Once it enters the plant, the pathogen colonizes tissues, either intracellularly or intercellularly, depending on the pathogen type.

- **Example**:
  - *Fusarium oxysporum* invades vascular tissues and spreads systemically in the plant.
  - Bacteria like *Xanthomonas* penetrate through natural openings (e.g., stomata) or wounds.

D. Incubation (Latent Period)

After infection, the pathogen enters a latent period during which it replicates and spreads within the host tissues, but visible symptoms do not yet appear. This period can vary in length depending on the pathogen and environmental conditions.

- **Example**:
  - In bacterial wilt caused by *Ralstonia solanacearum*, the latent period can last several days to weeks, depending on the environmental factors and host condition.

E. Symptom Expression

Symptoms of the disease begin to appear after the pathogen has spread sufficiently within the plant. Symptoms may include wilting, yellowing (chlorosis), necrosis, leaf spots, or stunting, and they are the result of pathogen toxins, enzymes, and plant immune responses.

- **Example**:
  - *Bacterium Xanthomonas* causes chlorotic leaf spots and necrosis in crops like tomatoes.

F. Reproduction and Release of Secondary Inoculum

Once the pathogen has colonized the host, it begins to reproduce. In fungi, this involves the formation of sexual or asexual spores, while bacteria reproduce through binary fission. The new generation of pathogen propagules, known as secondary inoculum, can then be dispersed to other plants, completing the cycle.

- **Example**:
  - *Alternaria* fungi produce conidia that are dispersed by wind or rain, causing new infections on other plants.
  - *Sclerotinia* fungi form sclerotia (resting bodies) that survive in soil and can sprout to infect new hosts.

G. Overwintering (Survival and Perpetuation)

Some pathogens can survive in the absence of a host during unfavorable conditions (such as the winter season or dry periods) by entering a dormant stage or forming resting structures. These structures can serve as a source of inoculum when the growing season resumes.

- **Example**:
  - *Puccinia* (rust fungi) forms teliospores that can overwinter on crop debris or in soil.
  - *Plasmopara viticola*, which causes downy mildew in grapes, overwinters as oospores in infected leaves or plant material.

Diagram of Disease Cycle:

1. Inoculum (Primary infection)
|
2. Dispersal (Spread of inoculum)
|
3. Infection (Penetration and colonization)
|
4. Incubation (Latent period)
|
5. Symptom Expression (Visible disease symptoms)
|
6. Reproduction & Secondary Inoculum (Pathogen reproduction)
|
7. Overwintering/Survival (Pathogen survival during non-growing season)
|
(Cycle repeats when favorable conditions return)

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3. Interrelationship Between Disease Triangle and Disease

Cycle

The **Disease Triangle** and the **Disease Cycle** are interconnected concepts. The Disease Triangle outlines the necessary factors for disease to develop, while the Disease Cycle explains the sequence of events that lead to disease progression and perpetuation.

- **The Disease Triangle** provides the conditions under which the pathogen, host, and environment must meet for infection to occur, and **the Disease Cycle** illustrates how the pathogen continues to infect and spread once it has established a presence.
- Understanding both concepts allows for effective management of plant diseases. For example, reducing pathogen inoculum (through sanitation or resistant cultivars) or altering environmental conditions (e.g., irrigation management to reduce humidity) can break the cycle and prevent disease development.

7.Bacteria: Morphology, reproduction classification of phytopathogenic bacteria.

BACTERIA- Bacteria are the microscopic, possess rigid cell wall, unicellular, prokaryotic protists lacking chlorophyll and divide chiefly by transverse binary fission. Among the major characteristics of bacterial cells are their size, shape, structure and arrangement, which constitute the morphology of the cell

Definition: Bacteria are extremely minute, rigid, essentially unicellular organisms (actinomycetes are filamentous), devoid of chlorophyll, most commonly reproduce by transverse binary fission and the resulting cells are identical in size and morphology.

IMPORTANT CHARACTERISTICS OF PHYTO PATHOGENIC BACTERIA:

1. Straight to curved rods with rigid cell walls (except filamentous bacteria). Some bacteria assume irregular shapes like V, Y, L etc., in different stages of their growth. Ex: V form of Corynebacterium (Clavibacter) and L-forms of Agrobacterium and Erwinia.

2. Carbohydrate decomposition is mostly aerobic or oxidative (except Erwinia, which is a facultative anaerobe) 3. Mostly gram negative, rarely gram positive (Gr +ve genera: Streptomyces, Corynebacterium, Clavibacter, Curtobacterium)

4. PPB can be cultured on artificial media. However, pathogenic bacteria grow slowly compared to saprophytes

5. Majority are flagellate

6. PPB can be identified based on flagellation, carbohydrate metabolism and pigment production
7. These are passive invaders, i.e., enter plants through wounds or natural openings
8. Survive, in/on the seed and in plant debris and spread by means of water, rain, insects, and agricultural implements
9. All are susceptible to phages
10.All are non-spore formers except Bacillus.
11. None of them cause human and animal diseases
12. Cell wall rigid 13. Aerobes/ facultative anaerobes
14. Slow growth compared to other saprophytic bacteria

15. Incubation period: 36- 48 hrs. 25˚C

16. Majority are flagellate and hence motile

Bacteria are second most important organisms which cause plant diseases.

- They are prokaryotic single celled mostly achlorophyllous organisms whose body is surrounded by cell wall and nuclear material is not surrounded by membrane.
- They lack membrane bound organelles such as mitochondria or plastids and also a visible endoplasmic reticulum.
- Most of the bacterial species are saprophytes living on dead organic matter. There are about 200 bacterial species which are plant pathogenic.
- Morphologically the bacteria are rod shaped (bacilli),

spherical (cocci), spiral (spirilli), coma shaped (vibrios) or thread like (filamentous).

- Streptomyces has a filamentous branched hypha-like structure, sometimes mistakenly called as ray fungi; and mycoplasma have no definite shape due to lack of cell wall.
- In young cultures the rod shaped bacteria range from 0.6 to 3.5 µm in length and from 0.5 to 1µm in diameter (0.6-3.5 x 0.5-1 µm size).
- Single bacterium mostly appears as hyaline or yellowish white under the compound microscope, when grown on a medium, soon a colony is formed.
- The colonies of most of bacteria have a whitish or greyish appearance but some of them develop yellow, red or other colours.

Bacterial morphology:

1. Shape (Cellular Morphology):
Bacterial cells exhibit various shapes that aid in their identification and classification. These shapes are primarily determined by the rigidness of the cell wall and the genetic factors.

- **Cocci (Plural: Cocci)**:
  - **Description**: Spherical or ovoid-shaped bacteria.
  - **Examples**:
    - *Staphylococcus* spp. (clusters, known as "grape-like" clusters)
    - *Streptococcus* spp. (chains)
    - *Neisseria* spp. (pairs, often referred to as "diplococci")
  - **Cell Division**: Cocci divide in one plane, resulting in chains or clusters depending on the species'

ability to separate after division.

- **Bacilli (Plural: Bacillus)**:
  - **Description**: Rod-shaped bacteria that may be straight or slightly curved.
  - **Examples**:
    - *Escherichia coli* (single, often found in intestines)
    - *Bacillus anthracis* (chains, causes anthrax)
  - **Cell Division**: Bacilli divide along a single plane but do not always separate completely after division, forming chains or pairs in some cases.
- **Spirilla (Plural: Spirillum)**:
  - **Description**: Rigid, spiral-shaped bacteria that possess a helical or corkscrew shape.
  - **Examples**:
    - *Spirillum volutans* (found in water)
  - **Cell Structure**: Characterized by a rigid cell wall, spirilla move via flagella (polar or tufted), which aid in their motility.
- **Vibrios**:
  - **Description**: Comma-shaped or curved rod-shaped bacteria.
  - **Examples**:
    - *Vibrio cholerae* (causes cholera)
  - **Cell Structure**: Similar to bacilli but with a characteristic bent appearance.
- **Spirochetes**:
  - **Description**: Long, thin, and flexible bacteria with a spiral or helical shape.
  - **Examples**:
    - *Treponema pallidum* (causes syphilis)
    - *Borrelia burgdorferi* (causes Lyme disease)
  - **Cell Structure**: Possess axial filaments (also known

as endoflagella), which are internal flagella that enable a twisting, corkscrew motion that allows them to burrow through tissues.

2. Size:
Bacterial cell size varies across species and is typically measured in micrometers (µm):

- **Typical Bacterial Size**:
  - Most bacteria range from 0.2 µm to 2.0 µm in diameter.
  - Cocci are often smaller, while bacilli can vary in size from 0.5 µm to 1.0 µm in width and 1.0 µm to 4.0 µm in length.
- **Large Bacteria**:
  - Some bacteria, such as *Epulopiscium* species (found in the intestines of fish), can reach lengths of several hundred micrometers, making them visible to the naked eye.

3. Arrangement:
Bacterial cell division and the subsequent arrangement of cells vary depending on the species and their mode of division.

- **Single**: Some bacteria exist as solitary, individual cells. E.g., *Escherichia coli*.
- **Pairs (Diplococci)**: When cocci divide in one plane and remain attached, they form pairs. Example: *Neisseria gonorrhoeae*.
- **Chains (Streptococci)**: Cocci that divide in one plane and form chains. Example: *Streptococcus pyogenes*.
- **Clusters (Staphylococci)**: Cocci divide in multiple planes, forming clusters. Example: *Staphylococcus aureus*.
- **Palisades**: In this arrangement, bacilli cells align side by

side, typically forming angular configurations. Common in *Corynebacterium* species.
- **Tetrads**: In some species, cocci divide in two planes and form packets of four cells, known as tetrads. E.g., *Micrococcus* spp.

4. Other Structures:

A. Flagella:

- **Function**: Flagella are long, whip-like appendages that allow bacteria to move through liquid environments by rotating in a propeller-like fashion.
- **Types**:
    - **Monotrichous**: Single flagellum at one pole (e.g., *Vibrio cholerae*).
    - **Lophotrichous**: A tuft of flagella at one or both poles.
    - **Peritrichous**: Flagella distributed over the entire surface of the bacterium (e.g., *Escherichia coli*).
    - **Amphitrichous**: Flagella at both poles of the cell.

B. Pili (Fimbriae):

- **Function**: Pili are shorter, hair-like structures that enable bacteria to adhere to surfaces or to each other. They also play a role in the exchange of genetic material (conjugation).
- **Types**:
    - **Type I Pili**: Adhesion to host cells.
    - **Sex Pili**: Used during conjugation, the process of horizontal gene transfer.

C. Capsules:

- **Function**: Some bacteria secrete a sticky, polysaccharide-rich outer layer known as the capsule. It provides protection against desiccation, phagocytosis, and antimicrobial agents.

- **Example**: *Streptococcus pneumoniae* has a capsule that enhances its virulence by evading the immune system.

D. Endospores:

- **Function**: Some bacteria (e.g., *Bacillus* spp., *Clostridium* spp.) form endospores—highly resistant, dormant structures that can survive extreme conditions (heat, radiation, desiccation).
- **Structure**: Endospores contain a small amount of cytoplasm and DNA, surrounded by multiple layers of protective proteins and peptidoglycan.

5. Cell Wall and Gram Staining:

The bacterial cell wall is a key determinant of the bacterial morphology and plays a critical role in classifying bacteria. The Gram stain is a method to categorize bacteria based on the structure of their cell walls.

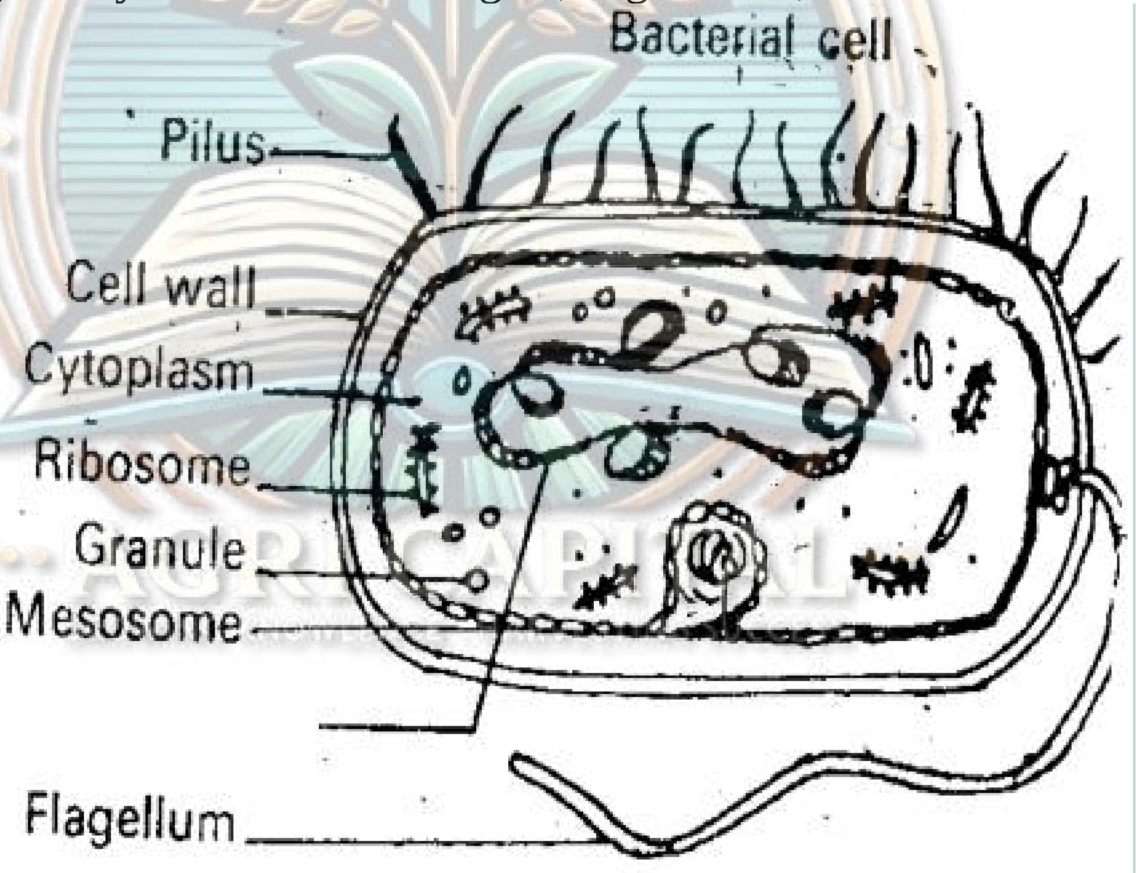
- **Gram-positive bacteria**: These bacteria have a thick peptidoglycan layer in their cell walls, which retains the crystal violet stain, appearing purple under a microscope.
    - Example: *Staphylococcus aureus*.
- **Gram-negative bacteria**: These bacteria have a thinner peptidoglycan layer, surrounded by an outer membrane, which prevents the crystal violet stain from being retained. They appear pink after Gram staining.
    - Example: *Escherichia coli*.

6. Morphological Variations:

- **Pleomorphism**: Some bacteria exhibit variable shapes under different environmental conditions. These bacteria lack a defined shape and are referred to as pleomorphic.
    - Example: *Mycoplasma* spp. (lack a cell wall and exhibit various forms).

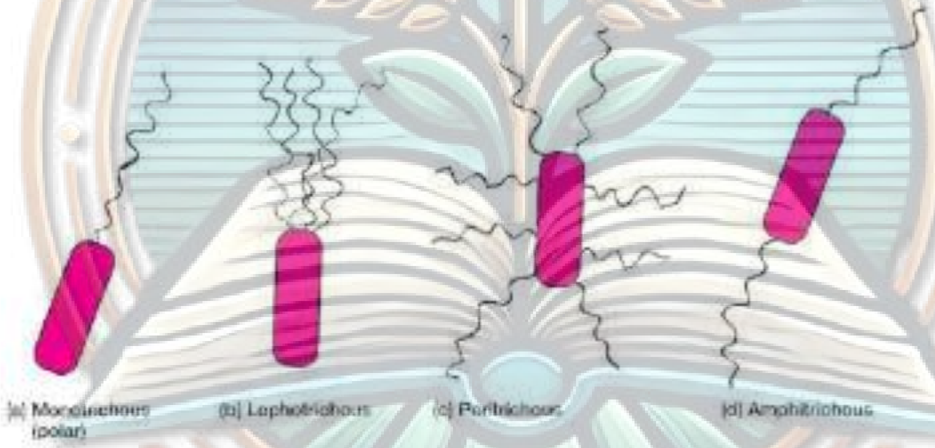
Bacterial Cell Structure

- A bacterium has a thin, relatively tough, rigid cell wall, and a distinct three layered but thin cytoplasmic membrane.
- Most bacteria have a slime layer made up of viscous gummy material. Slime layer has bacterial immunological property.
- When the layer is thick and firm, it is called capsule.
- Generally plant pathogenic bacteria lack capsule but some of them like Pseudomonas and Xanthomonas produce slime.
- Slime layer is mostly composed of polysaccharides but may rarely contain amino sugars, sugar acids, etc.



Flagella

- Most of the plant pathogenic bacteria have delicate thread like flagella, which are usually longer than the cell
- They are the organs of locomotion.
- The arrangement of flagella on bacterial cell is an important taxonomic character that aid in bacterial classification.
- This arrangement may be
- **Monotrichous-** with one polar flagellum
- **Lophotrichous** -tuft of flagella at one end
- **Amphitrichous-** at both the ends
- **Peritrichous -** distributed all around the cell or surface.
- **Atrichous-** bacteria lacking flagella.



2. Cell Wall

- Structure: The bacterial cell wall is made primarily of peptidoglycan (a polymer of sugars and amino acids). It serves as a rigid outer structure that maintains cell shape and protects the cell from osmotic pressure (which could otherwise cause it to burst).
- Types:
  - Gram-positive bacteria: These bacteria have a thick peptidoglycan layer and no outer membrane. The

thick wall is responsible for retaining the crystal violet stain in Gram staining, giving them a purple color (e.g., *Staphylococcus aureus*).
    - Gram-negative bacteria: These have a thin peptidoglycan layer surrounded by an outer membrane, which contains lipopolysaccharides (LPS). Gram-negative bacteria do not retain the crystal violet stain and appear pink after Gram staining (e.g., *Escherichia coli*).
- Function:
    - Provides mechanical support.
    - Protects the cell from harmful chemicals.
    - Prevents the cell from lysis due to osmotic imbalance.

Gram Staining

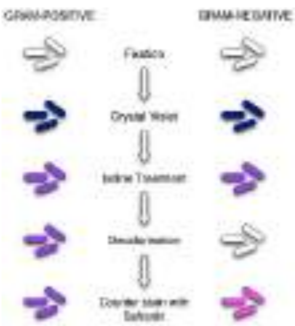
Bacterial species are often distinguished from one another by Gram staining.

- In this process, a bacterial smear is heat fixed on glass slide, stained with crystal violet and mordanted with iodine and finally rinsed with ethanol.
- When the bacteria retain the crystal violet stain after rinsing, the bacteria are called gram positive; and those which do not retain the stain are called gram negative.
- The later are then counter stained with pink colour safranin.
- The ability of bacteria to retain crystal violet stain or not, depends upon fundamental structure of cell wall.

Gram positive vs Gram negative bacteria

Gram Positive bacteria	Gram Negative

	bacteria
1. Cell wall is thicker and homogemous. 2. Contains lower content of lipids (5-10%) 3. Peptidoglycan comprises up to 90% of the cell wall and hence maximum lipid. 4. Techoic acid present. 5. Cell wall has higher amino sugar content (10-20%) 6. Cell wall is simple in shape and is single layered. 7. Mesosomes more prominent. 8. Retains violet dye 9. Examples: Bacillus, Clavibacter, Streptomyces	Cell wall is thinner and usually thin layered. Contains higher content of lipids (up to 40%) Peptidoglycan comprises only 10%. Techoic acid absent. Low content of amino sugars Varying cell wall shape and is tripartite (3-layered). Mesosomes less prominent. Retains red dye Examples: Erwinia, Pseudomonas, Xanthomonas, Agrobacterium, Xylella



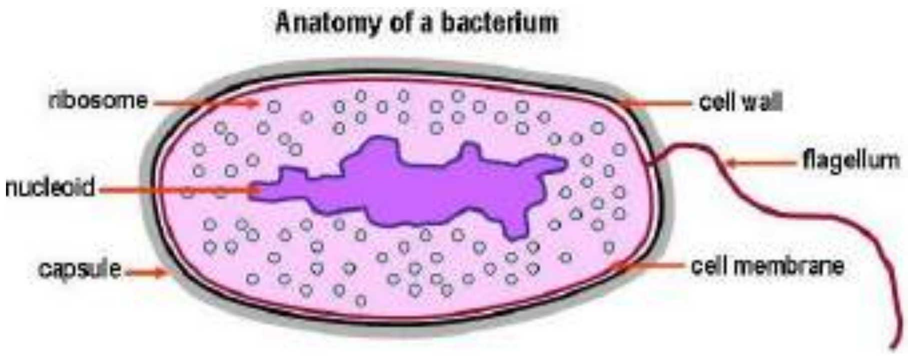
3.Plasma Membrane (Cytoplasmic Membrane)

- Structure: The plasma membrane is a lipid bilayer composed primarily of phospholipids and proteins. It is selectively permeable, meaning it controls the movement of substances into and out of the cell.
- Function:
  - Regulates the transport of nutrients, waste, and ions.
  - Houses enzymes involved in cellular processes like respiration (in some bacteria).
  - Contains protein transporters and receptors for communication and nutrient uptake.
  - Serves as the site for ATP synthesis in some bacteria (especially in the absence of mitochondria).

4. Cytoplasm

- Structure: The cytoplasm is a gel-like substance that fills the interior of the cell. It consists mainly of water, enzymes, nutrients, and other essential molecules.
- Function:
  - Contains the necessary components for metabolic processes.
  - Houses ribosomes and plasmids.
  - The site of cellular reactions, including protein synthesis and glycolysis.

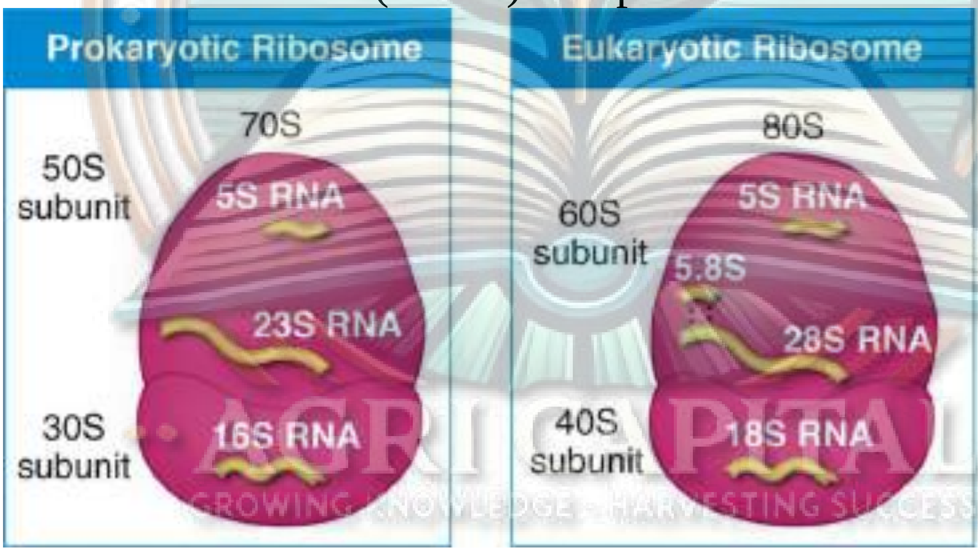
5.Nucleoid Structure: The nucleoid is the region within the bacterial cell that contains the genetic material (DNA). Unlike eukaryotic cells, bacteria do not have a membrane-bound nucleus. The nucleoid consists of a single, circular chromosome of DNA.



- Function:
  - Contains the essential genetic information required for the bacterial cell's functions and reproduction.
  - DNA in the nucleoid is not enclosed by a membrane but is in direct contact with the cytoplasm.

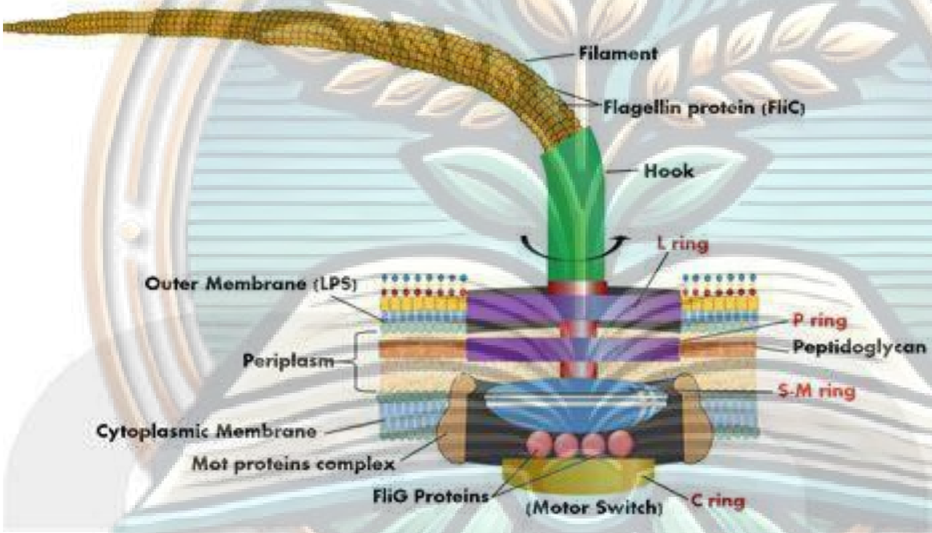
6.Ribosomes

- Structure: Ribosomes in bacteria are 70S (composed of a 50S large subunit and a 30S small subunit). They are made of ribosomal RNA (rRNA) and proteins.



- Function:
  - The site of protein synthesis (translation). mRNA from the nucleoid is translated into proteins by the ribosomes.
  - Ribosomes are dispersed throughout the cytoplasm or can be attached to the plasma membrane in some cases.

7.Flagella

- In bacteria, flagella are the organs of locomotion.
- They are very delicate and fragile and cultures are to be handled carefully for their staining.
- The flagella vary from 10-12 nm in width which is smaller than wavelength of light, therefore, cannot be seen by ordinary staining.
- Mordants like potassium sulphate and mercuric chloride are generally precipitated on flagella making the width more for making them visible under light microscope.
- 

Parts of a Flagellum

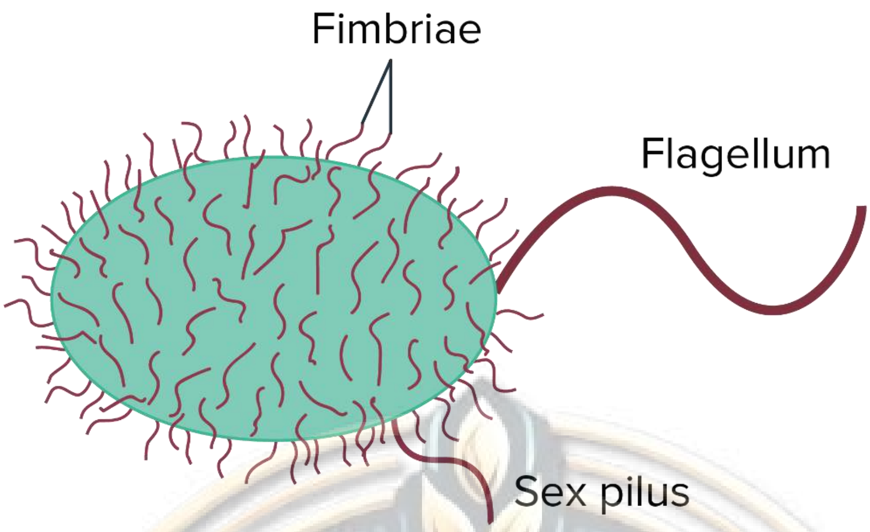
- Filament: It is the outermost region of flagellum, and is helical, composed of flagellin with a molecular weight of 30000-40000 and is synthesized in the cell, which moves to the hollow core of the flagellum to the tip. Flagellin is a protein with 14 amino acids and is characterised by higher content of aromatic amino acids and absence of cysteine in many cases.

- Hook: Filament is attached to hook which is wider than the flagellum. This is 45 nm wide and made up of different types of protein. The hook of gram positive bacterium is longer than that of gram negative bacteria.

- Basal body: The third part called basal body consists of small central rod which is inserted into a system of rings. The gram positive and gram negative bacteria are different in the number of rings. The inner pair of rings (S and M) are embedded in cell membrane and are formed in both gram positive and gram negative bacteria. L and P rings are formed only in gram negative bacteria. S and M rings are important for movement of flagella.

8.Pili

- In some bacteria, small hair like structures are also present which are called pili.
- These are shorter than the flagella and are thicker (3-15 nm in diameter).
- The term fimbriae is sometimes also used for pili, but the term pili is reserved for those which are involved in conjugation.



- They are made up of protein sub-units pilin of molecular weight of 70000.
- It consists of a helically coiled fibre with a central hole of 2 nm in diameter.
- Fimbriae may be involved in attachment, whenever there is infection. Both flagella and pili originate from cell membrane and extend outward through the cell wall.

9. Mesosomes

- Structure: Mesosomes are infoldings of the plasma membrane that may be observed in some bacterial cells under a microscope. However, their presence and function have been debated, and they may be artifacts created during cell preparation.
- Function: Some proposed functions include helping with cell division or the organization of enzymes for cellular respiration, although this is not universally accepted.

10. Capsule

- Structure: The capsule is a thick, gelatinous layer composed of polysaccharides (or occasionally polypeptides). It surrounds the cell wall and is often visible through a microscope as a clear halo.
- Function:
    - Provides protection against desiccation, the immune system (phagocytosis), and harmful chemicals.

- Enhances virulence by helping bacteria evade the host immune response, as it can prevent recognition by white blood cells.
- Helps bacteria adhere to surfaces.

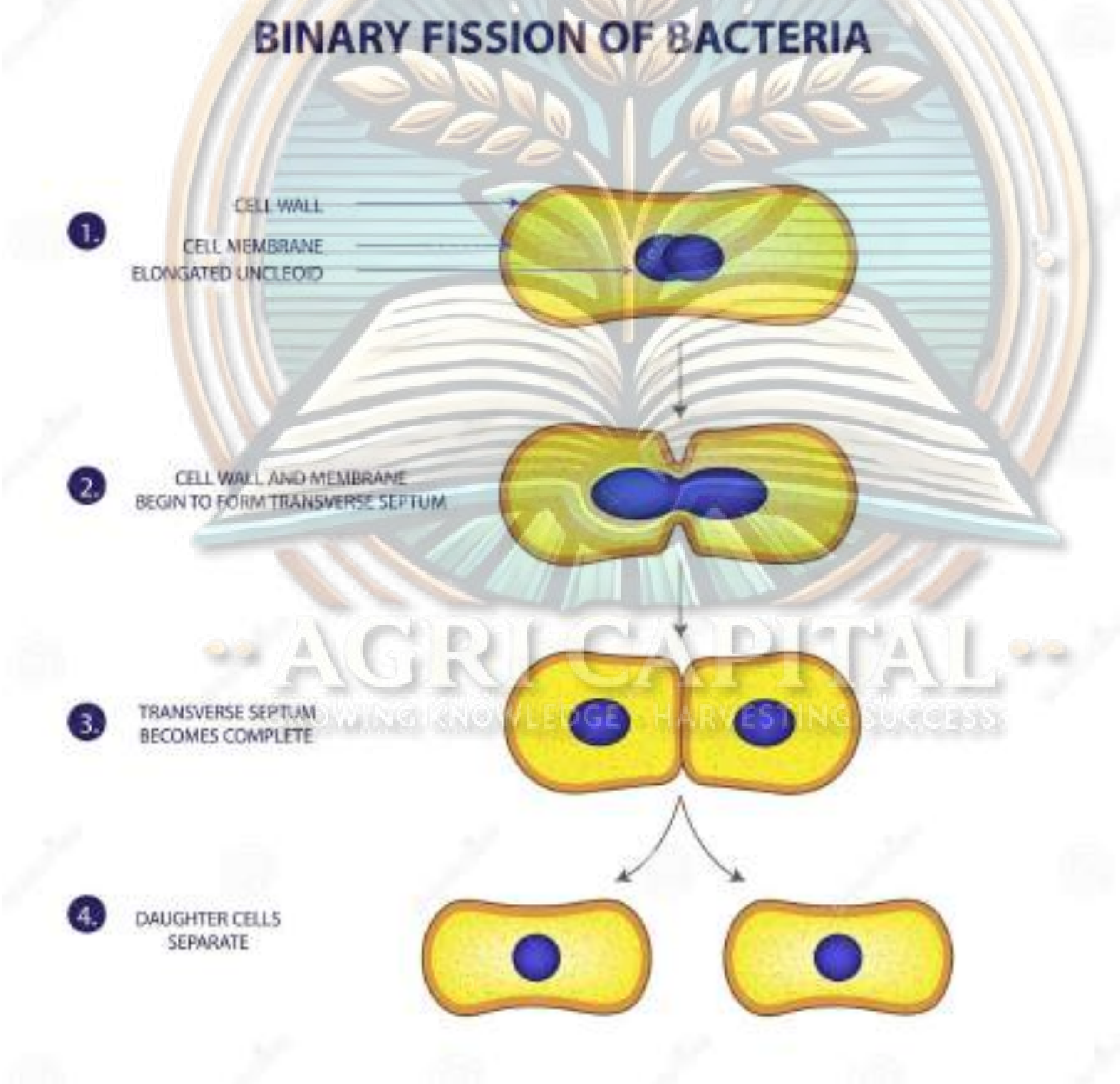
Structure	Function
Cell Wall	Provides shape, protection, and prevents osmotic lysis.
Plasma Membrane	Controls material exchange, houses enzymes for metabolism, and maintains homeostasis.
Cytoplasm	Contains the cell's metabolic machinery and components like ribosomes.
Nucleoid	Stores the genetic material (DNA), responsible for cell replication and function.
Ribosomes	Site of protein synthesis (translation).
Plasmids	Carry additional genetic information that may enhance survival, e.g., antibiotic resistance.
Flagella	Enable movement, provide motility, and help the bacterium respond to environmental stimuli.
Pili	Facilitate attachment to surfaces, contribute to conjugation, and increase virulence.
Capsule	Protects from phagocytosis, aids in attachment, and increases virulence.
Endospores	Provide survival in harsh conditions, allowing the bacterium to "hibernate" until conditions improve.
Mesosomes	Proposed to be involved in cellular processes like respiration and cell division (debated).
Inclusion Bodies	Store nutrients or reserve materials, such as lipids, starch, or iron.

Reproduction

Bacteria multiply at a phenomenal rate by the process of fission or binary fission.

- As the cytoplasm and cell wall undergo division into two, the nuclear material is organized into a circular chromosome like structure which ultimately duplicates itself and gets distributed equally into 2 newly formed cells.

- Similarly, plasmids also duplicate and come into 2 daughter cells.
- The duplication occurs rapidly, once every 20 minutes.
- As a result a bacterium like Eschersia coli, starting from one bacterium may produce 1 million bacteria in 10 hours.
- However, this number is not reached because of gradual limitations of nutrients and toxic metabolites. Still what is achieved normally is phenomenonal.
- Such prolificacy in multiplication must be of great advantage both in survival of bacterial pathogen, and also for successive plant infections.



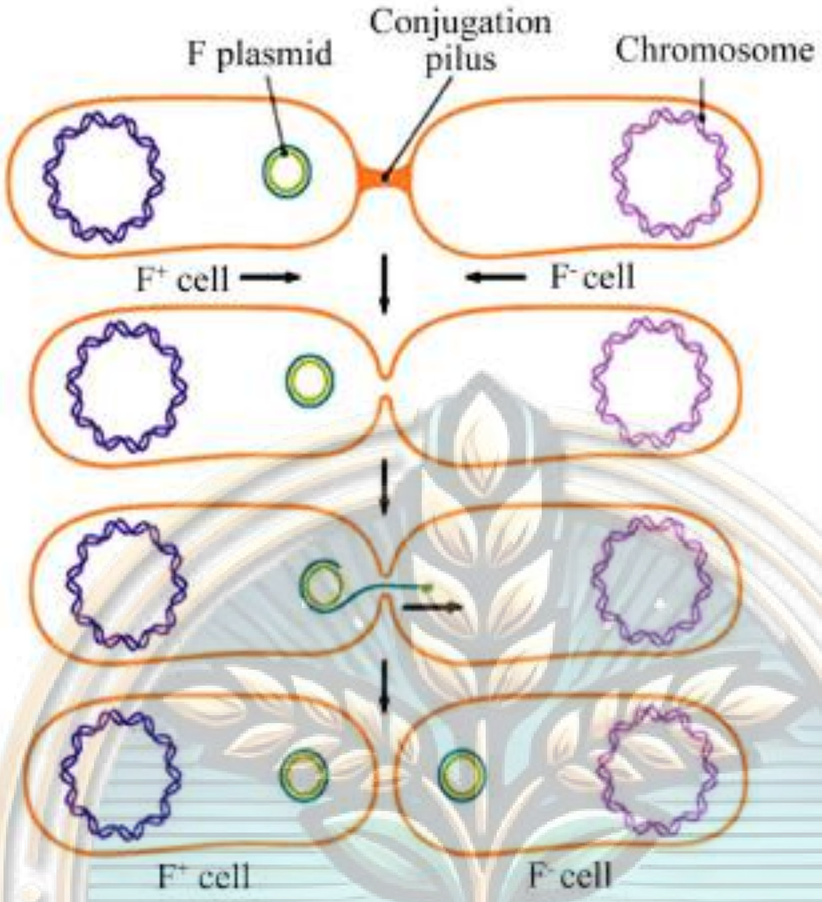
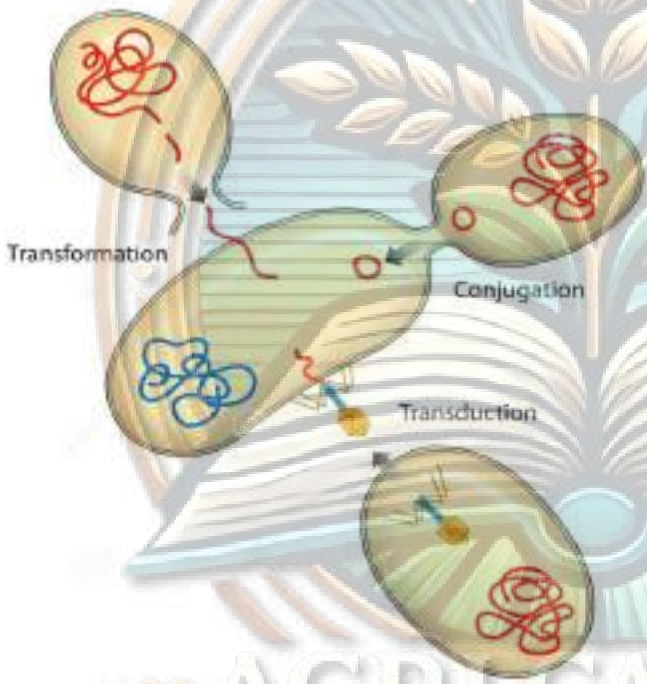


Figure: Bacterial conjugation involves several steps: First the physical contact between the cells is made by the Pilli. One strand of plasmid is transferred from the donor (F+) to the recipient (F-). The recipient synthesizes a complementary strand to become F+ cell and the donor synthesizes a complementary strand restoring its complete plasmid.

Recombination

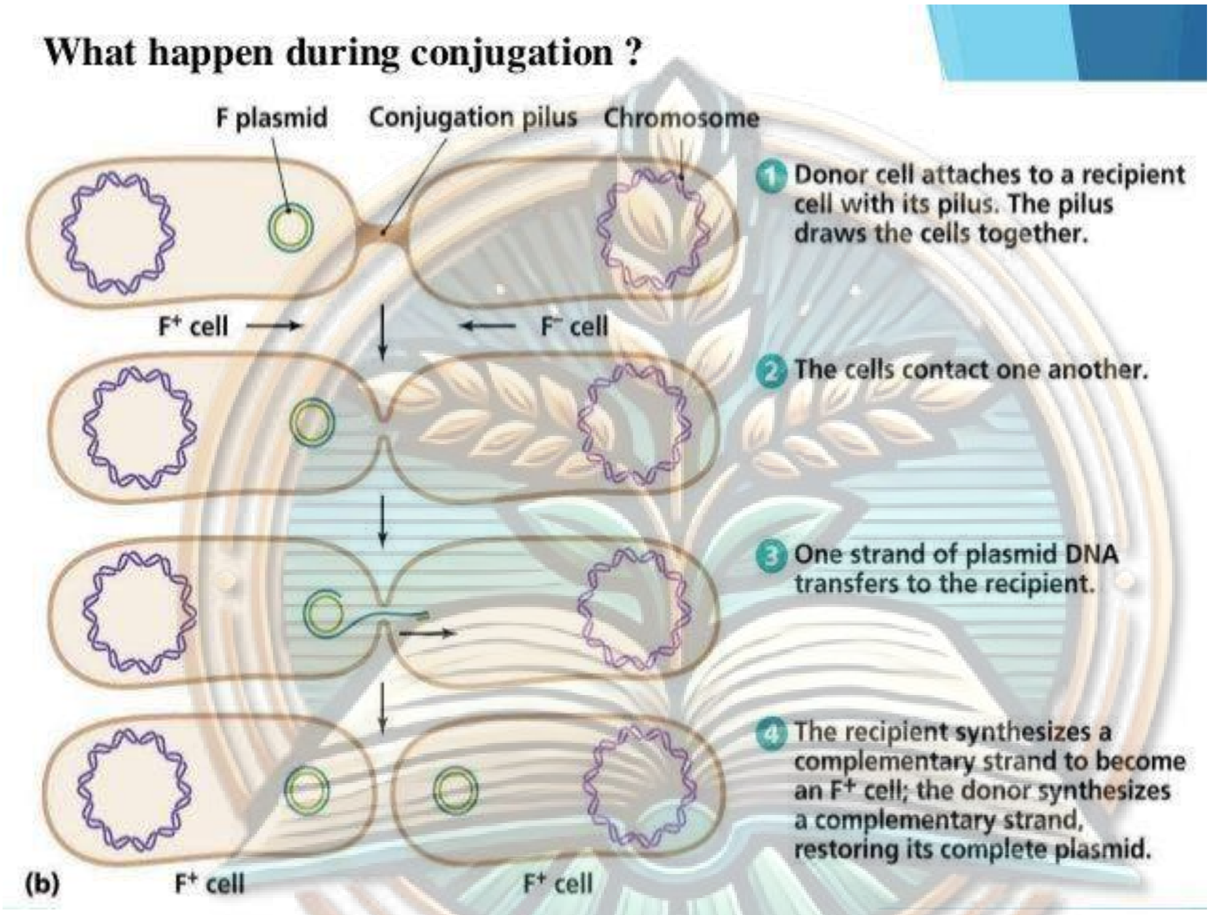
The genetical recombination in bacteria has been noticed by the following sexual-like processes:

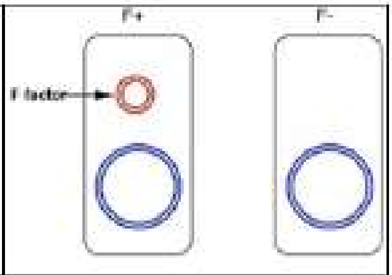
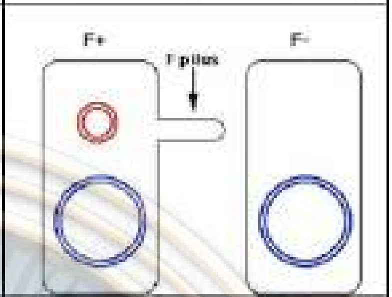
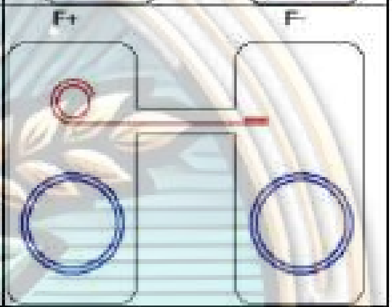
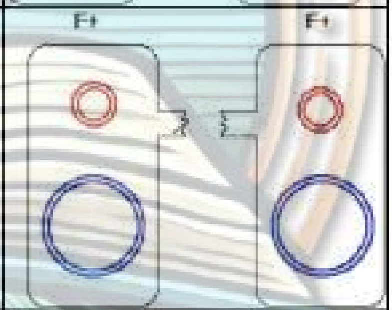
- Conjugation: Conjugation occurs when two compatible bacteria come into contact and part of the chromosomal or non-chromosomal genetic material of one is transferred to the other and incorporated into the genome of later through conjugal zygote formation and breakage and reunion. It was first observed by Lederberg and Tatum (1956) in E. coli.



- Transformation: It occurs when the bacterium is genetically transformed by absorption of genetic material of another compatible bacterium, secreated by or released in a culture during the rupture, and its incorporation into the genome of the former. It was first observed by Griffith (1928) in Enterococcus pneumoniae.
- Transduction: When genetic material from one bacterium is

carried by its phage (virus) to another bacterium that it visits next and the later is genetically transformed. It was first discovered by Zinder and Lederberg (1952) in Salmonella.



Basic conjugation occurs between an F+ cell and an F- cell. The difference between these two types of cells is the presence or absence of the F (fertility) factor, which is a circular DNA molecule independent of the bacterial chromosome (the larger circular molecule.	
The F+ cell initiates conjugation by extending an F pilus toward the F- cell. Among the genes present on the F factor are the genes encoding the proteins required for pilus construction.	
The F pilus, when finished, temporarily connects the two cells. On strand of the F factor is nicked, and begins unwinding from the other strand. The nicked strand begins to transfer through the F pilus to the F- cell. As it does so, this strand begins to be replicated, as does circular strand remaining behind in the F+ cell.	
Eventually, the nicked strand completely passes through to the recipient cell, and is completely replicated. This process produces a new F factor in the recipient cell. The pilus is broken, severing the connection between the two cells. Since both cells now contain an F factor, both cells are F+. The new F+ cell (which was the F- cell, can now initiate conjugation with another F- cell.	

Bacteria can pick up loose DNA in their environment through the process of transformation. The newly acquired DNA is rendered single stranded, and can recombine with the host chromosome.

• Bacteria can exchange DNA through the process of conjugation. The F factor confers the ability to initiate conjugation. If the F factor alone is transferred, no recombination will occur. Under certain circumstances, chromosomal DNA can be transferred to the recipient cell. In these cases, recombination will occur.

• Bacteria can receive bacterial DNA from viruses through the process of transduction. Bacterial viruses can accidentally pick up pieces of bacterial DNA. When they subsequently infect a cell, they transfer the pice of bacterial DNA, which can undergo recombination with the host bacterial chromosome.

• The result of recombination in the above cases may be gene conversion, in which a mutant allele becomes wild-type or vice versa.

• Conjugation involving Hfr bacteria can be used to map genes along the bacterial chromosome. This done by determining in what order genes are transferred during conjugation, waht the time difference is between the transfer of genes. Bacteria do not reproduce sexually but can acquire new DNA through transformation, transduction or conjugation.These natural processes have been modified so that DNA can be deliberately incorporated into host microbes- even genes that would normally never be transferred this way.

Mycoplasma/PPLO's

Mycoplasma, earlier known as 'Pleuro Pneumonia Like Organisms' (PPLO's) were discovered to be associated with the disease bovine pleuro pneumonia and were described in one of the orders mycoplasmatales under Eubacteria.

- Mycoplasma represent a group of organisms that lack cell wall and contain a very small genome.
- Phylogenetically, they are closely related to clostridia, the gram positive bacteria.
- As per the requirement for their growth, they can be divided into those which require sterol (mycoplasma and spiroplasma); and those which do not require sterols (acholeplasma and thermoplasma).
- The mycoplasma cells are small, pleomorphic (of different shapes) and divide by budding. The colonies of mycoplasma on agar exhibit a characteristic 'fried egg' appearance because of the formation of dense central core surrounded by lighter circular spreading area.
- The growth of mycoplasma is not inhibited by penicillin or other antibiotics that inhibit cell wall synthesis. But they are sensitive to tetracycline.
- The Spiroplasma genus is important plant pathogenically and has cork screw shaped cells. They are motile and exhibit undulating or rotating movement. Spiroplasma citri has been associated with citrus plants, where it causes citrus stubborn disease and corn plants which causes corn stunt.

Phytoplasma

They were earlier called MLO's and were found to be associated with several yellows and witches' broom diseases after their discovery by Doi et al. in 1967.

- They are different from mycoplasma in the sense that they can not be cultured on synthetic media.
- The change in terminology from MLO's to phytoplasma occurred since the studies of DNA homology in the highly conserved genes encoding ribosomal RNA and ribosomal protein.
- It showed that the phytoplasma comprise a coherent group distinct from other prokaryotes. Their closest relatives are in the genus Acholeplasma.
- As they have not been cultured on artificial medium in vitro and characterized apart from their host, they are referred to Candidatus status.
- They are associated with about 200 plant diseases including aster yellows, apple proliferation, peanut witches' broom, peach-x-disease, rice yellow dwarf and elm yellows.
- They are phloem inhabiting organisms and are graft transmissible in nature, and can also be transmitted by leaf hoppers.

Bacteria as Plant Pathogens

- Bacteria are known to grow in a wide range of habitat.
- All the plant pathogenic bacteria are mesophilic (they can grow at a temperature of 20-35ºC); and remain in the host plants as plant parasites and only partly in plant residues or as saprophytes in soil.
- They enter the plants either through natural openings such as stomata, lenticels or hydathodes or through wounds.

- The presence of free water is essential for bacterial infection. Once inside the plant tissues, they multiply only if there is water or at very high humidity.
- They multiply in the intercellular spaces and produce pectolytic and other cell wall degrading enzymes, thereby creating more space to move inside the host tissue.
- They kill the host cells by the action of extracellularly released enzymes and toxins and subsequently invade the dead cells. Most of the bacterial pathogens are necrotrophs.
- Some are apparently biotrophs.
- Some species colonize the xylem vessels and because of their physical presence or the slime ultimately cause the plugging of the water conducting tissues and cause wilt symptoms.
- Plant pathogenic bacteria produce various types of symptoms in plants as are caused by fungal pathogens. They cause soft rot of vegetables and fruits, wilts, cankers, scabs and also over-growths.

CLASSIFICATION

Traditionally bacteria have been included in Plantae kingdom under Thallophyta; however, Haeckel in 1966 proposed the kingdom Protista to include all unicellular organisms and placed various organisms of Thallophyta plants and Protozoa animals in Protista.

Later, the nucleus character was given more importance. Chatton proposed the most appropriate conceptual basis for taxa at the highest level by recognizing two general patterns of cellular organelles as prokaryotes and eukaryotes in 1937.

Stanier (1969) considered prokaryotes as lower protists including blue green algae, myxobacteria and eubacteria; and eukaryotes as higher protists including algae, fungi and protozoa. Prokaryotae was recognised a separate kingdom. However, the correct concept is that of 5 kingdoms according to Whittaker (1969) including Plantae, Animalia, Fungi, Protista and Monera (Prokaryotes).

- In 'Bergey's Manual of Determinative Bacteriology' the phytopathogenic bacteria have been classified into three divisions:

Division I – Gracilicutes
They include prokaryotes with thin cell walls consisting of outer membrane with fatty acid glycerol ester-type lipids and are usually gram negative. They do not form endospores.

Division II – Firmicutes
It included prokaryotes with thick (firm) cell wall consisting of peptidoglycan and unit membrane but without any outer membrane. Some of them produce endospore. They are gram positive.

Division III – Tenericutes
They lack cell wall and cells are enclosed by a unit membrane only. They include mollicutes or mycoplasma like organisms (now called phytoplasma).

Detailed Classification of Phytopathogenic Bacteria
Kingdom: Prokaryotae

Division I: Gracilicutes
Class: Proteobacteria (mostly single-celled, non-photosynthetic)
Family 1: Enterobacteriaceae (They are peritrichous bacteria)
Genus: Erwinia
E. amylovora causing fire blight of apple and pear
E. carotovora pv. *carotovora* causing soft rot of vegetables
E. carotovora pv. *atroseptica* causing black leg of potato
Family 2: Pseudomonadaceae
Genus: Pseudomonas
P. syringae pv. *syringae* causing stone fruit bacterial canker
P. syringae pv. *tabaci* causing wild fire disease of tobacco

Genus: Ralstonia
R. solanacearum causing bacterial wilt of solanaceous crops

Genus: Xanthomonas
X. campestris pv. *campestris* causing black rot of cabbage, *X. campestris* pv. *phaseoli* causing common bean blight
X. campestris pv. *vesicatoria* causing tomato bacterial spot
X. oryzae pv. *oryzae* causing bacterial leaf blight of rice
X. axonopodis pv. *citri* causing citrus canker

Family 3: Rhizobiaceae
Genus: Agrobacterium
A. tumefaciens causing crown gall of stone fruits
A. rhizogenes causing hairy root of apple

Family : Still unnamed
Genus: Xylella
X. fastidiosa [earlier called RLO's rickettssia like organisms] xylem- inhabiting causing Pierce's disease of grapevines, phony peach, almond leaf scortch
Candidatus liberobacter asiaticus, phloem-inhabiting causing citrus greening
Unnamed, latex-inhabiting, causing bunchy top disease of papaya

Division 2: Firmicutes
Class 1: Firmibacteria (Simple gram positive bacteria)
Bacillus subtilis – biocontrol agent

Class 2: Thallobacteria (Gram positive, branching bacteria)
Streptomyces scabies causing common scab of potato
Clavibacter michiganense pv. *sepedonicum* causing ring rot of potato
Clavibacter michiganense pv. *michiganense* causing bacterial canker of tomato
Curtobacterium (Corynebacterium) flaccumfaciens causing bacterial wilt of bean

Division 3: Tenericutes
Class: Mollicutes (wall less prokaryotes)
Family: Spiroplasmataceae
Spiroplasma citri causing citrus stubborn
Spiroplasma kunkelii causing corn stunt

Several organisms called phytoplasma have been reported to cause various yellows and witches' broom type diseases are included in this group and have been given Candidatus status for the time being due to the inability of their culturing.

8.Fungi and their morphology, reproduction and classification of fungi

Fungi

Definition:

Fungi are eukaryotic, spore-bearing, achlorophyllous, heterotrophic organisms that generally reproduce sexually and asexually. They possess filamentous, branched somatic structures surrounded by cell walls containing chitin or cellulose and exhibit absorptive nutrition.

Somatic Structures

1. Thallus (Soma)

- Also called the **vegetative body** or **fungal body**.
- Simple body devoid of chlorophyll, with no differentiation into stem, roots, or leaves.
- Lacks a vascular system.

2. Hypha (pl. Hyphae)

- Thin, transparent, tubular filament filled with protoplasm.
- Unit of filamentous thallus.
- Grows by **apical elongation**.

3. Mycelium (pl. Mycelia)

- A network of hyphae constituting the filamentous thallus.
- Can be **hyaline (colorless)** or **pigmented**.
- May be **ectophytic (external)** or **endophytic (internal)**.

Types of Fungal Thalli

1. Plasmodium

- A naked, multinucleate mass of protoplasm moving in an amoeboid fashion.
- **Example:** *Plasmodiophora brassicae*.

2. Unicellular Thallus

- Consists of a single cell.

- **Example:** *Chytrids*, *Synchytrium*.

3. Multicellular (Filamentous) Thallus

- Consists of branched, thread-like filaments called **hyphae**.
- **Example:** *Alternaria*.

Fungi Based on Reproductive Structures

1. Holocarpic

- Entire thallus is converted into one or more reproductive structures.
- **Example:** *Synchytrium*.

2. Eucarpic

- Thallus is differentiated into:
    - **Vegetative part** (absorbs nutrients).
    - **Reproductive part** (forms reproductive structures).
- **Example:** *Pythium*.

Types of Fungal Growth

1. Ectophytic Fungus

- Fungal thallus is present on the surface of the host plant.
- **Example:** *Oidium*.

2. Endophytic Fungus

- Fungal thallus penetrates the host cell.
- **Example:** *Puccinia*.
- Can be:
    - **Intercellular:** Hypha grows between cells (produces haustoria).
    - **Intracellular:** Hypha penetrates into host cells (no haustoria).
    - **Vascular:** Hypha grows inside xylem vessels (*Fusarium oxysporum*).

Septation in Fungi

1. Aseptate (Coenocytic) Hypha

- No septa; nuclei embedded in cytoplasm.

- **Example:** *Oomycetes, Zygomycetes*.

2. Septate Hypha

- Hyphae with septa or cross walls.
- **Example:** Higher fungi (*Ascomycotina, Basidiomycotina, Deuteromycotina*).

Types of Septa

Based on Formation:

- **Primary Septa:** Formed with nuclear division (mitotic or meiotic).
- **Adventitious Septa:** Formed independently of nuclear division (e.g., in gametangia).

Based on Construction:

- **Simple Septa:** Plate-like, with or without perforation.
- **Complex Septa:** Central pore surrounded by a barrel-shaped swelling and a perforated membrane (*Dolipore septum in Basidiomycotina*).

Based on Perforation:

- **Complete Septa:** Solid plate, no perforations.
- **Incomplete Septa:** Contains a central pore.

Fungal Tissues (Plectenchyma)

Plectenchyma refers to organized fungal mycelium forming vegetative and reproductive structures.

Types of Plectenchyma:

1. **Prosenchyma**
    - Loosely woven tissue.
    - Hyphae retain individuality and lie parallel.
    - **Example:** Trauma in *Agaricus*.
2. **Pseudoparenchyma**
    - Compactly woven tissue.
    - Consists of closely packed, isodiametric, or oval cells.
    - **Example:** *Sclerotium* bodies, rhizomorph of *Armillariella*.

Reproduction in Fungi

Reproduction is the process of forming new individuals that possess all the characteristics of the species.

Types of Reproduction in Fungi

1. **Asexual (Non-Sexual / Vegetative / Somatic) Reproduction**
2. **Sexual Reproduction**

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1. Asexual Reproduction

- Also called the **imperfect stage** or **anamorphic stage**.
- No union of nuclei, sex cells, or sex organs.
- Occurs multiple times in the fungal life cycle, producing numerous spores.
- **Asexual spores are formed through mitosis**, hence called **mitospores**.

Methods of Asexual Reproduction

1. Fragmentation

- Most common method.
- The fungal hypha breaks into small pieces called **fragments**, each growing into a new mycelium.
- Spores produced by fragmentation are called **arthrospores** or **oidia**.
  - *Example: Oidium, Geotrichum*
- Sometimes, thick-walled resistant spores called **chlamydospores** are formed.
  - *Example: Fusarium oxysporum, Ustilago tritici*

2. Fission (Transverse Fission)

- The parent cell elongates, and the nucleus undergoes mitosis to form two nuclei.
- A transverse septum is formed, dividing the cell into two daughter cells.
  - *Example: Saccharomyces cerevisiae*

3. Budding

- Small outgrowths called **buds** (blastospores) emerge from the parent cell.
- The nucleus divides, and one daughter nucleus enters the bud.
- The bud eventually separates and functions as an independent propagating unit.
  - *Example: Saccharomyces cerevisiae*

4. Sporulation (Production of Spores)

- **Spores**: Small propagating units functioning as seeds but lacking an embryo.
- Spores vary in **color, size, cell number, and method of production**.

- Two main types:
  1. **Sporangiospores** (formed inside sporangia)
  2. **Conidia (Conidiospores)** (formed externally)

Sporangiospores

- Produced **inside** a sac-like structure called **sporangium**, which is borne on **sporangiophore**.
- Types of sporangiospores:
  - **Zoospores (Planospores):** Motile spores with flagella.
    - *Example: Pythium, Phytophthora*
  - **Aplanospores:** Non-motile spores without flagella.
    - *Example: Rhizopus stolonifer, Mucor*

Flagella in Fungi

- Thin, hair-like structures aiding motility in lower and aquatic fungi.
- **Types of flagella:**
  - **Whiplash Flagella:** Thick, rigid basal portion with a flexible upper part.
  - **Tinsel Flagella:** Long rachis with lateral hair-like projections (mastigonemes).

Classification Based on Flagella

1. **Uniflagellate Zoospore:** Single flagellum (anterior or posterior).
2. **Biflagellate Zoospore:** Two flagella, either equal or unequal in size.

Conidia (Conidiospores)

- Non-motile spores, produced freely on **conidiophores** or within **asexual fruiting bodies**.
- **Asexual Fruiting Bodies:**
  1. **Pycnidium:** Flask-shaped with an opening (ostiole).
     - *Example: Phomopsis*
  2. **Acervulus:** Saucer-shaped, lacks a definite wall or ostiole.
     - *Example: Colletotrichum, Pestalotiopsis*
  3. **Sporodochium:** Cushion-shaped, with conidiophores forming a mass.
     - *Example: Fusarium*
  4. **Synnemata:** Group of conidiophores, resembling a feather duster.
     - *Example: Graphium*

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2. Sexual Reproduction

- Involves the union of two compatible nuclei, sex cells, sex organs, or hyphae.

- Known as the **perfect stage** or **teleomorphic stage**.
- Occurs **once** in a fungus's life cycle, producing thick-walled, resistant **sexual spores** (resting spores).

Sex Organs in Fungi

- **Gametangia:** Sex organs containing gametes.
- **Male Gametangium: Antheridium** (club-shaped).
- **Female Gametangium: Oogonium** (globose-shaped) or **Ascogonium**.
- **Gametes:**
  - Male: **Antherozoids/Sperm/Spermatozoids**
  - Female: **Egg/Oosphere**

Types of Gametangia and Gametes

- **Isogametangia:** Morphologically similar.
- **Heterogametangia:** Morphologically different.
- **Isogametes:** Morphologically similar gametes.
- **Heterogametes:** Morphologically different gametes.
- Some fungi use **+ and – symbols** instead of male/female differentiation.

Classification Based on Sex Organs

1. **Monoecious (Hermaphroditic) Fungi:** Male & female organs on the same thallus.
   - *Example: Pythium aphanidermatum*
2. **Dioecious Fungi:** Male & female organs on separate thalli.
   - *Example: Phytophthora infestans*

Classification Based on Compatibility

1. **Homothallic Fungi:** Self-fertile (both sexes on the same thallus).
   - *Example: Pythium aphanidermatum*
2. **Heterothallic Fungi:** Self-sterile, requiring two compatible thalli for reproduction.
   - *Example: Phytophthora infestans*

Phases in Sexual Reproduction

1. **Plasmogamy:** Fusion of protoplasts, bringing two nuclei together.
2. **Karyogamy:** Fusion of two nuclei to form a diploid nucleus (zygote).
3. **Meiosis:** Reduction division forming haploid nuclei.

Methods of Sexual Reproduction

1. **Planogametic Copulation:** Fusion of two naked gametes.
    - **Isogamy:** Similar motile gametes (*Plasmodiophora brassicae*).
    - **Anisogamy:** Dissimilar motile gametes (*Allomyces macrogynus*).
    - **Heterogamy:** One motile, one non-motile (*Monoblepharis polymorpha*).
2. **Gametangial Contact:** Fusion via a fertilization tube. (*Pythium aphanidermatum*).
3. **Gametangial Copulation:** Direct fusion of entire gametangia (*Rhizopus stolonifer*).
4. **Spermatization:** Transfer of **spermatia** into receptive hyphae (*Puccinia graminis*).
5. **Somatogamy:** Fusion of somatic hyphae (*Agaricus campestris*).

Parasexual Cycle

- Discovered in *Aspergillus nidulans* (1952, Pontecorvo & Roper).
- **Plasmogamy, Karyogamy, and Haploidization** occur randomly.
- **Importance:** Generates genetic variability, useful in Deuteromycotina.

Types of Sexual Spores

1. **Oospores** (*Pythium, Phytophthora*)
2. **Zygospores** (*Rhizopus*)
3. **Ascospores** (*Erysiphe*)
4. **Basidiospores** (*Puccinia*)

Life Cycle Patterns in Fungi

1. **Haplobiontic Life Cycle:** Single haploid/diploid phase. (*Schizosaccharomyces octosporus*).
2. **Diplobiontic Life Cycle:** Alternation of haploid & diploid thalli. (*Saccharomyces ludwigii*).

Classification of Fungi

Fungi are **eukaryotic, heterotrophic organisms** that may be **unicellular (Yeast)** or **multicellular (Mushrooms, Molds)**. They exist as **saprophytes, parasites, or symbionts** and reproduce via **spores**.

Basis of Fungal Classification

Fungi are classified based on:

1. **Structure of mycelium** (septate or aseptate)
2. **Mode of spore formation** (asexual or sexual)

3. **Type of fruiting bodies**

Major Groups of Fungi

1. Phycomycetes (Lower Fungi)

- Found in **moist and damp places, soil, decaying wood, or aquatic habitats**.
- Mycelium is **aseptate and coenocytic** (multinucleate).
- Asexual reproduction: By **motile zoospores** (in water) or **non-motile aplanospores** (in air), formed inside sporangia.
- Sexual reproduction: **Fusion of gametes → Zygospore formation**.

Examples of Phycomycetes:

- ✔ *Mucor* – Common bread mold
- ✔ *Rhizopus* – Causes soft rot of fruits
- ✔ *Albugo* – Parasitic fungus on mustard leaves

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2. Ascomycetes (Sac Fungi)

- Found in **soil, decaying wood, and in symbiotic associations (lichens)**.
- Mycelium is **septate and branched**.
- Asexual reproduction: By **conidia (exogenous spores)**.
- Sexual reproduction: By **ascospores**, formed inside a sac-like **ascus** (hence, called sac fungi).

Examples of Ascomycetes:

- ✔ *Saccharomyces* – Yeast, used in fermentation
- ✔ *Penicillium* – Produces antibiotics (Penicillin)
- ✔ *Aspergillus* – Used in industrial production of citric acid
- ✔ *Neurospora* – Used in genetic research
- ✔ *Claviceps* – Produces ergot alkaloids

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3. Basidiomycetes (Club Fungi)

- Mostly **terrestrial fungi** found on soil, tree trunks, and decaying wood.
- Mycelium is **septate and branched** (vegetative stage is **dikaryotic**).
- Asexual reproduction: **Rare or absent**.
- Sexual reproduction: By **basidiospores**, formed **exogenously** on a club-shaped structure called **basidium**.

Examples of Basidiomycetes:

- ✔ *Agaricus* – Edible mushroom
- ✔ *Ustilago* – Causes smut disease in plants
- ✔ *Puccinia* – Causes rust disease
- ✔ *Ganoderma* – Medicinal mushroom

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4. Deuteromycetes (Imperfect Fungi)

- **No known sexual reproduction**, so called "**imperfect fungi**".
- Mycelium is **septate and branched**.
- Asexual reproduction: By **conidia**.
- Important in **decomposition, soil fertility, and plant diseases**.

Examples of Deuteromycetes:

- ✔ *Alternaria* – Causes leaf spots
- ✔ *Colletotrichum* – Causes anthracnose disease
- ✔ *Trichoderma* – Used in biocontrol
- ✔ *Helminthosporium* – Causes plant diseases

Comparison Table: Fungal Groups (NCERT Level)

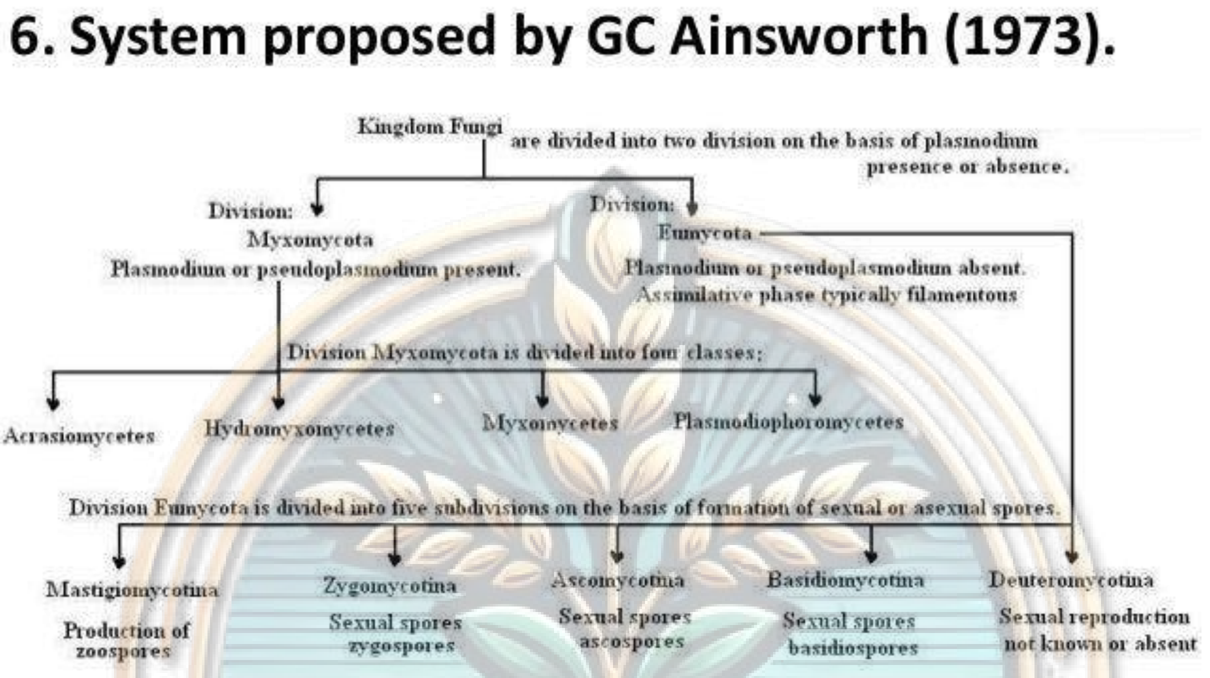
Group	Mycelium	Asexual Spores	Sexual Spores	Examples
Phycomycetes	Aseptate (Coenocytic)	Zoospores, Aplanospores	Zygospore	*Mucor*, *Rhizopus*, *Albugo*
Ascomycetes	Septate & Branched	Conidia (Exogenous)	Ascospores (Inside Ascus)	*Yeast*, *Penicillium*, *Aspergillus*
Basidiomycetes	Septate & Branched	Rare or Absent	Basidiospores (Exogenous)	*Mushrooms*, *Rusts*, *Smuts*
Deuteromycetes	Septate & Branched	Conidia	Absent (No Sexual Stage)	*Alternaria*, *Trichoderma*, *Colletotrichum*

Special Fungal Associations

✔ **Lichens** – Symbiotic association of fungi (**Ascomycetes**) with **algae** (Cyanobacteria).
✔ **Mycorrhiza** – Fungal association with plant roots (*Glomus* forms arbuscular mycorrhiza).

Classification of Fungi (Ainsworth, 1973)

Fungi are classified under the **Kingdom Mycota**, which is divided into **Myxomycota** and **Eumycota**.



I. Division: Myxomycota

- Plasmodial forms without a **cell wall**.
- The **plasmodium** is a naked multinucleate mass of protoplasm.
- Moves and feeds in an **amoeboid manner**.
- Also called **slime molds**.

Class: Plasmodiophoromycetes

- **Order: Plasmodiophorales**
    - **Family: Plasmodiophoraceae**
        - *Example: Plasmodiophora*

II. Division: Eumycota (True Fungi)

- **Thallus** is typically filamentous with a **cell wall**.
- **Plasmodium is absent**.
- Divided into **five subdivisions** based on reproductive structures and spores.

Subdivisions of Eumycota

1. Subdivision: Mastigomycotina

- **Thallus:** Unicellular or **aseptate mycelium**.
- **Asexual Spores: Zoospores** (motile spores).
- **Sexual Spores: Oospores**.
- **Sexual Reproduction: Gametangial contact**.

Classes of Mastigomycotina

1. Chytridiomycetes

- **Order: Chytridiales**
  - **Family: Synchytriaceae**
    - *Example: Synchytrium*

2. Oomycetes

- **Order: Peronosporales**
  - **Family: Pythiaceae**
    - *Examples: Pythium, Phytophthora*
  - **Family: Albuginaceae**
    - *Example: Albugo*
  - **Family: Peronosporaceae**
    - *Examples: Sclerospora, Peronospora, Peronosclerospora, Plasmopara, Pseudoperonospora, Bremia*

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2. Subdivision: Zygomycotina

- **Thallus:** Aseptate mycelium.
- **Motile spores are absent**.
- **Asexual Spores: Sporangiospores** (aplanospores).
- **Sexual Spores: Zygospores**.
- **Sexual Reproduction: Gametangial copulation**.

Class: Zygomycetes

- **Order: Mucorales**
  - **Family: Mucoraceae**
    - *Examples: Rhizopus, Mucor*

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3. Subdivision: Ascomycotina

- **Thallus: Septate mycelium**, rarely unicellular.
- **Motile spores are absent**.
- **Asexual Spores: Conidia**.
- **Sexual Spores: Ascospores**, produced endogenously in an **ascus**.
- **Sexual Reproduction: Gametangial contact**.

Classes of Ascomycotina

1. Hemiascomycetes

- **Order: Protomycetales**
  - *Examples: Protomyces, Protomycopsis*
- **Order: Taphrinales**
  - *Example: Taphrina*

2. Plectomycetes

- **Order: Eurotiales**
  - *Examples: Eurotium, Talaromyces*
- **Order: Erysiphales**
  - *Examples: Erysiphe, Leveillula, Phyllactinia, Uncinula, Sphaerotheca, Podosphaera, Microsphaera*

3. Pyrenomycetes

- **Order: Hypocreales**
  - *Example: Claviceps*

4. Discomycetes

- **Order: Tuberales**
  - *Example: Tuber*
- **Order: Pezizales**
  - *Example: Morchella*

5. Loculoascomycetes

- **Order: Pleosporales**
  - *Examples: Venturia, Cochliobolus*
- **Order: Myriangiales**
  - *Example: Elsinoe*
- **Order: Dothidiales**
  - *Example: Mycosphaerella*

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4. Subdivision: Basidiomycotina

- **Thallus: Septate mycelium**.

- **Motile spores are absent**.
- **Unique Features: Clamp connections & dolipore septum**.
- **Sexual Spores: Basidiospores**, produced exogenously on a **basidium**.
- **Sexual Reproduction: Spermatization & somatogamy**.

Classes of Basidiomycotina

1. Teliomycetes

- **Order: Uredinales**
  - *Examples: Puccinia, Uromyces, Hemileia*
- **Order: Ustilaginales**
  - *Examples: Ustilago, Sporisorium, Tilletia*

2. Hymenomycetes

- **Sub-Class: Holobasidiomycetidae**
  - **Order: Agaricales**
    - *Examples: Agaricus, Volvariella, Pleurotus*
  - **Order: Aphyllophorales**
    - *Examples: Polyporus, Ganoderma*

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5. Subdivision: Deuteromycotina (Imperfect Fungi)

- **Thallus: Septate mycelium**.
- **Motile spores are absent**.
- **Sexual spores are absent** (No sexual reproduction).
- **Asexual Spores: Conidia**.

Classes of Deuteromycotina

1. Coelomycetes

- **Order: Sphaeropsidales**
  - *Examples: Phoma, Phomopsis, Macrophomina, Diplodia, Botryodiplodia*
- **Order: Melanconiales**
  - *Examples: Colletotrichum, Pestalotiopsis*

2. Hyphomycetes

- **Order: Moniliales**
  - *Examples: Botrytis, Verticillium, Alternaria, Bipolaris, Cercospora*
- **Order: Tuberculariales**
  - *Examples: Fusarium, Myrothecium*
- **Order: Agonomycetales**
  - *Examples: Sclerotium, Rhizoctonia*

Summary of Characteristics of Fungal Divisions

Division	Mycelium Type	Asexual Spores	Sexual Spores	Reproduction Type
Myxomycota	Plasmodial, No Cell Wall	Absent	Absent	Amoeboid Movement
Mastigomycotina	Aseptate	Zoospores	Oospores	Gametangial Contact
Zygomycotina	Aseptate	Sporangiospores	Zygospores	Gametangial Copulation
Ascomycotina	Septate	Conidia	Ascospores	Gametangial Contact
Basidiomycotina	Septate	Absent	Basidiospores	Somatogamy, Spermatization
Deuteromycotina	Septate	Conidia	Absent	Asexual Only

Economic Importance of Fungi

✅ Beneficial Fungi

1. **Medicine:** *Penicillium* (Antibiotics), *Claviceps* (Ergot alkaloids)
2. **Fermentation:** *Saccharomyces* (Alcohol, Bread-making)
3. **Biocontrol Agents:** *Trichoderma* (Controls plant pathogens)
4. **Food Production:** Mushrooms (*Agaricus*), Cheese ripening (*Penicillium*)

❌ Harmful Fungi

1. **Plant Diseases:**
   - *Puccinia* (Wheat Rust)
   - *Albugo* (White Rust)
   - *Ustilago* (Smut in cereals)
   - *Alternaria* (Leaf spots)
2. **Human Diseases (Mycoses):**
   - *Candida* (Oral & Vaginal Infections)
   - *Aspergillus* (Respiratory infections)
   - *Dermatophytes* (*Trichophyton*, *Microsporum*) – Cause Ringworm

Conclusion

- Fungi play a **crucial role in nature**, from **decomposers** to **pathogens**.
- They are **classified based on their reproductive structures and mycelial organization**.
- **Ascomycetes and Basidiomycetes** are the most **economically important groups**.
- **Deuteromycetes** are fungi with **no known sexual stage** and are often later classified as **Ascomycetes or Basidiomycetes** after discovering their sexual forms.

Other plant pathogens:

Flagellant protozoa(BACTERIA); Mollicutes; FVB; Green algae and parasitic higher plants; Viruses and viroid's, virus transmission

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Phytopathogenic Bacteria

Definition

Bacteria are extremely **minute, rigid, unicellular organisms** (except **actinomycetes**, which are filamentous). They **lack chlorophyll** and **reproduce mainly by transverse binary fission**, producing identical daughter cells.

General Characteristics of Phytopathogenic Bacteria (PPB)

Characteristic	Description
Shape	Straight to curved rods with rigid cell walls (except filamentous bacteria)
Growth Variability	Some bacteria assume irregular shapes (V, Y, L forms)
Carbohydrate Metabolism	Mostly aerobic or oxidative (except *Erwinia*, which is facultative anaerobe)
Gram Staining	Mostly **Gram-negative**, few **Gram-positive** (e.g., *Streptomyces, Corynebacterium, Clavibacter, Curtobacterium*)
Culturing	Can be grown on artificial media, but pathogenic bacteria grow slower than saprophytes
Motility	Majority are **flagellate**
Entry into Host	Passive invaders – enter through **wounds or natural openings**
Survival & Spread	Survive in **seeds, plant debris**, spread via **water, insects, rain, and agricultural tools**
Spore Formation	**Non-spore formers** (except *Bacillus*)
Host Specificity	Do not cause diseases in humans/animals
Cell Wall	Rigid
Oxygen Requirement	**Aerobic or facultative anaerobes**
Growth Rate	Slow-growing compared to saprophytic bacteria
Incubation Period	**36-48 hours at 25°C**

Key for Identification of Phytopathogenic Bacteria

1. Filamentous Bacteria

Genus	Gram Reaction	Morphological Features
Nocardia	**Gram +ve**	Conidia not in chains
Streptomyces	**Gram +ve**	Conidia in chains

2. Non-Filamentous Bacteria

Genus	Gram Reaction	Key Features
Corynebacterium (Clavibacter)	**Gram +ve**	Pleomorphic, non-motile
Pseudomonas	**Gram -ve**	Mono/lophotrichous flagella, fluorescent pigments
Xanthomonas	**Gram -ve**	Single polar flagellum, yellow non-soluble pigment
Erwinia	**Gram -ve**	Facultative anaerobe, peritrichous flagella
Agrobacterium	**Gram -ve**	Subpolar flagella, forms galls
Ralstonia	**Gram -ve**	Aerobic, causes wilts

Important Characteristics of Specific Phytopathogenic Bacteria

1. Pseudomonas (Including *Ralstonia*)

Feature	Description
Cell Shape	Straight to curved rods
Gram Reaction	Gram-negative
Oxygen Requirement	Aerobic
Flagellation	Polar (Mono/lophotrichous)
Metabolism	Chemoorganotroph
Pigment Production	Fluorescent (yellow-green) or non-fluorescent

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2. Xanthomonas

Feature	Description
Cell Shape	Straight rods

Feature	Description
Gram Reaction	Gram-negative
Oxygen Requirement	Aerobic
Flagellation	Single polar flagellum
Metabolism	Chemoorganotroph
Pigment Production	Yellow, non-water-soluble
Pathogenicity	All species are plant pathogens

3. Agrobacterium

Feature	Description
Cell Shape	Rods
Gram Reaction	Gram-negative
Oxygen Requirement	Aerobic
Flagellation	1 lateral or sparsely peritrichous (up to 4)
Colony Features	White, non-pigmented, smooth
Habitat	Rhizosphere & soil
Pathogenicity	Causes plant galls (except *A. radiobacter*)
Slime Production	Produces abundant polysaccharide slime

4. Erwinia

Feature	Description
Cell Shape	Straight rods
Gram Reaction	Gram-negative
Oxygen Requirement	Facultative anaerobe
Flagellation	Peritrichous (many)
Capsulation	Non-capsulated
Metabolism	Chemoorganotroph
Acid Fast	Non-acid fast

5. Clavibacter (*Corynebacterium*)

Feature	Description
Cell Shape	Straight or curved rods, pleomorphic (V/Y shapes, palisade arrangement)
Gram Reaction	Gram-positive
Oxygen Requirement	Aerobic
Flagellation	Non-flagellate or few (1-3 polar)

Feature	Description
Metabolism	Chemoorganotroph

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6. Streptomyces

Feature	Description
Cell Shape	Filamentous, spherical
Gram Reaction	Gram-positive
Oxygen Requirement	Aerobic
Metabolism	Chemoorganotroph
Reproduction	Conidia in chains

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7. Pectobacterium

Feature	Description
Separation	Previously part of *Erwinia*
Disease Type	Causes soft rot
Gram Reaction	Gram-negative
Oxygen Requirement	Facultative anaerobe
Cell Shape	Rods
Enzymatic Activity	Strongly pectolytic
Flagellation	Peritrichous

Phytopathogenic bacteria exhibit **diverse morphological, physiological, and biochemical characteristics**. They are primarily **Gram-negative, motile, and aerobic/facultative anaerobes**, except for some Gram-positive genera (*Streptomyces, Clavibacter*). Identification is based on **flagellation, pigment production, carbohydrate metabolism, and pathogenicity**. Some bacteria cause wilts (*Ralstonia*), galls (*Agrobacterium*), necrosis (*Erwinia*), and soft rot (*Pectobacterium*). Understanding these characteristics helps in **plant disease management** and **pathogen identification**.

Spiroplasmas (Helical Mollicutes) – Spiroplasmatology

Definition

Spiroplasmas are **helical, wall-less prokaryotes** found in the **phloem of diseased plants**. They are a type of **mycoplasma** but differ due to their **helical shape** in liquid culture. Unlike mycoplasmas, **spiroplasmas can be cultured in the laboratory**.

General Characteristics of Spiroplasmas

Feature	Description
Shape	Helical in liquid media
Size	Varies from **100-240 nm diameter**
Gram Staining	**Gram-positive (+ve)**
Cell Wall	**Absent** (Wall-less)
Motility	No **flagella**; movement via helical flexing
Colony Morphology	Resembles **fried egg** in culture medium
Reproduction	**Transverse binary fission**
Culturing	Can be grown on **laboratory culture media**
Antibiotic Sensitivity	**Resistant to penicillin**, but **sensitive to tetracycline**

Comparison of Spiroplasmas with Other Mollicutes

Feature	Spiroplasmas	Mycoplasmas	Phytoplasmas
Shape	Helical	Pleomorphic (round, filamentous)	Pleomorphic
Cell Wall	Absent	Absent	Absent
Culture in Lab	**Yes**	Yes	**No**
Gram Staining	Gram +ve	Gram +ve	Gram +ve
Motility	Yes (helical movement)	No	No
Colony Morphology	Fried-egg colonies	Fried-egg colonies	Not culturable
Antibiotic Sensitivity	Tetracycline-sensitive, Penicillin-resistant	Tetracycline-sensitive, Penicillin-resistant	Tetracycline-sensitive, Penicillin-resistant

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Major Plant Diseases Caused by Spiroplasmas

Disease	Affected Plant	Vector (Leafhopper Species)
Corn Stunt	Corn (*Zea mays*)	*Dalbulus elimatus*
Citrus Stubborn Disease	Citrus (*Citrus spp.*)	*Circulifer tenellus*

Disease	Affected Plant	Vector (Leafhopper Species)
Carrot Purple Leaf Disease	Carrot (*Daucus carota*)	*Circulifer tenellus*
Periwinkle Virescence	Periwinkle (*Catharanthus roseus*)	Various leafhoppers

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Transmission and Spread of Spiroplasmas

Mode of Transmission	Details
Insect Vectors	Primarily transmitted by **leafhoppers**
Vector Specificity	Spiroplasmas exhibit **vector specificity** (certain leafhoppers spread specific diseases)
Phloem-Restricted	Remains **confined to the phloem**, affecting nutrient transport
Persistent Transmission	Once inside the vector, **spiroplasmas multiply and persist** throughout its lifespan
Grafting	Can be **mechanically transmitted via grafting**

Symptoms of Spiroplasma-Infected Plants

Symptom	Description
Stunting	Reduced growth due to phloem blockage
Leaf Yellowing	Chlorosis and leaf discoloration
Witches' Broom	Excessive shoot proliferation
Leaf Curling	Twisted or rolled leaves
Reduced Yield	Affected plants produce fewer and smaller fruits/grains
Phloem Necrosis	Breakdown of vascular tissues

Economic Importance of Spiroplasmas

- **Severe crop losses** in cereals (*Corn Stunt*), citrus (*Citrus Stubborn*), and vegetables (*Carrot Purple Leaf*).
- **Phloem clogging disrupts nutrient transport**, leading to **yield reduction**.
- **Difficult to control** due to **persistent transmission by insect vectors**.
- **Potential threat to global agriculture** if vector populations increase.

Management and Control Strategies

Control Method	Details
Vector Control	Use **insecticides** to control **leafhoppers**
Resistant Varieties	Develop and use **spiroplasma-resistant plant varieties**
Cultural Practices	Remove infected plants to **prevent further spread**
Biological Control	Utilize **natural enemies** of leafhoppers
Chemical Treatment	**Tetracycline-based antibiotics** (limited due to plant uptake issues)
Quarantine Measures	**Restrict movement** of infected plant materials

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Spiroplasmas are unique **helical, wall-less bacteria** that **infect plant phloem** and cause economically significant diseases. They are **transmitted by leafhoppers** and can be **cultured in the laboratory**. Managing these pathogens requires a **combination of vector control, cultural practices, and resistant plant varieties**. Understanding their **biology, transmission, and pathogenicity** is crucial for effective plant disease management.

Here are structured notes on **FYB (Fig Yellowing Bacterium), Green Algae, and Parasitic Higher Plants**:

Fig Yellowing Bacterium (FYB)

Definition:

- A bacterial pathogen affecting fig trees, leading to yellowing of leaves and reduced plant health.

Causes:

- Caused by a bacterium (possibly a species of *Candidatus Phytoplasma* or another unclassified pathogen).
- Spread by insect vectors such as leafhoppers or sap-feeding insects.

Symptoms:

- Yellowing and curling of leaves.
- Stunted growth and reduced fruit production.
- Early leaf drop leading to plant weakening.

Management and Control:

- Use of resistant fig varieties.
- Controlling insect vectors with insecticides or biological control methods.
- Proper sanitation by removing infected plant material.
- Application of antibiotics or bactericides (if applicable).

Green Algae

Definition:

- A diverse group of photosynthetic organisms found in aquatic and terrestrial environments.

Characteristics:

- Belong to the division *Chlorophyta*.
- Contain chlorophyll a and b, giving them a green color.
- Store food as starch in plastids.
- Have a cell wall composed mainly of cellulose.

Reproduction:

- Asexual reproduction via fragmentation, binary fission, or spores.
- Sexual reproduction through isogamy, anisogamy, or oogamy.

Ecological Importance:

- Primary producers in aquatic ecosystems.
- Oxygen producers through photosynthesis.
- Serve as food for aquatic organisms.
- Contribute to the formation of biofilms and lichens.

Economic Uses:

- Used in biofuel production.
- Some species (*Chlorella, Spirulina*) are used as dietary supplements.
- Used in wastewater treatment for nutrient absorption.

Parasitic Higher Plants

Definition:

- Plants that derive nutrients and water from a host plant, reducing its growth and productivity.

Types:

1. **Obligate Parasites** – Require a host to complete their life cycle (e.g., *Cuscuta*).

2. **Facultative Parasites** – Can survive independently but parasitize other plants when possible.
3. **Hemi-Parasites** – Partially parasitic, obtaining water and nutrients from the host while performing photosynthesis (e.g., *Striga*, *Viscum*).
4. **Holoparasites** – Fully dependent on the host for survival, lacking chlorophyll (e.g., *Rafflesia*, *Orobanche*).

Examples:

- *Cuscuta* (Dodder) – Twining stem parasite that lacks chlorophyll.
- *Striga* (Witchweed) – A root parasite affecting cereal crops.
- *Orobanche* (Broomrape) – A holoparasitic plant that attacks various legumes and vegetables.
- *Viscum* (Mistletoe) – A hemi-parasite that extracts water and nutrients from tree hosts.

Impact on Agriculture:

- Causes yield loss in crops by competing for nutrients and water.
- Difficult to control due to complex host-plant relationships.

Control Measures:

- **Cultural methods** – Crop rotation, resistant varieties, and removing infected plants.
- **Biological control** – Use of natural enemies or fungal pathogens.
- **Chemical control** – Herbicides targeting parasitic plant seeds.

Here are structured notes on **Viruses and Founders of Virology**:

VIRUSES

Definition:

- Viruses are microscopic infectious agents that can replicate only inside the living cells of a host organism.
- They consist of genetic material (DNA or RNA) enclosed in a protein coat (capsid), and some viruses have an additional lipid envelope.

FOUNDERS OF VIROLOGY

1. Adolf Mayer (1843 – 1942)

- German agricultural chemist who played a crucial role in the discovery of the **Tobacco Mosaic Virus (TMV)**.

- Studied **Tobacco Mosaic Disease** in 1879 and demonstrated that it could be transmitted through plant sap.
- Used **optical microscopy** but could not detect any bacteria, leading to early theories about filterable infectious agents.
- His work laid the foundation for the later discovery of viruses.

2. Dmitri Ivanovsky (1864 – 1920)

- Russian botanist who is credited with the discovery of viruses (1892).
- Conducted experiments on **Tobacco Mosaic Disease** and found that the infectious agent could pass through **porcelain Chamberland filters** (which bacteria could not pass through).
- His work suggested the existence of a new type of pathogen, smaller than bacteria.

3. Martinus Beijerinck (1851 – 1931)

- Dutch microbiologist who coined the term **"virus"** (Latin for poison).
- Conducted **filtration experiments** in 1898 and concluded that the infectious agent was **"Contagium vivum fluidum"** (a contagious living fluid).
- Unlike Ivanovsky, he **recognized that viruses could replicate inside living cells**, marking the true beginning of **virology as a distinct field**.
- Also made contributions to **nitrogen fixation** and **bacterial sulfate reduction**.

4. Wendell Stanley (1904 – 1971)

- In 1935, **crystallized the Tobacco Mosaic Virus (TMV)**, proving that viruses are particulate and not fluid in nature.
- Used **electron microscopy (1939) and X-ray crystallography (1941)** to further study virus structure.

5. David Baltimore (b. 1938)

- Discovered **reverse transcriptase enzyme** in 1970, proving that some viruses (retroviruses) could convert RNA into DNA.
- His work on **retroviruses** (such as HIV) revolutionized molecular biology and led to a **Nobel Prize in Physiology or Medicine in 1975**.

TYPES OF VIRUSES BASED ON GENETIC MATERIAL

1. Positive-Strand RNA Viruses (+ssRNA)

- The viral **RNA acts directly as mRNA** for protein synthesis.
- Genome is translated by host ribosomes to produce viral proteins and **RNA polymerase**, which synthesizes complementary (-) strand RNA.
- The (-) strand serves as a template for making new (+) strands.

- Example: **Poliovirus, Hepatitis A virus, SARS-CoV-2**.

2. Negative-Strand RNA Viruses (-ssRNA)

- The **RNA itself is not infectious** because it cannot be directly translated.
- It carries an enzyme **RNA-dependent RNA polymerase (transcriptase)** that transcribes the (-) strand into a (+) strand inside the host cell.
- The (+) strand is used to synthesize viral proteins and generate more (-) strands for packaging into new virions.
- Example: **Rhabdoviruses (Rabies virus), Influenza virus, Ebola virus**.

3. Double-Stranded RNA Viruses (dsRNA)

- Genome consists of **double-stranded RNA**.
- The viral **RNA-dependent RNA polymerase** transcribes mRNA from the dsRNA.
- The mRNA is used for protein synthesis and replication.
- Example: **Rotavirus, Reovirus**.

4. Double-Stranded DNA Viruses (dsDNA)

- Viral dsDNA enters the host **nucleus** and is transcribed into mRNA.
- mRNA is transported to the cytoplasm for protein synthesis.
- Some dsDNA viruses integrate into the host genome (*provirus formation*).
- Example: **Herpesvirus, Adenovirus, Poxvirus**.

5. Single-Stranded DNA Viruses (ssDNA)

- ssDNA replicates through a **rolling-circle mechanism**, generating multimeric (-) strands.
- The (-) strand serves as a template for the synthesis of (+) strands.
- The (+) strand is used for translation into viral proteins.
- Example: **Parvovirus, Geminivirus (plant virus)**.

SPECIAL VIRAL MECHANISMS

1. Reverse Transcription in Retroviruses (HIV, HTLV)

- Retroviruses use **reverse transcriptase** to convert their **RNA genome into DNA**.
- The viral DNA integrates into the **host genome** and directs the production of new viruses.
- Example: **HIV (Human Immunodeficiency Virus), Rous Sarcoma Virus**.

2. Virus Replication Strategies

- **Lytic Cycle**: Virus replicates rapidly, lysing the host cell (e.g., Bacteriophage T4).
- **Lysogenic Cycle**: Viral DNA integrates into the host genome, remaining dormant before activation (e.g., Lambda phage, HIV).

SIGNIFICANCE OF VIRUSES

1. Medical and Agricultural Impact

- Cause **human diseases** (e.g., Influenza, COVID-19, HIV).
- Cause **plant diseases** (e.g., Tobacco Mosaic Virus, Maize Streak Virus).
- Some viruses are used in **gene therapy and vaccine production**.

2. Economic Importance

- Crop loss due to viral infections leads to financial losses in agriculture.
- Biotechnological applications in **genetic engineering** and **vaccine production**.

3. Role in Evolution

- Viral genes have influenced the evolution of **prokaryotic and eukaryotic genomes**.
- Horizontal gene transfer facilitated by viruses contributes to **genetic diversity**.

TRANSMISSION OF VIRUSES

1) Transmission by Vegetative Propagation/Grafting

- Any virus can theoretically be transmitted through **grafting**, provided that the **stock and scion** are compatible.
- **Systemic viruses** (which spread throughout the plant) can be transmitted in this way.

2) Mechanical Transmission

- Involves the **transfer of plant sap** from a diseased plant to a healthy plant by artificial or natural means.
- Occurs through **rubbing, injecting, or wounding** by:
  - **Wind damage**
  - **Cultural practices** (tools, hands, clothes)
  - **Animal feeding**
- Examples:
  - **Potato virus X**
  - **Tobacco mosaic virus**
  - **Cucumber mosaic virus**

3) Seed Transmission

- More than **100 viruses** are known to be seed-transmitted.
- Transmission types:

1. **Surface seed transmission**: Virus particles adhere to the seed surface and infect the seedling through small wounds during germination.
2. **Internal seed transmission**: Virus particles enter the reproductive organs during seed formation.

- Examples:
    - **Tobacco mosaic virus** (carried externally on tomato seeds)
    - **Bean mosaic virus** (transmitted through bean seeds)

4) Pollen Transmission

- Viruses transmitted via **pollen** can:
    - Reduce **fruit set**.
    - Infect the **seed** and **seedling**.
    - Spread through the fertilized **flower** into the **mother plant**.
- Example:
    - **Prunus necrotic ring spot virus** (infects sour cherry through pollen).

5) Vector Transmission

- **Vectors** are organisms that transmit viruses from infected to healthy plants.
- Transmission types:
    - **Non-persistent**: Virus remains in the vector's **stylet** (short retention, seconds to minutes).
    - **Semi-persistent**: Virus binds to the **gut lining** of the vector but does not enter tissues (retained for hours to days).
    - **Persistent**: Virus invades **vector tissues** and reaches the **salivary glands** (retained for days to weeks).
        - **Circulative, non-propagative**: Virus moves through the vector's body but does not replicate.
        - **Circulative, propagative**: Virus **replicates** inside the vector before transmission.

Vector Categories & Examples

a) Aphids (e.g., *Myzus persicae*)

- Most important virus vectors, divided into:
    - **Non-persistent**: Stylet-borne.
        - Example: **Cardamom "Chirke" disease** (*Ropalosiphum maidis, R. padi, Brachycaudus helichrisi, Silobion aveneae*)
    - **Persistent**:
        - Example: **Cardamom dwarf or Foorkey disease** (*Pentalonia nigronervosa, Micromyzus kalimpongensis, Mollitrichosiphum sp.*)

b) Leafhoppers & Planthoppers

- Almost all are **persistent** virus vectors, except:
    - **Rice tungro virus** (non-persistent; vector: *Nephotettix implicticeps*)
- Examples:

- **Maize streak virus** (*Cicadulina mbila*)
- **Rice dwarf virus** (*Nephotettix cincticeps*, *Nephotettix nigropictus*)

c) Whiteflies (*Bemisia tabaci*)

- Transmit major plant diseases:
  - **Tobacco leaf curl virus**
  - **Abutilon mosaic virus**
  - **Yellow mosaic virus of bhindi**
- Semi-persistent example: **Lettuce infectious yellows virus** (LIYV)

d) Mealybugs

- Sedentary vectors that spread viruses slowly.
- Example: **Cacao swollen shoot disease** (*Planococcoides njalensis*, *Planococcus citri*)

e) Thrips (*Frankliniella insularis*)

- Example: **Tomato spotted wilt virus**

f) Mites (*Aceria cajani*)

- Example: **Pigeonpea sterility mosaic disease**

g) Beetles

- Example:
  - **Squash mosaic virus** (*Diabrotica undecimpunctata*, *Henosepilachna vigintioctopunctata*)

h) Grasshoppers (*Locusta migratoria*)

- Example:
  - **Turnip crinkle virus**

i) Nematodes

- Example:
  - **Grapevine fanleaf virus** (*Xiphenema index*)
  - **Tobacco rattle virus** (*Trichodorus pachydermus*)

j) Chytrid Fungi (*Olpidium spp.*)

- Example:
  - **Tobacco necrosis virus**
  - **Lettuce big vein virus**

k) Dodders (Parasitic Plants) (*Cuscuta spp.*)

- Example:

- **Sugar beet curly top virus** (*Cuscuta subinclusa*)
- **Cucumber mosaic virus** (*Cuscuta californica*)

Feature	Viruses	Viroids
Basic Composition	Nucleic acid (DNA or RNA) enclosed in a protein coat (capsid)	Single-stranded circular RNA without a protein coat
Genetic Material	Can be **DNA or RNA** (single-stranded or double-stranded)	Only **RNA** (single-stranded, circular, non-coding)
Capsid (Protein Coat)	Present (made of protein subunits called capsomers)	Absent (no protective protein coat)
Envelope	Present in some viruses (lipid membrane derived from host cell)	Absent
Size	Larger (20–300 nm)	Smaller (5–150 nm)
Structural Complexity	More complex (capsid, sometimes envelope, enzymes)	Simpler (only naked RNA)
Enzymes	Some viruses carry enzymes (e.g., reverse transcriptase in retroviruses)	No enzymes present
Genome Coding Ability	Encodes proteins for replication and infection	Does not code for proteins; affects host gene expression
Replication Site	Inside the host cell (nucleus or cytoplasm)	Inside the host cell nucleus
Replication Mechanism	Uses host machinery to synthesize viral proteins and assemble new viruses	Replicates using host RNA polymerase (RNA-dependent RNA replication)
Infects	Animals, plants, bacteria, and fungi	Mainly plants
Example	HIV, Influenza virus, Tobacco Mosaic Virus (TMV)	Potato spindle tuber viroid (PSTVd), Hop stunt viroid (HSVd)

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SUMMARY TABLE

Scientist	Contribution
Adolf Mayer	First studied **Tobacco Mosaic Disease** (1886).
Dmitri Ivanovsky	Discovered a filterable infectious agent (1892).
Martinus Beijerinck	Coined the term **"virus"**, proposed the "Contagium vivum fluidum" (1898).
Wendell Stanley	Crystallized **TMV**, proving viruses are particulate (1935).
David Baltimore	Discovered **reverse transcriptase** and retroviruses (1970).

Principles of Plant disease management:
Disease management with chemicals, cultural and biological method of Integrated Disease Management (IDM), Host Plant Resistance

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Principles of Plant Disease Management

1. Disease Management with Chemicals

Definition:

- The use of chemical agents such as fungicides, bactericides, and nematicides to control plant diseases.

Types of Chemicals Used:

- **Fungicides** – Control fungal diseases (*e.g., Mancozeb, Carbendazim*).
- **Bactericides** – Suppress bacterial infections (*e.g., Copper compounds, Streptomycin*).
- **Nematicides** – Manage plant-parasitic nematodes (*e.g., Fosthiazate, Carbofuran*).

Modes of Action:

1. **Protectant** – Prevent infection before it occurs (*e.g., Sulfur, Bordeaux mixture*).
2. **Systemic** – Absorbed and moved within the plant (*e.g., Propiconazole, Metalaxyl*).
3. **Eradicant** – Kill pathogens after infection has occurred (*e.g., Thiophanate-methyl*).

Advantages:

- Rapid action against pathogens.
- Effective for large-scale disease management.

Disadvantages:

- Development of pathogen resistance.
- Environmental pollution and toxicity risks.
- Residue concerns in food crops.

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2. Cultural Methods of Disease Management

Definition:

- Agronomic and management practices that reduce disease incidence and spread.

Common Cultural Practices:

1. **Crop Rotation** – Reduces soil-borne pathogens by breaking their life cycle.
2. **Sanitation** – Removing infected plant debris and weeds to minimize disease sources.
3. **Plant Spacing & Pruning** – Improves air circulation, reducing humidity and disease spread.
4. **Soil Solarization** – Uses plastic mulching to raise soil temperature and kill pathogens.
5. **Adjusting Planting Time** – Avoids peak conditions favorable for pathogen development.
6. **Proper Irrigation Management** – Reduces excess moisture that favors fungal and bacterial infections.

Advantages:

- Sustainable and environmentally friendly.
- Reduces reliance on chemicals.

Disadvantages:

- May not provide immediate control.
- Requires long-term planning and proper implementation.

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3. Biological Methods of Disease Management

Definition:

- Use of beneficial organisms to control plant pathogens.

Types of Biological Control Agents:

1. **Fungi** – *Trichoderma spp.* (antagonistic to soil-borne fungi).
2. **Bacteria** – *Pseudomonas fluorescens*, *Bacillus subtilis* (suppress pathogens).
3. **Viruses** – *Mycoviruses* infecting plant-pathogenic fungi.
4. **Predatory Organisms** – Nematode-trapping fungi (e.g., *Arthrobotrys*).

Modes of Action:

- **Competition** – Beneficial microbes outcompete pathogens for nutrients and space.
- **Antibiosis** – Production of antimicrobial compounds that inhibit pathogens.
- **Parasitism** – Direct attack and destruction of pathogens.
- **Induced Systemic Resistance (ISR)** – Activation of plant defense mechanisms.

Advantages:

- Environmentally safe and sustainable.
- Reduces chemical pesticide use.

Disadvantages:

- Slower action compared to chemicals.
- Effectiveness depends on environmental conditions.

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4. Integrated Disease Management (IDM)

Definition:

- A holistic approach that integrates multiple disease management strategies to minimize pathogen impact while ensuring environmental sustainability.

Components of IDM:

1. **Host Plant Resistance** – Use of disease-resistant varieties.
2. **Cultural Methods** – Crop rotation, sanitation, and proper planting techniques.
3. **Biological Control** – Beneficial microorganisms to suppress pathogens.
4. **Chemical Control** – Judicious use of fungicides and bactericides when necessary.
5. **Legislative Measures** – Quarantine regulations to prevent disease spread.

Advantages:

- Reduces reliance on chemicals.
- Enhances long-term disease control.
- Minimizes environmental and health risks.

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5. Host Plant Resistance

Definition:

- The ability of plants to resist or tolerate pathogen attack through genetic traits.

Types of Resistance:

1. **Vertical Resistance (Monogenic)** – Controlled by a single gene, highly specific but can break down quickly.
2. **Horizontal Resistance (Polygenic)** – Controlled by multiple genes, providing broad-spectrum and durable resistance.

Examples of Resistant Crops:

- *Wheat* – Rust-resistant varieties (*e.g., HD 2967*).
- *Rice* – Blast-resistant varieties (*e.g., IR-64*).
- *Potato* – Late blight-resistant varieties (*e.g., Kufri Jyoti*).

Strategies to Develop Resistant Varieties:

1. **Conventional Breeding** – Crossbreeding of resistant and susceptible plants.

2. **Genetic Engineering** – Introduction of resistance genes through biotechnology.
3. **Mutation Breeding** – Inducing mutations to enhance resistance traits.

Advantages:

- Cost-effective and long-lasting solution.
- Reduces dependence on fungicides and pesticides.

Disadvantages:

- Resistance can break down due to pathogen evolution.
- Development of resistant varieties takes time.

Thank so much

Team Agri Capital