AN OUTLINE OF PLANT PATHOLOGY

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PREFACE

Plant Pathology, one of the prominent branches of Agricultural as well as Horticultural has expanded by during the last three decades and assumed new dimension the subject. It gives us pleasure and satisfaction to fulfill the long felt need of the pathologists and students for a comprehensive book on basics of plant pathology. In this book fundamentals of fungi, bacteria, viruses, classifications and principles of plant pathology have been presented in a short form so that it would be easily for undergraduate students, this book will definitely useful for the young aspiring, budding pathology minds to take up the subject with confidence.

I wish to express my deep sense of gratitude to those who helped me directly or indirectly during the preparation of the manuscript of this text. The cooperation extended by my family members, teachers and friends during the preparation of this manuscript is highly appreciable. Criticism and suggestions for the improvement of the present book from worthy teachers and students will be gratefully acknowledged.

Anantharajupeta YERRAMALA CHANDRA SEKHAR
DEDICATED TO

BELOVED PARENTS

&

TEACHERS
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1. HISTORY OF PLANT PATHOLOGY

A) Mycology

1) Dutch worker Anton von Leeuwenhoek developed the first microscope.

2) Italian botanist P. A. Micheli proposed fungi comes from spores, considered he was a father of Mycology.

3) French botanist Tillet published a paper on bunt or stinking smut of wheat, discovered bunt is a disease of wheat.

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

5) E. M. Fries published Systema Mycologicum for naming of fungi, he was named as Linnaeus of Mycology.

6) Robertson of England stated that sulphur is effective against peach mildew.

7) J. G. Kuhn published first textbook in Plant Pathology - The Diseases of Cultivated Crops, their Causes and their Control.

8) Anton de Bary (Germany) worked out the life cycle of potato late blight and first to prove experimentally Phytophthora infestans is the cause of potato late blight. He proved that fungi are causes but not the results of diseases. He is the Father of Modern Plant Pathology.

9) Anton de Bary reported heteroecious nature of wheat stem rust.

10) England loses coffee production to coffee rust, forced to grow tea.


12) Brefeld discovered the methods of artificial culture of microorganisms; he also illustrated the complete life cycles of cereal smut fungi and diseases caused by them.
13) M. S. Woronin discovered and named the Club root of Cabbage pathogen as *Plasmodiophora brassicae*.

14) M. S. Woronin found out the life cycle of potato wart disease.

15) Downy mildew of grapevine was introduced into Europe from America. The disease almost ruined the wine industry.

16) H.M. Ward worked out the life cycle of coffee leaf rust. He is called as Father of Tropical Plant Pathology.

17) Robert Hartig published a textbook - Diseases of Trees. He is called as "Father of Forest Pathology".

18) Pierre Marie Alexis Millardet accidentally discovered the Bordeaux mixture for the control of downy mildew of grapevine.

19) A. B. Frank defined and named mycorrhizal associations in plant roots.

20) Burgundy mixture was introduced by Mason of France.

21) Swedish scientist Eriksson described the phenomenon of physiologic races in cereal rust fungus, *Puccinia graminis*.

22) W. A. Orton selected and bred water-melon, cowpea and cotton for resistance to Fusarium wilt diseases. He is considered as a pioneer worker in the development of disease resistant varieties.

23) A. F. Blakeslee, American Geneticist founded heterothallism in *Rhizopus*

24) R. H. Biffen pioneer in genetics of plant disease resistance.

25) H. Burgeff reported that within a cell of a fungus, fusion between dissimilar nuclei can occur. He called this phenomenon as heterokaryosis.

26) E. C. Stakman demonstrated physiologic forms in stem rust of wheat.

27) E.J. Butler published book on Fungi and Disease in Plants
28) Sir Alexander Fleming isolated the antibiotic, Penicillin from the fungus, *Penicillium notatum*.

29) H. N. Hansen and R. E. Smith were the first to demonstrate the origin of physiologic races through heterokaryosis.

30) W. H. Tisdale and I. Williams studied the organic fungicides by discovering alkyl dithiocarbamates.

31) H. N. Hansen found out dual phenomenon in Fungi Imperfecti.

32) H. H. Flor developed gene-for-gene hypothesis in flax rust.

33) Great Bengal Famine due to *Helminthosporium oryzae* caused death of 2 million people in India.

34) Dimond, Heuberger and Horsfall discovered the ethylene bis dithiocarbamates.

35) J. G. Horsfall explored the mechanism of fungicidal action.

36) B. B. Mundkur started Indian Phytopathological Society with its journal Indian Phytopathology. He has written a book ‘Fungi and Plant Diseases’ in 1949, which is the second, book in plant pathology in India.

37) E. A. Gaümann was one of the first to investigate the physiology of the wilts caused by *Fusarium* spp. He put forth the involvement of toxin (toxin theory) in wilt diseases.

38) N.F. Jensen suggested blending of different resistant genotypes of similar agronomic characters in fields of oats to reduce the spread of rust and losses from rust. 1953 -N. E. Borlaug and associates developed multiline cultivars for wheat.

39) Pontecorvo and his associates demonstrated parasexualism in fungi.

40) J. G. Horsfall published a book entitled "Principles of Fungicidal action"
42) J. E. Van der Plank found out vertical and horizontal types of resistance in crop plants.
43) Van Schmeling and Marshall Kulka were the first to find out systemic fungicides (oxathiin compounds – carboxin and oxycarboxin).
44) S. D. Garrett investigated the management of root diseases and he is the pioneer worker in the field of biological control.
45) G. Rangaswami wrote a book on Diseases of Crop Plants in India.

B) Plant Bacteriology
1) Anton von Leeuwenhoek first observed bacteria.
2) Louis Pasteur and Robert Koch - They proved that anthrax disease of cattle was caused by specific bacterium.
3) Robert Koch of Germany described the theory called "Koch's postulates." He established the principles of pure culture technique.
4) Robert Koch and Pasteur disproved the theory of spontaneous generation of diseases and propose germ theory in relation to the diseases of man and animal.
5) American Plant Pathologist - T. J. Burrill first time proved that fire blight of apple and pear was caused by a bacterium (now known as *Erwinia amylovora*).
6) E.F. Smith (U.S.A) He was worked on the bacterial wilt of cucurbits and crown gall disease. He is also called as "Father of Phytobacteriology”
7) C. O. Jensen related crown gall of plants to cancer of animals.
8) J. Lederberg coined the term plasmid
9) S. A. Waksman won Nobel prize for the discovery of streptomycin.
10) Zinder and J. Lederberg discovered transduction in bacteria
11) H. Stolp discovered bdellovibrios.
12) P. B. New and A. Kerr success in biological control of A. radiobacter strain K.
13) I. M. Windsor and L. M. Black observed a new kind of phloem inhabiting bacterium causing clover club leaf disease.
14) I. Zanen et al. demonstrated Ti plasmid in *Agrobacterium tumefaciens*.
15) D. W. Dye et al. introduced the pathovar in the taxonomy of plant pathogenic bacteria.

**C) Plant Virology**

1) Adolf Mayer described a disease of tobacco called mosaikkranheit (tobacco mosaic). Adolf Mayer demonstrated the sap transmission of Tobacco Mosaic Virus disease.
2) Dimitri Ivanowski demonstrated that the causal agent of tobacco mosaic could pass through bacterial filter.
3) E.F. Smith of U.S.A. showed the peach yellows was a contagious disease.
4) M.W. Beijerinck - He believed it to be contagium vivum fluidum (infectious living fluid). He was the first to use the term virus, which is the Latin word for poison.
5) W. M. Stanley proved that viruses can be made as crystals. He got Nobel Prize in 1946.
6) F. C. Bawden and, N.W. Pirie (Britain) found that the crystalline nature of the virus contains nucleic acid and protein.
7) Kausche and colleagues first time saw the TMV virus particles with the help of Electron microscope.
8) Gierer and Schramm proved that the nucleic acid fraction of the virus is actually the infectious agent.
9) Munday succeeded in inducing TMV mutations.
10) Kassanis discovered the satellite viruses.
11) T. O. Diener discovered viroids, which only consist of nucleic acids. Smaller than viruses, caused potato spindle tuber disease

D) Phytoplasma
1) Doi et al and Ishiie et al, the Japanese scientists found that mycoplasma like organisms (MLO) could be responsible for the disease of the yellows type.
2) Ishiie observed MLO's temporarily disappeared when the plants are treated with tetracycline antibodies.

E) Spiroplasma
1) Davies et al., observed that a motile, helical wall-less microorganism associated with corn stunt diseases, which could be cultured and characterized and they named it as spiroplasma.
2. GENERAL ACCOUNT OF PLANT PATHOLOGY

A) Plant Pathology/Phytopathology
(i.e., the study of nature, development and management of plant diseases)

**Definition:**
A branch of Agricultural or horticultural science which deals with cause, etiology, resulting losses and management of plant diseases

**Pathogen** is an entity usually a micro organism that can incite disease in susceptible plants.

It is also referred to as incitant, causal agent or causal organism

**Plant Disease:**
It is the malfunctioning of host cells and tissue 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

B) Importance of plant pathogens:

1. Plant diseases caused by micro organisms 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.
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 i.e., the money spent for plant protection chemicals.
10. Changes agricultural pattern.
11. Influences the industries i.e., lack of raw material.
12. Some plant diseases even change food habits of human population.

**Important Phytopathogenic organisms**

Fungi, Bacteria, Fastidious vascular bacteria (RLO’s), Mollicutes(phytoplasma & spiroplasma), viruses, viroids, Algae and Flagellated protozoans

**Fungi:**
Eukaryotic, spore bearing, achlorophyllous organisms that generally reproduce sexually and asexually and whose filamentous, branched somatic structures are typically surrounded by cell walls consisting chitin or cellulose or both with many organic molecules

![Fungal cell structure](image1)

![Hyphae](image2)

**Bacteria:**
Extremely minute, rigid, essentially unicellular organisms free of true chlorophyll, most commonly multiplying asexually by simple transverse fission, the resulting cell, being of equal or nearly equal in size

**Fastidious vascular bacteria (RLO’s)**
These are similar to bacteria in most respects but are obligate parasites or can not be grown on routene bacteriological media.
Mollicutes (phytoplasma and spiroplasma):

**Phytoplasma:** Pleomorphic, wall less prokaryotic microorganisms that can infect plants and can not yet to be grown in culture

**Spiroplasma:**
1) These are helical, wall less prokaryotic microorganisms present in phloem of diseased plants
2) these are often helical in culture
3) It can be cultured on artificial medium
4) Carrot purple leaf disease- *Spiroplasma citri*

**Virus:**
Sub-microscopic, obligate parasite consisting of nucleic acid and protein that multiplies only intracellularly and is potentially pathogenic

**Viroids:**
Small, low molecular weight ribonucleic acids (RNA) that can infect plant cells, replicate themselves and cause disease in plants

**Algae:**
Algae are eukaryotic, photosynthetic, uni or multicellular organisms, containing chlorophyll and a few algae mainly green algae cause plant diseases
3. DETAILED ACCOUNT OF FUNGI

Contributions of scientists in the field of mycology

**Pier Antonio micheli:**
- He is an Italy botanist
- He considered as ‘Founder and father of mycology’.
- He was published a book in 1729 ‘ nova plantarum genera’ in Latin - *mucor, aspergillus niger, botrytis, tuber, polyergus*
- First scientist observed fungal spores for the first time
- Conducted spore germination tests
- Described asci and ascospores

**Mathieu Tillet:**
- He is an French botanist
- He has published a paper on bunt or stinking smut of wheat
- He has established role of fungi in plant disease
- Proved wheat seeds contained black powder on their surface. Produced more diseased plants than clean seeds
- He emphasized contagious nature of wheat bunt disease
- He believed that the disease was caused by some toxin produced by the black powder
- He reported chemical treatment of seeds with common salt and lime inhibited the contagious activity

**Benedict Prevost:**
- He is an French scientist
- He proved diseases are caused by micro-organisms
- Proved *tilletia* caries as causal organism of wheat bunt
- Observed germination of bunt spores
- Discovered life cycle of bunt fungus
- Suggested control of bunt disease by seed treatment with *cuso*₄
Published classic paper ‘memoir on the immediate cause of bunt or smut of wheat
Studied fungicidal and fungistatic properties of chemicals

**Christian Hendrik Persoon:**
- He is belongs to South african
- He has published observations mycologicae in first
- In 1801 published ‘synopsis methodica fungorum’
- For nomenclature of uredinales, ustilaginales and gasteromycetes
- In 1822 published ‘mycologia europica’.
- He gave the name ‘*puccinia graminis*’ to wheat rust fungus in 1794

**Elias Magnus Fries:**
- He published three volumes of ‘systema mycologicum’
- For the nomenclature of Hymenomycetes and ustilaginales
- Introduced binomial system of nomenclature to Classify the fungal organisms

**Pier Andrea Saccardo:**
- Professor at padua university in italy
- Developed spore group system for ascomycotina and deuteromycotina fungi in 1899
- Wrote a book in 1882 sylloge fungorum omnium hucusque cognitorum in 25 volumes
- Initiated systematic grouping of fungi

**E.F.Smith (U.S.A):**
- He gave proof bacteria could be causal organisms of plant diseases
- In 1920 wrote a book ‘Bacterial diseases of plants’
- He also worked on bacterial wilt of cucurbits and crown gall disease
- He is also called as “Father of Phytobacteriology”. 
In 1981, he demonstrated for the first time transmission of plant viruses by budding or grafting. He showed the contagious nature of peach yellows.

**T.J.Burrill (U.S.A):**
- First scientist to relate bacterium as cause of plant disease.
- He proved fire blight of apple and pear was caused by a bacterium, *Erwinia amylovora*.

**M.K Patel:**
- Started plant bacterial research at pune – 1948.
- Reported about 40 bacterial plant diseases.
- Introduced post of “plant bacteriologist” at IARI, in 1955.

**M.W.Beijerinck (Dutch):**
- Father of virology.
- More extensively studied tobacco mosaic disease.
- He proved virus causing tobacco mosaic is not a living microorganism.
- He named infectious agent as ‘*contagium vivum fluidum*’.
- Subsequently called the agent as “virus”.

**W.M.Stanley (U.S.A):**
- Initiated ‘biochemical nature of virus’.
- In 1935, viruses can be crystallized & got a nobel prize.
- Viruses was crystallized by using ammonium sulphate.
- He was isolate proteinaceous sap (globular protein).
- He finally proved viruses are not living microorganisms.

**F.C.Bawden (plant virologist) and N.W.Pirie (biochemist):**
- Established complete chemical nature of purified TMV.
- Characterised TMV chemically as nucleic acid 5 %, proteins 95%
Also worked on turnip mosaic virus & tobacco bushy stunt virus

**DOI:**
- In 1967, Doi and his colleagues in Japan observed mollicutes
- First identified phytoplasmas as causal agent of Aster yellows and Mulberry dwarf in phloem sieves
- They showed the MLOs
- Symptoms disappeared when the plants were treated with tetracycline antibiotics

**Diener:**
- Discovered the potato spindle tuber
- It was caused by small naked SSRNA
- which he called as viroid

**Bove:**
- In 1968 first identified spiroplasmas as causal agent of corn stunt

**Howard Taylor Ricketts:**
- 1916- first discovered rickettsia
- In 1972 first observation in phloem of clover and periwinkle causing clover club leaf disease
- In 1973 observed in xylem causing pierce’s disease of grapes

**Fungi:**

**Definition:** Fungi are eukaryotic, spore bearing, achlorophyllous, heterotrophic organisms that generally reproduce sexually and asexually and whose filamentous, branched somatic structures are typically surrounded by cell walls containing chitin or cellulose or both with many organic molecules

**Somatic structures:**
- Thallus/ Soma Commonly called as vegetative body or fungal body
➢ A thallus (pl. thalli) is a simple, entire body of the fungus devoid of chlorophyll with no differentiation into stem, roots and leaves lacking vascular system.

*Rhizopus stolensfer*

**Hypha** (hypha=web) (pl. hyphae):

➢ Hypha is a thin, transparent, tubular filament filled with protoplasm.

**Mycelium (pl. mycelia):**

1) A net work of hyphae (aggregation of hyphae)
2) constituting the filamentous thallus of a fungus
3) It may be colourless i.e., hyaline or coloured due to presence of pigments in cell wall
4) The mycelium may be ectophytic or endophytic.
Types of fungal thalli:

1. **Plasmodium** (plasma = moulded body):
   
   It is a naked, multinucleate mass of protoplasm moving and feeding in amoeboïd fashion
   
   Eg. *Plasmodiophora brassicae*

2. **Unicellular thallus**: Consisting of a single cell
   
   Eg. Chytrids, *Synchytrium*

3. **Multi cellular or filamentous thallus**:
   
   ➢ Majority of fungi are filamentous
   ➢ Consisting of a number of branched
   ➢ Thread like filaments called hyphae
   
   Eg. Many fungi, *Alternaria*
Fungi based on reproductive structures:
1. Holocarpic 2. Eucarpic

1) Holocarpic:
➢ Thallus is entirely converted into one or more reproductive structures, such thallus is called holocarpic thallus.
Eg. *Synchytrium*

Eucarpic:
➢ If the thallus is differentiated into a two parts i.e,
➢ Vegetative part which absorbs nutrients
➢ Reproductive part which forms reproductive structures, such thallus is called eucarpic thallus, eg. *Pythium*

Ectophytic fungus:
➢ If the fungal thallus is present on the surface of the host plant, it is called ectophytic
Eg. *Oidium*

Endophytic fungus:
➢ If the fungus penetrates into the host cell / present inside the host, it is called endophytic.
Eg. *Puccinia*

- It may be intercellular (hypha grows in between the cells), or intra cellular (hypha penetrates into host cell)

Eg. *Ustilago*, or vascular (xylem vessels)

Eg. *Fusarium oxysporum*

- Inter cellular hyphae produce special organs called haustoria in epidermal cells
- which penetrate the host cell and absorb food
- These are absent in intracellular hyphae

![Diagram of haustoria](image)

A) Elongated, B) Branched haustorium

**Septation in Fungi:**

- Some fungal hyphae are provided with partitions or cross walls which divide the fungus into a number of compartments /cells called as septa

![Diagram of septate hyphae](image)

**Septate hyphae**

**Aseptate hypha/coenocytic hypha:**

- Hypha without septa is called aseptate /non-septate/ coenocytic hypha, wherein the nuclei are embedded in cytoplasm.

Eg. Lower fungi like Oomycetes and Zygomyces.
Aseptate hypha

**General types of septa:**
1. Based on formation  
2. Based on construction  
3. Based on perforation

1. **Based on formation**

A) **Primary septa:**
- Formed in direct association with nuclear division (mitotic or meiotic)
- Laid down between daughter nuclei separating the nuclei/cells.
  
  Eg. Higher fungi like Ascomycotina and Basidiomycotina.

B) **Adventitious septa:**
- These are formed independent of nuclear division and
- These are produced to delimit the reproductive structures.
  
  Eg. Lower fungi like Oomycetes and Zygomycetes

2. **Based on construction:**

A) **Simple septa:**
- It is most common which a plate like, with or without perforations
B) Complex septa:

- Septum with a central pore surrounded by a barrel shaped swelling of the septal wall and covered on both sides by a perforated membrane termed the septal pore cap or parenthosome

  Eg. Dolipore septum in Basidiomycotina.

3. Based on perforation:

A) Complete septa:

- Septum is a solid plate without any pore or perforations

  Eg. Adventitious septa in lower fungi

B) Incomplete septa:

- A septum with a central pore
Fungal tissues

Plectenchyma:

- Fungal tissues are called plectenchyma
- i.e., mycelium becomes organized into loosely or compactly woven tissue.
- This tissue compose various types of vegetative and reproductive structures

Types of plectenchyma:
1. Prosenchyma 2. Pseudoparenchyma

1. Prosenchyma:

- It is a loosely woven tissue
- Component hyphae retain their individuality which can be easily distinguishable as hyphae
- Lie parallel to one another

Eg. Trauma in *Agaricus*

![Tissue of Prosenchyma](image)

2. Pseudoparenchyma:

- It is compactly woven tissue
- It consists of closely packed cells which are isodiametric or oval in shape resembling parenchymatous cells of plants and hence the name
- The component hyphae loose their individuality and are not distinguishable as hyphae

Eg. Sclerotial bodies of *Sclerotium* and rhizomorph of *Armillariella*
Tissue of Pseudoparenchyma

Modification of mycelium/ specialised somatic structures

Purpose:

➢ To obtain nourishment i.e., for nutrition
➢ To resist or tolerate unfavourable conditions
➢ For reproduction
1) Rhizomorphs
2) Sclerotium
3) Stroma
4) Haustorium
5) Rhizoids
6) Appresorium

1. Rhizomorphs: (rhiza=root, morph=shape)
   ➢ Thick strands of somatic hyphae
   ➢ Which the hyphae loose their individuality
   ➢ Resistant to adverse conditions
   ➢ Remain dormant until favourable conditions return
   ➢ Structure of growing tip of rhizomorphs resemble that of a root tip, hence the name rhizomorph

Eg. Armillariella mellea

Armillariella mellea
2. **Sclerotium**: (skleron=hard) pl. sclerotia:
It is a hard, round (looks like mustard seed)/cylindrical or elongated (*Claviceps*) dark coloured (black or brown) resting body
- Formed due to aggregation of mycelium
- The component hyphae lose their individuality
- Resistant to unfavourable conditions
- Remain dormant for a longer period of time
- Germinate on the return of favourable conditions
Eg. *Sclerotium, Rhizoctonia*

![Sclerotium](image)

3. **Stroma**: (stroma=mattress) pl. stromata.
- It is a compact somatic structure looks like a mattress or a cushion
- On which or in which fructifications (spores or fruiting bodies) are formed

A) **Sub stomatal stroma:**
- Cushion like structure formed below epidermis in sub stomatal region from which sporophores are produced
Eg. *Cercospora personata*

B) **Perithecial stroma:**
- When reproductive bodies like perithecia of some fungi
- Embedded periphery of stroma, called as perithecial stroma. Eg. *Claviceps, Xylaria*
4. **Haustorium**: (hauster=drinker) pl.haustoria

- It is an outgrowth of somatic hyphae
- Special absorbing organ produced on certain hyphae by parasitic fungi
- For obtaining nourishment by piercing into living cells of host
- They may be knob like (Albugo)
- Elongated (Erysiphe, Uncinula)
- Finger like (Peronospora)

5. **Rhizoids**: (rhiza=root, oeides=like)

- These are slender root like branched structures
- Found in the substratum produced by some fungi
- It is useful for anchoring the thallus to substratum
- For obtaining nourishment from the substrate
  
  Eg. *Rhizopus stolonifer*
6. **Appressorium**: (apprimere=to press against pl.appressoria)

- Flattened tip of hyphae or germ tube acting as pressing organ by attaching to the host surface
- It gives rise to a minute infection peg
- Which usually grows and penetrates the epidermal cells of the host

Eg. *Puccinia, Colletotrichum, Erysiphe*

**Fungal cell**

**General characteristics of fungal cell**

1) Cells are typically eukaryotic and lack chloroplasts
2) Cell is bounded by cell wall
3) Cell is made up of chitin or cellulose or both
4) Surrounding by cytoplasm is called cytoplasmic membrane or plasmalemma
5) Protoplasm contains a true nucleus
6) Surrounded by two layered membrane with nucleolus, cytoplasm
7) Endoplasmic reticulum is not well developed
8) It contain may be rough ribosomes or smooth ribosomes
9) Fungal cell contain vacuoles and are bounded by a membrane called tonoplast
10) Ribosomes are protenaceous bodies scattered all over cytoplasm, play a role in protein synthesis
11) Mitochondria are the sites of respiratory activities
12) Lomasomes are the swollen membranous structures of plasmalemma
13) Cytoplasm also contains fat particles, calcium oxalate crystals, resins, glycogen

Structure of fungal cell

**Fungal nutrition:**
1) It is a heterotrophic with holophytic nutrition (absorptive type)
2) Elements for fungi are, C, H, O, N, P, K, S, Zn, Fe, Mg, Mn, Mo, Cu and Ca
3) Reserve food material in the cell either fat or carbohydrates
4) Fats is present in the form of oil drops
5) Carbohydrates in the form of glycogen or sugars
6) Starch is never present in the fungal cell
Groups of fungi based on mode of nutrition

1. Saprophytes
   a. Obligate saprophytes
   b. Facultative parasite

2. Parasites
   a. Obligate parasites
   b. Facultative saprophytes

Saprophytes:
1) Organisms which obtain nutrition on from dead organic matter either completely or part of their life
2) A large number of fungi fall under this category
3) Eg. *Saprolegnia, Rhizopus, Alternaria*

A) Obligate saprophytes:
1) Organisms which can never grow on living organisms or can never obtain their food from living source
2) They get food only from dead organic matter
   Eg. *Mucor, Agaricus*

B) Facultative parasite:
Organisms which are usually saprophytic but have ability to become as parasites
Eg. *Pythium aphanidermatum, Fusarium solani, Rhizoctonia solani*

2. Parasites:
Organisms which live within or outside other organisms for their nutrition either completely or part of life

Pathogen:
1) If a parasite damages the host then they are called as pathogens
2) All pathogens are not parasites and all parasites need not be pathogens
A) Obligate parasites:
Organisms which obtain food only from living organisms (living protoplasm) and can never derive their food from dead organic matter or artificial medium.
Eg. *Puccinia graminis, Plasmopara viticola*

B) Facultative saprophytes:
Organisms which are usually parasites but have ability to become saprophytes.
Eg. *Ustilago maydis*

There are 2 main types of spores
1. Sporangiospores 2. Conidia

1. Sporangiospores:
- When the asexual spores are produced internally, within the sporangia, such spores are called sporangiospores.
- The sac-like structure which produces sporangiospores is called sporangium.
- The special hypha bearing sporangium is called sporangiophore.
- A small sporangium with or without columella.
- Containing a few or single spore is called as sporangiolum.
Eg. *Rhizopus stolonifer*
2. Conidia / Conidiospores:

- Conidia are non-motile
- Asexual spores which may arise directly from somatic hyphae or from specialized structures
- Conidia are produced freely on conidiophore ie., At the tips or sides of conidiophore or
- May be produced in specialized asexual fruiting bodies

**Types of reproduction:**

I. Asexual / non-sexual / vegetative / somatic reproduction

II. Sexual reproduction

I. Asexual reproduction:

- It is also known as imperfect stage and technically called as anamorphic stage
- There is no union of nuclei / sex cells / sex organs
- It is repeated several times during life span of fungus producing numerous asexual spores
- Hence, it is more important for fungi than sexual reproduction
- Asexual spores are formed after mitosis, hence also called mitospores

**Methods of asexual reproduction:**

1. Fragmentation
2. Fission.
3. Budding
4. Sporulation (production of spores)

1. Fragmentation:
   - It is the most common method
   - Hypha of fungus breaks into small pieces, each broken piece is called a fragment,
   - Which function as a propagating unit and grows into a new mycelium.
   - The spores produced by fragmentation are called arthrospores
     Eg. *Oidium, Geotrichum*.

![Geotrichum](image)

2. Fission / Transverse fission:
   - Sometimes, the contents of intercalary cells
   - terminal cells of hypha rounded off and surrounded by thick wall and formed as chlamydospores
   - which are thick walled resistant spores produced either singly or in chains
     Eg. *Fusarium oxysporum, Ustilago tritici*

![Chlamydospores of Fusarium](image)
then the contents divide into equal halves by the formation of a transverse septum

Separates into two daughter cells

Eg. *Saccharomyces cerevisiae*

![Fission of cells](image)

3. Budding:

- Spores formed through budding are called blastospores
- Parent cell puts out initially a small out growth called bud / blastos ie., sprout or
- Later, bud increases in size and a constriction is formed at the base of bud, cutting off completely from parent cell
- when separated from parent cell, can function as an independent propagating unit
- Sometimes multiple buds are also seen i.e., bud over bud

Eg. *Saccharomyces cerevisiae*

![Process of budding of cells](image)

4. Sporulation (spores):

Process of production of spores is called sporulation
Spore:

- It is a minute, simple propagating unit of the fungi, functioning as a seed
- But differs from it in lacking a embryo that serves in the reproduction of same species
- Spores vary in colour, size, number of cells and the way in which they are borne

**Types of Asexual fruiting bodies**

**A). Pycnidium:**

1. It is a globose or flask shaped fruiting body
2. lined inside with conidiophores which produce conidia
3. It may be completely closed or may have an opening called ostiole
4. Pycnidium may be provided with small papillum or long neck
   
   Eg. *Phomopsis.*

![Pycnidium](image)

**B). Acervulus:**

1. A flat or saucer shaped fruiting body
2. with a stromatic mat of hyphae producing conidia on short conidiophores
3. An acervulus lacks a definite wall structure and not having an ostiole
   
   Eg. *Colletotrichum, Pestalotiopsis.*
C). Sporodochium:
1. A cushion shaped asexual fruiting body
2. Conidiophores arise from a central stroma and they are woven together on a mass of hyphae and produce conidia
   Eg. Fusarium

D). Synnemata:
1. A group of conidiophores often united at the base and free at the top
2. Conidia may be formed at its tip or along the length of synnema
3. Resembling a long handled feather duster
   Eg. Graphium
Sexual reproduction

➢ Sexual reproduction involves union of two compatible nuclei or sex cells or sex organs or somatic cells or somatic hyphae for the formation of new individuals.

➢ Sexual stage is perfect stage and technically called as teleomorphic stage

Sex organs of fungi:

Gametangia:

Sex organs of fungi are called gametangia containing gametes

Gametes: Sex cells are called as gametes

Antheridium: (pl.antheridia) Male gametangium is called as Antheridium

➢ It is small and club shaped

Oogonium / Ascogonium: (pl.oogonia/ascogonia):

➢ Female gametangium is called Oogonium (oomycetes) or ascogonium (ascomycotina)

➢ It is large and globose shaped

➢ Male gametes are called antherozoids or sperm or spermatozoids

➢ Female gametes are called egg or oosphere

Methods of sexual reproduction

1. Planogametic copulation.
2. Gametangial contact
3. Gametangial copulation
4. Spermatisation
5. Somatogamy
1. Planogametic copulation (gametogamy):
   This involves the union of 2 naked gametes one or both of which are motile
   a. Isogamy (Isogamous planogametic copulation):
      If both gametes are motile and similar
      Eg. Plasmodiophora brassicae.
   b. Anisogamy (Anisogamous planogametic copulation):
      If both gametes are motile but dissimilar.
      Eg. Allomyces, macrogynus
   c. Heterogamy:
      If gametes are dissimilar, one motile, another is non motile.
      Eg. Monoblepharis, polymorpha

2. Gametangial contact (Gametangy / Oogamy):
   - Male and female gametangia come in contact At the place of contact,
   - Dissolution of wall occurs and a fertilization tube is formed
   - Contents of male gametangium migrate into female gametangium through a pore or fertilization tube developed at the point of contact
   - Gametangia do not loose their identity
   Eg. Pythium aphanidermatum
3. Gametangial copulation (Gametangiogamy):

- Isogametangia come in contact, their intervening wall dissolves leading to fusion of entire contents of two contacting gametangia to form a single unit
- Gametangia loose their identity
- The protoplasts fuse and the unit increases in size

Eg. *Rhizopus stolonifer*
4. Spermatization:
- Minute, uninucleate male cells called as spermatia
- which are produced on spermatiophores in a fruiting body (pycnium) are carried to female reproductive structures called receptive hyphae
- Spermatia and receptive hyphae come in contact
- Contents of male spermatium migrate into female receptive hypha, making the cell binucleate This process is called dikaryotization
  Eg. *Puccinia graminis tritici*

![Spermatization](image)

5. Somatogamy:
- Many higher fungi do not produce sex organs
- In such cases somatogamy takes place
- It is the union of 2 somatic hyphae or somatic cells representing opposite sexes to form sexual spores
  Eg. *Agaricus campestris*

![Somatogamy](image)
4. TAXONOMY AND NOMENCLATURE OF FUNGI

Taxonomy:
➢ The science of classification
➢ It is concerned with principles of classification

Classification:
➢ Grouping of organisms into classes, orders, families, genera, species

Nomenclature:
➢ Art of naming living organisms

Importance of taxonomy and nomenclature
For study of fungi
For scientific communication between mycologists and plant pathologists throughout the world

1. Binomial system of nomenclature was originally introduced by Carl Linnaeus for higher plants
2. Later, this classification was adopted to fungi by his students C.H. Persoon and E.M. Fries

Important rules of nomenclature:
According to International code of Botanical Nomenclature, the names of organisms should be binomial i.e., 2 parts,

1. First part is noun designating genus and first letter is in capital
2. Second name is an adjective, describing the species, and first letter should be in small letter
   Eg. Puccinia graminis
3. Binomials are usually derived from Greek or Latin
4. Binomials when hand written should be underlined and when printed italicised
   Eg. Puccinia graminis (hand written)
   Puccinia graminis (printed)
5. Taxa (groups) used in classification are Kingdom, Division, Class, Order, Family, Genus and Species
6. Each category may be sub divided into sub groups
7. Like Sub- Division, Sub- Class, Sub- Order
8. Species is the unit of classification or
9. Basic taxonomic category (taxon)
10. Species sometimes broken into variety/formae speciales (f.sp.)
11. Varieties into races and races into biotypes
12. Standard endings of TAXA
    ➢ Division ends with mycota
    ➢ Sub- Division ends with mycotina
    ➢ Class with mycetes
    ➢ Sub- class with mycetidae
    ➢ Order with ales
    ➢ Family with aceae
    ➢ No special ending for genus and species
      Eg. *Puccinia graminis tritici* race 1
1. Kingdom : Fungi
2. Division : Eumycota
3. Sub-division : Basidiomycotina
4. Class : Teliomycetes
5. Order : Uredinales
6. Family : Pucciniaceae
7. Genus : Puccinia
8. Species : graminis
9. Variety : tritici
10. Race : 1
5. CLASSIFICATION OF FUNGI  
(classification by Ainsworth, 1973)

KINGDOM: MYCOTA

DIVISIONS
MYXOMYCOTA            EUMYCOTA

CLASS
PLASMODIOPHOROMYCETES  SUB DIVISIONS
1. MASTIGOMYCOTINA

ORDER
PLASMODIOPHORALES
2. ZYGOMYCOTINA
3. ASCOMYCOTINA

FAMILY
PLASMODIOPHORACEAE
Eg. Plasmodiophora
4. BASIDIOMYCOTINA
5. DEUTEROMYCOTINA

Important Characteristics of Divisions Myxomycota:
1. Plasmodial forms with out cell wall
2. Plasmodium is a naked multinucleate mass of protoplasm which moves and feeds in an amoeboid direction
3. Also called as slime molds
   Eg. Plasmodiophora

Important Characteristics of Divisions Eumycota:
1. These are true fungi
2. Thallus is typically filamentous with cell wall
3. Plasmodium is absent

Important Characteristics of Sub-division Mastigomycotina
1. Thallus is unicellular or aseptate mycelium
2. Asexual spores are zoospores (motile spores)
3. Sexual spores are oospores
4. Sexual reproduction by gametangial contact
   Eg: Pythium, P hytophthora
Detailed account of *Pythium aphanidermatum*

It causes damping of diseases in vegetables

**Damping off diseases Symptoms:** Symptoms are two phases

1) Pre-emergence damping-off and
   2) Post-emergence damping-off.

1) Pre-emergence damping-off:
   - Failure of seedling emergence due to seed rots
   - Killing of young seedlings
   - Patchy appearance of seedlings stands

2) Post emergence damping-off:
   - Toppling over of infected seedlings
   - Infected tissue initially appears to be water-soaked and soft
   - Mass death of seedlings

![Death of seedlings](image-url)
Pathogen:
- Mycelium is intracellular, slender, coenocytic and branched hyphae
- Asexual reproduction - Zoospores
- Kidney shaped and biflagellate - Zoospores
- In sexual reproduction - Oospore

Disease cycle and epidemiology:
- It is a both seed and soil borne disease
- Survives in plant debris or oospores in the soil
- It require high soil moisture, pH 6.0
- Heavy soils favour disease development
- Pre-emergence damping-off is maximum at 20-25°C
- While post emergence at 30-40°C
- Sever in ill-aerated soils with poor drainage having thick stand of the seedlings

*Life cycle of Pythium aphanidermatum*
Management:

➢ Change the nursery site every year
➢ Solarize soil bed with polyethylene (25 µm) sheet for 40-45 days during summer months
➢ Treat the soil with Formalin (5%) at least 20 days before sowing
➢ Apply bioagents like Trichoderma harzianum or T. viride (40 g/m²).
➢ Treat the seed with Captan (0.3%)
➢ Soil, drench the bed with mixture of Mancozeb (0.25%) and Carbendazim (0.1%) and repeat at 7-10 days interval
➢ Give light but frequent irrigations

Detailed account of Late blight

It causes late blight disease in potato

➢ The disease infection starts in 6 weeks old plants
➢ First reported from Andes mountains of South America
➢ In India, the disease was first reported in Darjeeling district in India (1880)

Symptoms of late blight disease

➢ Initially starts from leaf tips or margins and spread inward
➢ Water soaked stripes on stem which becomes necrotic
➢ Purplish brown spots appear on skin of tubers
➢ On cutting, the affected tubers show rusty brown necrosis
➢ Decay of infected plant parts which comes emits foul smell
Brown necrotic spots on leaves  Decay of infected tuber

**Disease cycle**

P.I: IPD or oospores  
Collateral host: Tomato, Pepper and egg plant  
S.I: Conidia dispersed by wind or water

---

**Life cycle of Phytophthora infestans**

**Favourable conditions for pathogen:**

- Cool moist conditions
- RH: >90% and temperature (12-24°C)
- Night temperature not below 10°C
- Cloudiness on the next day
- Rainfall at least 0.1mm on the following day
Management:
➢ Select healthy tubers for planting
➢ Delayed harvesting
➢ Grow resistant varieties such as Kufri Jyothi, Kufri Badshah, Kufri Jeevan, Kufri Sherpa

Prophylactic measures:
➢ Spray chemicals like Metalaxyl (0.1%) or Mancozeb (0.25%)
➢ Dip sprouted tubers in 0.2% metalaxyl for 30 min

White rust or blister - *Albugo candida*
Symptoms:
➢ White, shiny raised blisters (pustules) on lower surfaces of leaves, stems & flowers
➢ Pustules coalesce to form irregular patches
➢ Epidermis ruptures exposing white spore mass which gives the pustule a powdery appearance
➢ Distortion of the floral parts including petals, pistils and anthers due to hypertrophy and hyperplasia
➢ Infected plants are malformed

![Blisters on under surface leaf](image)

Pathogen:
➢ *Albugo candida* is an obligate parasite
➢ Mycelium is intercellular and non-septate
➢ Short conidiophores arise from the mycelium, which are arranged in rows
➢ Sporangia are produced in chains arising from the sporangiophores
➢ Sporangia germinate either by germtube or by producing zoospores
➢ Oospore is spherical with thick irregular wall, deep yellow to dark brown in colour

**Disease cycle and epidemiology:**
➢ Survives as oospores in IPD or contaminated seeds or mycelium in weed hosts
➢ Primary inoculum - oospores
➢ Secondary spread - sporangia (zoospores)

**Life cycle of Albugo candida**

**Management:**
➢ Collection and burning of infected IPD
➢ Avoids the humid conditions around the plants by maintaining proper spacing
➢ Crucifer weed free cultivation
➢ Application of fertilizers like phosphorus, potassium
➢ Avoidance of excess application of nitrogen
➢ Spray the crop with metalaxyl + mancozeb (0.25%) followed by sprays of Bordeaux mixture (4:4:50) or
Mancozeb (0.25%) or Copper oxychloride (0.30%) repeat at 10 to 14 days interval

**Study of different genera of downy mildew fungi**

1. Sclerospora
2. Peronospora
3. Peronosclerospora
4. Pseudoperonospora
5. Plasmopara
6. Bremia

**1. Sclerospora:**
- Sporangioles are stout, having upright branches, bearing sporangia on sterigmata.
- Sporangia are hyaline, ovoid, Smooth walled, papillate and germinate by zoosporangia.
- Oospore is plerotic.

Eg. *Sclerospora graminicola* – Downy mildew of bajra

**2. Peronospora:**
- Sporangioles are dichotomously branched 2-7 times at acute angles and tips of branches are curved and pointed bearing sporangia on sterigmata.
- Sporangia are hyaline, ovoid, non-papillate and always germinate by germ tube. i.e. sporangia behave like conidia.

Eg: *Peronospora destructor* - Downy mildew of onion
3. Peronosclerospora:

- Possess characteristics of both Peronospora and Sclerospora.
- Sporangiophores are erect, short, stout, dichotomously branched 2-5 times at apex bearing sporangia on sterigmata.
- Sporangia are hyaline, ovoid, thin walled, non-papillate and germinate by germ tube like Peronospora.
- Oospore is plerotic type like Sclerospora. Eg. *Peronosclerospora sorghi*-downy mildew of jowar *P.philippinensis*-downy mildew of maize
4. **Pseudoperonospora**:  
- Sporangiophores are branched at acute angles with curved, blunt tips, bearing sporangia on sterigmata  
- Sterigmata are unequal (1 big and 1 small)  
- Sporangia are greyish, ovoid, papillate and germinate by zoospores.  
  Eg. *Pseudoperonospora cubensis* - *Downy mildew of cucurbits*

![Image of Pseudoperonospora](image.png)

6. **Plasmopara**:  
- Sporangiophores are branched at right angles to main axis at regular intervals.  
- Monopodial branching is observed.  
- Subsequent branches are 3-6 which end in blunt sterigmata of 3 in number.  
- Sporangia are ovoid and germinate by zoospores.  
  Eg. *Plasmopara viticola* - *Downy mildew of grapes*

![Image of Plasmopara](image.png)
6. Bremia:

➢ Sporangio phores are dichotomously branched, tips of branches are expanded to cup shaped apophysis with four sterigmata bearing sporangia.

➢ Sporangia are ovoid, papillate germinate by zoospores.

Eg: *Bremia lactucae-downy mildew of lettuce*

![Bremia](image)

### Difference between powdery and downy mildew diseases

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<th>Downy mildew</th>
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<td>These are true fungi</td>
<td>These are false fungi</td>
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<td>2</td>
<td>Symptoms seen on upper surface of leaf</td>
<td>Symptoms seen on under surface of leaf</td>
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<td>3</td>
<td>Consists of conidiophores &amp; conidia</td>
<td>Consists of sporangiophore &amp; sporangia</td>
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<td>4</td>
<td>Mycelium septate mycelium</td>
<td>Mycelium is non-septate</td>
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<td>5</td>
<td>Asexual spores are conidia</td>
<td>Asexual spores are zoospores</td>
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<td>Asexual spores are non-motile</td>
<td>Asexual spores are motile</td>
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<td>7</td>
<td>Sexual spores are ascospores enclosed in cleistothecium</td>
<td>Sexual spores are oospores</td>
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<td>Occurs during dry weather</td>
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<td>Ex : Leveillula</td>
<td>Ex : Sclerospora</td>
</tr>
</tbody>
</table>
Important Characteristics of Sub-division Zygomycotina

1. Thallus is aseptate mycelium
2. Motile spores are absent
3. Asexual spores are sporangiospores (aplanospores)
4. Sexual spores are zygospores
5. Sexual reproduction through gametangial copulation

SUB DIVISIONS  ZYGOMYCOTINA

CLASSES  ZYGOMYCETES

ORDER  MUCORALES

FAMILY  MUCORACEAE
Eg. Rhizopus, Mucor

Important Characteristics of Sub-division Ascomycotina

1. Thallus is septate mycelium
2. Rarely unicellular
3. Motile spores are absent
4. Asexual spores are conidia
5. Sexual spores are ascospores produced endogenously in an ascus
6. Sexual reproduction mainly by gametangial contact
Classification of sub division Ascomycotina

Types of Sexual fruiting bodies or Ascocarps
There are four types of ascocarps
1. Cleistothecium:
2. Perithecium
3. Apothecium
4. Ascostromata

1. Cleistothecium:
   - Completely closed ball like ascocarp
   - Made up of a wall pseudoparenchymatous tissue called as peridium.
   - Asci are distributed at different levels in ascocarp.
   - Asci are matured, ascospores are released by disintegration of peridium.
   Eg. *Eurotium, Erysiphe*
2. **Perithecium:**

- Flask shaped fruiting body
- With a pore or opening at the tip called true ostiole
- Ostiole is lined inside with sterile structures called as periphysis
- Asci are arranged in definite layer called hymenium
- In between asci, sterile thread like structures called paraphyses which help in liberation of ascospores.
  
  Eg. *Claviceps, Xylaria*

3. **Apothecium:**

- Open cup shaped ascocarp
- Asci are exposed from beginning or later exposed
- Sterile structures called paraphyses (intermingled with asci)
  
  Eg. *Peziza, Tuber*
4. **Ascostromata:**
- Asci are formed directly in cavities called locules
- Sterile structures called pseudoparaphyses
  - Eg. Elsinoe
- If the ascostromata is with a single locule ie., unilocular ascostroma resembles perithecium with pseudoparaphyses is called as pseusthecium.
  - Eg. Venturia

**Important characteristics of Order: Erysiphales**

**Family: Erysiphaceae**
- Having a Cleistothecium
- They cause powdery mildew diseases
- Mycelium is hyaline and mostly ectophytic
- Members are obligate parasites and nourishment through haustoria
Asci are globose and explodes at the time of release of ascospores

**Important plant pathogenic genera of powdery mildew**

1. Erysiphe
2. Leveillula
3. Phyllactinia
4. Uncinula
5. Sphaerotheca
6. Podosphaera
7. Microsphaera

**Asexual reproduction:**

- Through conidia produced on conidiophores.
- Conidiophores are long, erect and hyaline.

Three types of conidial stages are recognised in powdery mildews.

1. Oidium
2. Oidiopsis
3. Ovulariopsis

**1. Oidium (Acrosporium):**

- Mycelium is ectophytic, hyaline.
- Conidia are developed from a flask shaped mother cell (spore mother cell) formed on a short conidiophore.
- Conidia are barrel shaped and are produced in chains.
- Conidia are formed by fragmentation of hyphae called as arthrospores.

Eg. *Erysiphe, Podosphaera, Uncinula, Sphaerotheca* and *Microsphaera*
2. **Oidiopsis:**

- Mycelium is endophytic.
- Conidiophores may be branched or unbranched, erect, septate, hyaline and emerge through stomata.
- Conidia are produced singly and cylindrical in shape.
- Conidia are of two types. A. blunt tip B. pointed tip.
  
  *Eg. Leveillula*

![Oidiopsis]

3. **Ovulariopsis:**

- Mycelium is partly ectophytic and partly endophytic.
- Conidiophores are hyaline, septate, unbranched, and bear a single conidium.
- Conidia are rhomboid in shape.
- In some species, conidiophores are spiral in shape.
  
  *Eg. Phyllactinia subspiralis*

![Ovulariopsis]

Powdery mildews are produce ascospores in cleistothecia through Sexual reproduction.
Types of cleistothecial appendages

1. Mycelioid appendages:
   - Flexible, flaccid and resemble somatic hyphae
     Eg. *Erysiphe, Sphaerotheca, Leveillula.*

2. Circinoid / hooked / coiled appendages:
   - These are rigid with curled or coiled tips.
     Eg. *Uncinula*

3. Dichotomously branched tips:
   - These are rigid, flattened with dichotomously branched tips
Eg. *Podosphaera, Microsphaera*

Dichotomously branched tips

4. Bulbous base with pointed tip:
   - These are rigid, spear like with bulbous base and pointed tip.
   - Eg. *Phyllactinia*

Bulbous base with pointed tip

**KEY FOR THE IDENTIFICATION OF POWDERY MILDEW GENERA**

1. **Type of cleistothecial appendage**
   - a. Mycelioid
   - b. Dichotomously branched
   - c. Circinoid
   - d. Bulbous base with pointed tip

2. **Number of asci in cleistothecium**
   - a. One
   - b. Many

3. **Type of conidial stage**
   - a. *Oidium*
   - b. *Oidiopsis*
   - c. *Ovulariopsis*

4. **Nature of mycelium**
   - a. Ectophytic
   - b. Endophytic
   - c. Semi-endophytic
Important Characteristics of Sub-division Basidiomycotina

1. Thallus is septate mycelium
2. Motile spores are absent.
3. Clamp connections and dolipore septum are present
4. Sexual spores are basidiospores produced exogenously on basidium
5. Sexual reproduction is by spermatization and somatogamy
Classification of sub division Basidiomycotina

SUB DIVISIONS

BASIDIOMYCOTINA

CLASSES

1. TELIOMYCETES
2. HYMENOMYCETES

ORDER

UREDINALES
USTILAGINALES

FAMILY

USTILAGINACEAE
TILLETIACEAE
GRAPHIOLACEAE

Eg. Ustilago,
Sphaecelotheca
Tolyposporium

Eg. Tilletia,
Neovossia,
Urocystis

Eg. Graphiola

PUCCINIACEAE
MELAMPSORACEAE

ORDER

HOLOBASIDIOMYCETIDAE

FAMILY

AGARICACEAE

Eg. Puccinia,
Uromyces,
Hemileia

Eg. Melampsora

AGARICALES
APHYLOPHORALES

POLYPORACEAE
GANODERMATACEAE

Eg. Polyporus,
Fomes,
peria

Eg. Ganoderma

Important Characteristics of Sub-division Deuteromycotina:

1. Thallus is septate mycelium
2. Motile spores are absent
3. Sexual spores are absent
4. Asexual spores called conidia are present
Classification of sub division Deuteromycotina

SUB DIVISION

1. COELOMYCETES

SPHAEROPSIDALES

SPHAEROPSIDACEAE

Eg. Phoma,
Phomopsis,
Macrophonia,
Phyllosticta,
Diplodia, Boryodi,
plodia

EXCIPELACEAE

NECTRIIODACEAE

LEPTOSTROMATACEAE

Eg. Leptostroma

MELANCONIALES

MELANCONIACEAE

Eg. Colletotrichum,
Gioeasporium,
Pestalotiopsis, Pestalotia

2. HYPHOMYCETES

SPHAEROPSIDALES

HYPHOMYCETALES

STILBELLALES

TUBERCULARIALES

AGONYMCTALES

MONILIACEAE

DEMATHIACEAE

STILBELLACEAE

TUBERCULARIAE

AGONYMCTACEAE

Eg. Pyricularia,
Botrytis,
Verticillium

Eg. Alternaria,
Bipolaris,
Cercospora,
Phaeosariopsis

Eg. Graphium

Eg. Fusarium,
Myrothecium

Eg. Sclerotium,
Rhizoconia

Eg. Ephelis

Eg. Zythia
6. DETAIL ACCOUNT OF PLANT BACTERIOLOGY

Contribution of scientist in the field of plant bacteriology

1. E.F. Smith (U.S.A):
   - He gave proof bacteria could be causal organisms of plant diseases
   - In 1920 wrote a book ‘Bacterial diseases of plants’
   - He also worked on bacterial wilt of cucurbits and crown gall disease
   - He is also called as “Father of Phytobacteriology”
   - In 1981, he demonstrated for the first time transmission of plant viruses by budding or grafting
   - He showed the contagious nature of peach yellows

2. T.J. Burrill (U.S.A):
   - First scientist to relate bacterium as cause of plant disease
   - He proved fire blight of apple and pear was caused by a bacterium, *Erwinia amylovora*

3. M.K Patel (India)
   - He is started plant bacterial research at Pune – 1948
   - He is reported about 40 bacterial plant diseases
   - He is introduced post of “plant bacteriologist“ at IARI, in 1955

**Definition:**

Bacteria are extremely minute, rigid, essentially unicellular organisms, lack of chlorophyll, most commonly reproduce by transverse binary fission resulting cells are identical in size and morphology

**Important characteristics of phytopathogenic bacteria**

1. Straight to curved rods with rigid cell walls
2. Some bacteria assume irregular shapes like v, y, L
   - Ex: v form of *corynebacterium* (*clavibacter*)
   - L-forms of *agrobacterium* and *erwinia*
3. Mostly gram negative, rarely gram positive (gr +ve genera: streptomyces, corynebacterium, clavibacter, curtobacterium)
4. Can be cultured on artificial media
5. Majority are flagellate
6. Can be identified based on flagellation, 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. Cell wall rigid
12. Aerobes/ facultative anaerobes
13. Slow growth compared to other saprophytic bacteria
14. Incubation period: 36-48 hrs. At 25° c
15. Majority are flagellate and hence motile

Structure of bacteria
Identification of gram – Ve (negative) bacteria

Identified based on

- Morphological differences-flagellation
- Cultural characteristics
- Physiological characteristics
- Biochemical characteristics
- Pathogenicity – Host range
Pseudomonas (Ralstonia):

- Cells single, gram – ve, aerobic, straight to curved rods
- Flagella - polar (mono / lophotrichous)
- Chemoorganotrophs
- Fluorescent pseudomonas with water soluble pigments (yellow - green)

Xanthomonas:

- Cells single, gram – ve, aerobic, straight rods
- Having a single polar flagella
- Yellowish, non water soluble pigments
- All species are plant pathogens
**Agrobacterium:**
- Gram – ve, aerobic, rods
- Flagella- 1 , peritrichous
- Colonies white ( non pigmented), smooth
- Habitat: rhizosphere and soil
- All produce galls , except *A. radiobacter*
- Produce abundant polysaccharide slime

**Erwinia:**
- Cells single, gram – ve, straight rods
- Flagella ( peritrichous- many )
- Non capsulated
- Facultative anaerobes
- Cause necrosis or wilt diseases

**Clavibacter (corynebacterium):**
- Gram + ve, aerobic
- Straight or curved rods or
- Pleomorphic (club shaped , v / y )
- Non flagellate/ few 1 - 3 polar flagella

**Streptomyces:**
- Mycelium is filamentous
- Gram + ve bacteria
- Cells are spherical in shape
- Survives as aerobic
- Conidia forms in chains

**Important phytopathogenic bacterial diseases**

<table>
<thead>
<tr>
<th>Disease</th>
<th>Bacteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Wilt of solanaceous Cropsc (tomato)</td>
<td><em>Ralstonia solanacearum</em> (non fluorescent psudomonads)</td>
</tr>
<tr>
<td>2. Wild fire of tobacco</td>
<td><em>P. syringae pv. Tabaci</em> (fluorescent psudomonads)</td>
</tr>
<tr>
<td>3. Bacterial blight of paddy</td>
<td><em>Xanthomonas campestris</em> pv. <em>Oryzae</em></td>
</tr>
<tr>
<td>4. Citrus canker</td>
<td><em>X. axonopodis</em> pv. <em>Citri</em></td>
</tr>
</tbody>
</table>
5. Black arm/Angular leaf spot of cotton  \( X. \textit{campestris} \) pv. \textit{malvacerum}  
6. Black rot of crucifers  \( X. \textit{campestris} \) pv. \textit{Campestris}  
7. Crown gall of apple \( \text{Agrobacterium tumefaciens} \)  
8. Soft rot of vegetables \( \text{Erwinia carotovora} \)  
9. Fire blight of apple \( E. \textit{amylovora} \)  
10. Tundu diseases of wheat \( \text{Corynebacterium tritici} \)  
11. Comman scab of potato \( \text{Streptomyces scabies} \)  

**Fastidious vascular bacteria (rickettsia like organisms)**  
Definition:  
Similar to bacteria in all respects but can not be grown on conventional bacteriological media but requiring complex / special nutrient medium for its multiplication  
- \( \text{Howard Taylor Ricketts (1916)} \) – first discovered rickettsia  
- 1972- first observation in phloem of clover and periwinkle causing clover club leaf disease  
- 1973- observed in xylem causing pierce’s disease of grapes  

**Important characteristics of Fastidious vascular bacteria**  
1. Cell wall is thin (20-30 nm thickness) and undulating  
2. Rods / pleomorphic in shape  
3. Size vary from 1-4 mm, 0.2-0.5 mm dia.  
4. No flagella hence, non motile  
5. All Are gram negative except sugarcane ratoon stunt  
6. These are non spore former  
7. Found in xylem and phloem vessels of plants  
8. These are living in intra cellular parasites  
9. Transmission by leaf hoppers, bugs, psyllids and mechanical  
10. Sensitive to tetracycline, penicillin high temperatures
11. Can be eliminated by immersing propagative material in hot water at 45-50 o c for 2 -3 hrs. Or keep in hot air at 50- 58 o c for 4 -8 hrs.
Ex: Sugarcane ratoon stunt and pierce’s disease of grapes

Fastidious vascular bacteria

*Leifsonia xyli* - *Sugarcane ratoon stunt*
- Xylem inhabitant, gram + ve
- Transmission no vector, mechanical ( sap ) or through implements
- It can growth on special / complex nutrient medium

*Candidatus liberobacter* - *Citrus greening*
- Phloem inhabitant, gram - ve , rigid rods
- Transmission by *Diaphorina citri* (psyllid) or vegetative propagation

*Xylella fastidiosa* - *Pierce’s disease of grapes*
- Xylem inhabitant, gram - ve
- Transmission by leaf hopper and grafting

**Phytoplasmas and spiroplasmas**
MLO’s / phytoplasmas

**Definition:** Prokaryotic, pleomorphic, resemble mycoplasma , wall less, self replicating, pass through filters, sensitive to tetracyclines, transmission by leaf hoppers ,found in sieve elements.
Important characteristics of phytoplasmas:
1. Size vary from 100 nanometers to 1 micrometer dia
2. Wall less, covered by trilamellar unit membrane with lipoproteins
3. Cells are pleomorphic
4. Aerobic to facultative anaerobes
5. Found in intracellularly in phloem vessels of plants
6. Genome is made up of ds circular DNA
7. Self replicable by transverse binary fission
8. These are obligate parasites
10. Resistant to penicillin but sensitive to tetracycline & chloramphenicol
11. Transmission by leaf hoppers and grafting
12. Can be controlled by cross protection
13. Require sterols for growth
14. Can be controlled by thermotherapy by growing plants at 37- 40°c.
   Ex. Mulberry dwarf

Phytoplasma in plant cell

Symptoms of phytoplasmal diseases
- Yellows of leaves (yellowing and stunting)
- Little leaf, (greening of flowers)
- Phyllody (flowers turn into green leafy structures)
- Witches broom (broom like growth or massed proliferation caused by the mass clustering of branches)
- Bronzing of leaves
**Diseases caused by phytoplasmas and vectors**

<table>
<thead>
<tr>
<th>Disease</th>
<th>Vector (leaf hopper)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Asters yellows</td>
<td><em>Macrosteleles fascifrons</em></td>
</tr>
<tr>
<td>2. Sesamum phyllody</td>
<td><em>Orosius albicinctus</em></td>
</tr>
<tr>
<td>3. Mulberry dwarf</td>
<td><em>Hishimonas sellatus</em></td>
</tr>
<tr>
<td>4. Sandal spike</td>
<td><em>Jassus indicus</em></td>
</tr>
<tr>
<td>5. Littel leaf brinjal</td>
<td><em>Hishimonas phycitis</em></td>
</tr>
<tr>
<td>6. Grassy shoot sugarcane</td>
<td><em>Aphis maydis</em></td>
</tr>
<tr>
<td>7. Potato witches broom</td>
<td><em>Orosius albicinctus</em></td>
</tr>
</tbody>
</table>

**Spiroplasmas (helical mollicutes) (spiroplasmatology)**

**Important characteristics:**
- These are helical in liquid media
- Size vary from 100-240 nm diameter
- These are grown on culture medium in laboratory medium.
- These are gram positive (+ve) bacteria
- Colonies appear like fried egg in culture medium
- Multiplication by transverse binary fission
- Having a no flagella
- These are resistant to penicillin but sensitive to tetracycline

**Important diseases and transmission**

<table>
<thead>
<tr>
<th>Disease</th>
<th>Vector (leaf hopper)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Cirn stunt</td>
<td><em>Dalbulus elimatus</em></td>
</tr>
<tr>
<td>2. Citrus stubborn</td>
<td><em>Circulifer tenellus</em></td>
</tr>
</tbody>
</table>
7. DETAILED ACCOUNT OF PLANT VIROLOGY

Contributation of scientists in the field of plant bacteriology

M.W. Beijerinck (Dutch):
- He considered as a father of virology
- He was more extensively studied tobacco mosaic disease
- He proved virus causing tobacco mosaic is not a living microorganism
- He named infectious agent as ‘contagium vivum fluidum’
- Subsequently called the agent as ‘virus’

W.M. Stanley (U.S.A):
- He was Initiated ‘biochemical nature of virus’
- He got a nobel prize In 1935 for crystallization of viruses
- He was used ammonium sulphate for crystallization viruses
- He finally proved viruses are not living microorganisms

F.C. Bawden (plant virologist) and N.W. Pirie (biochemist)
- Both are established complete chemical nature of purified TMV
- Pirie was proved characterised TMV chemically as nucleic acid 5 %, proteins 95%
- Both are also worked on turnip mosaic virus & tobacco bushy stunt virus

Adolf Mayer (German):
- He Worked on TMV
- He demonstrated sap transmission of the diseases

Iwanowski (Russia)
- He demonstrated TMV could pass through bacterial proof filters
Definition of viruses:
➢ Virus particles are sub microscopic, infectious entities, multiply intracellular, potentially pathogenic

Important characteristics of plant viruses:
➢ These are ultra microscopic
➢ Can pass through bacterial proof filters hence called filterable agents
➢ These are obligate Parasites, highly infectious
➢ Do not have enzyme system for energy generation
➢ Multiplication in terms of genetic material (DNA/ RNA)
➢ No binary fission
➢ Virus particle called as virions
➢ Virion consist of protein coat (capsid)
➢ Genome: majority RNA viruses
   Eg. *Tobamovirus* (Tobacco mosaic virus)
➢ Few are DNA viruses
   Eg. 1. *Caulimovirus* (cauliflower mosaic virus)

Influenza virus  Bacteriophage
Maintain definite shape
1. Rod (end open) A. Rigid rod, Eg. Tmv
   B. Flexible rod , Eg. Pv-x
2. Polyhedral virus (spherical / icosahedran)
   Eg Tobacco necrosis & cucumber mosaic virus

3. Polyhedral virus (end covered by protein sub units)
   Eg Alfalfa mosaic virus
## Classification of Viruses (According to ICTV)

**Kingdom: Viruses**

### RNA Viruses
- **a. Single stranded RNA viruses**

#### 1. Rod shaped particles
- Eg. Tobamovirus (tobacco mosaic virus)
- Furovirus (potato mop top virus)

#### 2. Filamentous particles
- Eg. Potexvirus (potato virus - x)
- Potyvirus (potato virus - y)

#### 3. Isometric particles
- Eg. Waikavirus (rice tungro virus)
- Comovirus (cowpea mosaic virus)
- Tospovirus (tomato spotted wilt virus)
- Nepovirus (grape fan leaf virus)
- Potato leaf roll virus

### DNA Viruses

#### A. Double stranded DNA viruses
- **1. Isometric particles**
  - Eg. Caulimovirus (cauliflower mosaic virus)

#### B. Single stranded DNA particles
- **1. Geminate (twin) particles**
  - Eg. Geminivirus (maize streak virus)
- **2. Single isometric particles**
  - Eg. Banana bunchy top virus

---

### Symptoms of Viral Diseases

#### A. External Symptoms
- 1. Mosaic
- 2. Vein clearing
- 3. Veinbanding
  - a) X- bodies - amorphous like
  - b) Flat crystalline plates
- 4. Ring spot
- 5. Necrosis
- 6. Distortion / malformation
- 7. Enation
- 8. Masked symptoms
- 9. Symptomless carrier

#### B. Internal Symptoms
- 1. Cell inclusion bodies
- 2. Destruction of normal tissue
  - a) Stem pittings
  - Eg. Tristeza virus

---

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A. External symptoms

1. Mosaic: Alternate green and yellow patches
   Eg: TMV

   [Image: Tomato mosaic]

2. Vein clearing: Tissue close to vein yellow, remaining area green
   Eg: Vein clearing of bhendi

   [Image: Vein clearing in bhendi]

3. Vein banding: Tissue along vein green, tissue between vein chlorotic

   [Image: Vein banding]

4. Ring spot: Circular chlorosis with green centre
   Eg: Papaya ring spot

   [Image: Papaya ring spot]
5. Necrosis: Death of cells in infected area
   Eg. Top rot of potato

6. Distortion / malformation:
   - Leaves and flowers twisted, become narrow
   - End of the leaf is appear as rat tail
   Eg. Leaf curl of papaya

7. Enation: Masses of hypertrophoid tissue on leaf surface
   Eg. Leaf curl of tobacco
Leaf curl in tobacco

8. Masked symptoms:
   - Plants contain virus, but symptomless under unfavourable conditions
   - Symptoms appear under favourable conditions

Masked virus:
   - Virus showing phenomenon of masking
     Eg. Cauliflower mosaic virus at > 24°C

9. Symptomless carrier:
   - Infected plant showing no obvious symptoms

Latent virus:
   - Virus not inducing development of symptoms in its host
     Eg. Tristeza virus on sweet orange

B. Internal symptoms:
1. Cell inclusion bodies
   a) X-bodies - amorphous like
   b) Flat crystalline plates
2. Destruction of normal tissue
   a) Stem pittings
   Eg. Tristeza virus
METHODS OF TRANSMISSION OF PLANT VIRUSES

a) Artificial transmission
   1. Mechanically through Sap
      Eg. Tobacco tomato mosaic virus
   2. Grafting
      Eg. Citrus tristeza
      Tobacco leaf curl

b) Natural transmission
   1. Contact
      Eg. TMV, PV-X
      a. Internal seed borne viruses
         Eg. Bean, cowpea, soybean mosaic virus
      b. Vegetatively propagating material
         Eg. Sugarcane mosaic virus – setts
         PV-X -tubers
   2. Seed/ propagative material
   3. Phanerogamic parasites
      Eg. Dodder
      Cuscuta campestris – Tomato bushy stunt virus
      C. californica – TSWV
   4. Soil
      Virus viable for 6 yrs in soil
      Eg. Wheat mosaic virus
   5. Fungi
      Eg. Synchytrium endobioticum – PV-X
      Olpidium brassicae – Tobacco necrosis virus
   6. Nematodes
      Nepoviruses (NEPO)
      Eg. Xiphinema index- Grape fan leaf virus
      Longidorus attenuatus - Tomato black ring virus
      Netuviruses (NETU)
      Eg. Trichodorus cylindricus
      - Tobacco rattle virus
   7. Insect vectors
      Eg. Onion yellow- aphids
Difference between persistent and non persistent virus

<table>
<thead>
<tr>
<th>Persistent virus</th>
<th>Non persistent virus</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Vectors retain the virus in their body throughout the life</td>
<td>Retained only for a short period in the body of vector</td>
</tr>
<tr>
<td>2. Virus are retained even after moulting</td>
<td>Lost when the insect is moulted</td>
</tr>
<tr>
<td>3. Acquisition feeding period is long (2 hrs)</td>
<td>Acquisition feeding period is short (15 sec)</td>
</tr>
<tr>
<td>4. Latent period in vector is present</td>
<td>No latent period in the vector</td>
</tr>
<tr>
<td>5. Long incubation period in the vector</td>
<td>Only short incubation period</td>
</tr>
<tr>
<td>6. Virus is circulative &amp; propagative</td>
<td>Do not multiply inside the vector</td>
</tr>
</tbody>
</table>

Transmission by Insects

1) Aphids:

<table>
<thead>
<tr>
<th>Virus</th>
<th>Vector</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Bean common mosaic virus</td>
<td><em>Aphis craccivora</em></td>
</tr>
<tr>
<td>2. Citrus tristeza virus</td>
<td><em>Toxoptera citricida</em></td>
</tr>
<tr>
<td>3. Potato virus Y</td>
<td><em>Myzus persicae</em></td>
</tr>
<tr>
<td>4. Barley yellow dwarf virus</td>
<td><em>Aphis dirhodum</em></td>
</tr>
<tr>
<td>5. Banana bunchy top virus</td>
<td><em>Pentalonia nigronervosa</em></td>
</tr>
<tr>
<td>6. Beet yellow virus</td>
<td><em>Myzus persicae</em></td>
</tr>
<tr>
<td>7. Cardomum dwarf virus</td>
<td><em>Micromyzus kalimpongegenes</em></td>
</tr>
<tr>
<td>8. Cardomum mosaic virus</td>
<td><em>Pentalonia nigronervosa</em></td>
</tr>
<tr>
<td>9. Cauliflower mosaic virus</td>
<td><em>Brevicoryne brassicae</em></td>
</tr>
</tbody>
</table>

2) Leaf hoppers:

<table>
<thead>
<tr>
<th>Virus</th>
<th>Vector</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Rice tungro virus</td>
<td><em>Nephotettix virescens</em></td>
</tr>
<tr>
<td>2. Maize streak virus</td>
<td><em>Cicadulinia cinai</em></td>
</tr>
<tr>
<td>3. Rice grassy stunt virus</td>
<td><em>Nilaparvatha lugens</em></td>
</tr>
<tr>
<td>4. Beet curly top virus</td>
<td><em>Ciculifer tenellus</em></td>
</tr>
<tr>
<td>5. Potato yellow dwarf virus</td>
<td><em>Agallia constricta</em></td>
</tr>
</tbody>
</table>
6) Maize chlorotic dwarf virus  
7) Rice stripe virus  
8) Rice dwarf virus  
9) Rice hoja blanca virus

3) Whiteflies:

<table>
<thead>
<tr>
<th>Virus</th>
<th>Vector</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Cassava mosaic virus</td>
<td>Bemisia tabaci</td>
</tr>
<tr>
<td>2. Bhendi vein clearing virus</td>
<td>Bemisia tabaci</td>
</tr>
<tr>
<td>3. Cotton/Mungbeen leaf curl virus</td>
<td>Bemisia tabaci</td>
</tr>
<tr>
<td>4. Mungbeen yellow mosaic virus</td>
<td>Bemisia tabaci</td>
</tr>
<tr>
<td>5. Tobacco leaf curl virus</td>
<td>Bemisia tabaci</td>
</tr>
</tbody>
</table>

4) Thrips:

<table>
<thead>
<tr>
<th>Virus</th>
<th>Vector</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Tomato spotted wilt</td>
<td>Thrips tabaci, Frankliniella schultzei, Scirtothrips dorsalis</td>
</tr>
<tr>
<td>2. Tobacco ring spot virus</td>
<td>Thrips tabaci, Frankliniella schultzei, Scirtothrips dorsalis</td>
</tr>
<tr>
<td>3. Tobacco streak virus</td>
<td>Thrips tabaci, Frankliniella schultzei, Scirtothrips dorsalis</td>
</tr>
</tbody>
</table>

5) Beetles:

<table>
<thead>
<tr>
<th>Virus</th>
<th>Vector</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Cowpea mosaic virus</td>
<td>Ceratoma trifurcate</td>
</tr>
<tr>
<td>2. Squash mosaic virus</td>
<td>Diabrotica longicornis</td>
</tr>
<tr>
<td>3. Turnip yellow mosaic virus</td>
<td>Psylloides</td>
</tr>
<tr>
<td>4. Radish mosaic virus</td>
<td>Epitrix hirtipennis</td>
</tr>
<tr>
<td>5. Bhendi mosaic</td>
<td>Podagria sp</td>
</tr>
<tr>
<td>6. Broad bean stain virus</td>
<td>Sitona lindata</td>
</tr>
<tr>
<td>7. Bean pod mottle virus</td>
<td>Eipcauta vittata</td>
</tr>
</tbody>
</table>

6) Mealy bugs:

<table>
<thead>
<tr>
<th>Virus</th>
<th>Vector</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Cocoa swollen shoot virus</td>
<td>Planococcoides njalensis</td>
</tr>
</tbody>
</table>

Transmission by Nematode

1. NEPO: Nematode transmitting polyhedral viruses

<table>
<thead>
<tr>
<th>Virus</th>
<th>Nematode</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Grape vine fan leaf virus</td>
<td>Xiphinema index</td>
</tr>
</tbody>
</table>
2. **NETU**: Nematode transmitting tubular virus

<table>
<thead>
<tr>
<th>Virus</th>
<th>Nematode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tobacco rattle virus</td>
<td>Paratrichodorus allius</td>
</tr>
<tr>
<td>TRV &amp; Pepper ring spot virus</td>
<td>Paratrichodorus minor</td>
</tr>
<tr>
<td>Pea early browning virus</td>
<td>Paratrichodorus teres</td>
</tr>
<tr>
<td>Tobacco rattle virus</td>
<td>Trichodorus cylindricus</td>
</tr>
<tr>
<td>Tobacco rattle virus</td>
<td>Trichodorus similis</td>
</tr>
<tr>
<td>Pea early browning virus</td>
<td>Trichodorus viruliferus</td>
</tr>
</tbody>
</table>

**Transmission by Fungi**

<table>
<thead>
<tr>
<th>Virus</th>
<th>Fungi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tobacco necrosis virus</td>
<td>Olpidium brassicae</td>
</tr>
<tr>
<td>Tobacco stunt virus</td>
<td></td>
</tr>
<tr>
<td>Lettuce big vine virus</td>
<td></td>
</tr>
<tr>
<td>Cucumber necrosis virus</td>
<td>Olpidium cucurbitacearum</td>
</tr>
<tr>
<td>Barly yellow mosaic virus</td>
<td></td>
</tr>
<tr>
<td>Oat mosaic virus</td>
<td>Polymyxa graminis</td>
</tr>
<tr>
<td>Wheat soil born mosaic virus</td>
<td></td>
</tr>
<tr>
<td>Wheat spindle streak virus</td>
<td></td>
</tr>
<tr>
<td>Potato mop top virus</td>
<td>Spongospora subterranean</td>
</tr>
</tbody>
</table>

**Viroids (mini naked virus)**

Definition:

- These are obligate, parasites, low molecular weight nucleic acids (ss RNA) with out protein coat, replicate themselves and cause diseases only in plants
- Diener (1971) – first time discovered viroid causing potato spindle tuber about 20 plant diseases are known to be caused by viroids

**Important characteristics of viroids**

- These are obligate parasites
- Lacks protein coat
Having a genome – circular ss RNA
Transmission through sap and by vegetative propagation
Replication mechanism is not known
Can survive outside the host or dead plant debris for few min. to few hrs.
Resistant to high temperatures

Viroid diseases:
Potato spindle tuber
Citrus exocortis
Coconut cadang cadang
8. TERMS AND CONCEPTS USED IN PLANT PATHOLOGY

**Disease:** Disease is a malfunctioning process that is caused by continuous irritation which results in some suffering producing symptoms (American Phytopathological society & British Mycological society).

**Disorder:** Non-infectious plant diseases due to abiotic causes such as adverse soil and environmental conditions are termed disorders.

**Pathogen:** An entity, usually a micro-organism that can incite disease.

**Parasite:** Organisms which derive the materials they need for growth from living plants (host or suscept) are called parasites.

**Pathogenicity:** is the ability of the pathogen to cause disease

**Pathogenesis:** is the chain of events that lead to development of disease in the host Sign: The pathogen or its parts or products seen on a host plant.

**Symptom:** The external or internal reactions or alterations of a plant as a result of a disease.

**Syndrome:** The set of varying symptoms characterizing a disease are collectively called a syndrome.

**Biotroph:** An organism that can live and multiply only on another living organism. They always obtain their food from living tissues on which they complete their life cycle. Ex: Rust, smut and powdery mildew fungi.

**Hemibiotroph (Facultative Saprophyte):** The parasites which attack living tissues in the same way as biotrophs but will continue to grow and reproduce after the tissue is dead called as facultative saprophytes.

**Perthotrophs or perthophytes (Necrotroph):** A parasite is a necrotroph when it kills the host tissues in advance of penetration and then lives saprophytically

Ex: *Sclerotium rolfsii.*
**Inoculum**: It is the part of the pathogen (or) infective propagules which on coming in contact with the host plant causes an infection are known as inoculum.

**Inoculum potential**: The resultant of the action of environment, the vigour of the pathogen to establish an infection, the susceptibility of the host and the amount of inoculum present.

**Incubation period**: The period of time (or time lapse) between penetration of a host by a pathogen and the first appearance of symptoms on the host.

**Predisposition**: It is the action of set of environments, prior to penetration and infection, which makes the plant vulnerable to attack by the pathogen.

**Hypersensitivity**: Excessive sensitivity of plant tissues to certain pathogens. Affected cells are killed quickly, blocking the advance of obligate parasites.

**Systemic infection**: The growth of pathogen from the point of entry to varying extents without showing adverse effect on tissues through which it passes.

**Epidemic or Epiphytotic disease**: A disease usually occurs widely but periodically in a destructive form is referred as epidemic or epiphytotic disease. Ex: Late blight of potato – Irish famine (1845)

**Endemic**: Constantly present in a moderate to severe form and is confined to a particular country or district. Ex: Club root of cabbage in Nilgiris

**Sporadic disease**: Occur at very irregular intervals and locations and in relatively fewer instances. Ex: Udbatta disease of rice

**Pandemic**: A disease is said to be pandemic when it is prevalent throughout the country, continent or world involving mass mortality. E.g. Late blight of potato and wheat stem rust.
The basically symptoms are caused 4 main categories viz.,

1. Colour change
2. Necrosis
3. Hypertrophy and hyperplasia
4. Hypoplasia

1. Colour change:
   - Green pigment may disappear entirely and its place may be taken by a yellow pigment called yellowing or chlorosis
   - Sometimes the diseased portion become colourless this condition is called as albinism
   - If the green pigment is replaced by red or orange or purple pigment this condition is called as chromosis

2. Necrosis:
   - It means death of tissue
   - Necrotic tissue are often gray, brown, black colour
   - Ex: leaf spot, blights, damping off, rots, scald, die-back, scab, smut, rust.

3. Hypertrophy and hyperplasia:
   - It involves various overgrowth
   - Increase in size of the individual cells called as hypertrophy
   - Increase in number of the individual cells called as hyperplasia
   - Ex: warts and galls

4. Hypoplasia:
   - Reduced development of whole plant or parts of the plant or certain tissues or flowers or fruits
   - In extreme cases in which the organ or tissue does not develop is called atrophy
   - Ex: Dwafing, stunting, shoe-string, fern leaf, little leaf.
Classification of the Plant Diseases

I Basis of the effect

II Basis of their cause

CLASSIFICATION OF PLANT DISEASES

I Basis of the effect

1 based on type of infection
   a. Localized
   b. Systemic

2 based on type of perpetuation or spread
   a. Air born
   b. Seed born
   c. Soil born
   d. Vector born

3. Based on occurrence and geographic distribution
   a. Endemic
   b. Epidemic
   c. sporadic
   d. pandamic
   c. sporadic

4. Based on multiplication of inoculum
   a. Compound interest
   b. Simple interest

5. Based on kind of symptom produced
   Wilt, soft rot in fruits, anthracnose, rust, DM, PM

II Basis of their cause

a. Infectious
   Fungal, bacterial, viral, planerogamic parasites

b. Non infectious
   Freezing injury, high temperature, high soil moisture, mineral toxicity, mineral deficieny

6. Based on host plant affected
   a. Cereal crop diseases, pulse crop, oilseed, vegetables disease ect

7 based on parts of the plant affected
   Root, stem, foliar, fruit, seed diseases
9. SURVIVAL OF PLANT PATHOGENS

Primary infection:
➢ The initial infection that occurs from the sources of pathogen survival in the crop is primary infection.

Primary inoculum:
➢ The propagules that cause this infection are called primary inoculum.

Secondary inoculum:
➢ After initiation of the disease in the crop, spores or other structures of the pathogen are sources of secondary inoculum and cause secondary infection.
➢ Primary infection initiates the disease and secondary infection spreads the disease.

Sources of survival of pathogens
1) Infected host as reservoir of inoculum
2) Survival as saprophytes outside the host
3) Survival by means of specialized resting structures in or on the host or outside the host.
4) Survival in association with insects, nematodes and fungi.
1) Infected host as reservoir of inoculum
   
a) Seed:
   ❖ Seed may be externally or internally infected by plant pathogens
     Ex 1: loose smut of wheat, *Ustilago nuda tritici*,
     Ex 2: *Pseudomonas syringae pv*. Has been shown to survive in dried tomato seed for 20 years

b) Collateral hosts (wild hosts of same families):
   ❖ Provide adequate facilities for growth and reproduction of the pathogens during offseason
   ❖ weed hosts help to bridge the gap between two crop seasons
     Ex: blast disease of rice, *Pyricularia grisea* infect the grass weeds like *Brachiaria mutica, Leersia hexandra, Panicum repens*

c) Alternate hosts (Wild hosts of other families):
   ❖ Alternate hosts are very important for the completion of the life cycle of heteroecious rust pathogens
     Ex: Temperate regions the alternate host of *Puccinia graminis tritici* (black or stem rust pathogen of wheat),
     ❖ The barberry is a alternate host for the wheat stem rust Pathogen has very wide host range
     (*Sclerotium rolfsii, Rhizoctonia solani, Fusarium moniliforme*)

d) Self sown crops:
   ✓ Self sown crops, voluntary crops and early sown crops are reservoirs of many plant pathogens
     Ex: Self sown rice plants harbour the pathogen *(Rice tungro virus)* as well as vector *(Nephottetix virescens)*

e) Ratoon crops:
   ❖ Sometimes ratoon crops also harbour the plant pathogens
     Ex: Sugarcane mosaic
f) **Survival by latent infection**
- Plant pathogens may survive for a long time in plant tissue without development of visual symptoms
  - Ex: *Xylella fastidiosa*

2) **Saprophytic survival outside the host**
- Saprophytic survival usually occurs in or on the soil
  - Waksman (1971) distinguished between soil inhabitants and soil invaders

<table>
<thead>
<tr>
<th>Soil inhabitants</th>
<th>Soil invaders</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. These are unspelized parasites</td>
<td>1. These are specialized parasites</td>
</tr>
<tr>
<td>2. These are having wide host range</td>
<td>2. These are close host range</td>
</tr>
<tr>
<td>3. These are obligate parasites and facultative parasites</td>
<td>3. These are facultative parasites</td>
</tr>
<tr>
<td>4. These are exp-pathogens</td>
<td>4. These are endo-pathogens</td>
</tr>
<tr>
<td>5. They have high competitive saprophytics</td>
<td>5. They have how competitive saprophytics</td>
</tr>
</tbody>
</table>

Ex: *Pythium, rhizoctonia, Sclerotia*.

**Rhizosphere colonizers:**
- which colonize the dead substrates in the root region and continue to live like that for a longer period
- which are more tolerant to soil antagonism
  - Ex: Leaf mold in tomato: *Cladosporium fulvum*

3) **Survival as dormant spores or specialized resting structures**

**Plant viruses:** have no resting stage and are transmitted through a continuous infection chain

**Phytopathogenic bacteria:** continuously live in their active parasitic stage in the living host or as active saprophytes on dead plant debris also do not produce resting spores
**Nematodes:** survive in the form of active parasitic phase also survive through dormant structures, i.e., eggs, cysts, galls, formed in host tissues

**Phanerogamic parasites:** survive in dormant state for many years through seeds, Ex: Seeds of Orobanche survive in soil for more than 7 years

1) **Soil borne fungi:**
   a) **Dormant spores**
      - Conidia - *Taphrina deformans*
      - Oospores - *Downy mildew fungi*
      - Chlamydospores - *Fusarium*
      - Perithecia - *Venturia inaequalis*

   ![Oospore](image1) ![Chlamydospores](image2) ![Perithecia](image3)

   b) **Other dormant structures**
      - Thickened hypha
      - Sclerotia - *Sclerotinia sclerotiorum*
      - *Microsclerotia* - *Verticillium*
      - *Rhizomorphs* - *Armillaria mellea*

   ![Thickened hypha](image4) ![Sclerotia](image5) ![Microsclerotia](image6)
2) Seed borne fungi:

a) Externally seed borne
Dormant spores on seed coat
   Ex: Covered smut of barley, grain smut of jowar, bunt of wheat

b) Internally seed borne
Dormant mycelium under the seed coat or in the embryo
   Ex: Loose smut of wheat - *Ustilago nuda tritici*

![Grain smut of jowar & Loose smut of wheat]

4) Survival in association with insects, nematodes and fungi
   - Important plant pathogens may survive within the insect body and over winter
   Ex: Corn flea beetle, *Cheatocnema pulicaria* carries inside its body
   Corn wilt pathogen, *Xanthomonas stewartii*
10. DISSEMINATION OF THE PATHOGEN

Transport of spores or infectious bodies, acting as inoculum, from one host to another host at various distances resulting in the spread of the disease, is called dispersal or dissemination or transmission of plant pathogens. Second link in infection chain is dissemination of plant pathogens

**Infection chain**

- Fungal diseases: through asexual and sexual spores dispersed by mechanically by various means
- Bacterial diseases: through bacterial cells as ooze or tissues dispersed by various physical and biological agencies
- Viral diseases: through virus particles and transmitted by insects, mites, phanerogamic parasites, nematodes and human beings.

Basically the dissemination of the pathogens is two types they are,
1. Autonomous or direct or active dispersal
2. Indirect or passive dispersal
I. Autonomous or direct or active dispersal

1) Seed as the source of autonomous dispersal
   a) Contamination of the seed
   b) Externally seed borne
   c) Internally seed borne

2) Soil as a means of autonomous dispersal
   a) Dispersal in soil
   b) Dispersal by the soil
      i) Contamination of soil
      ii) Growth and spread of a pathogen in soil
      iii) Persistence of the pathogen in soil

3) The plant and the plant organs as a means of autonomous dispersal

II. Passive or Indirect dispersal

1) Animate agents
   a) Insects
   b) Mites
   c) Fungi
   d) Nematodes
   e) Human beings
   f) Dispersal by phanerogamic parasites
   g) Dispersal by birds
   h) Farm and wild animals

2) Inanimate agents
   a) Wind
   b) Water
      → Fungi
      → Nematodes
      → Bacteria
      → Viruses & phytoplasmas

Transportation of seeds
Planting diseased seed materials
During adoption of normal farming practices
By use of contaminated implements
By use of diseased grafting and budding material
I) Autonomous or direct or active dispersal

1. Seed as the source of autonomous dispersal
2. Soil as a means of autonomous dispersal
3. The plant and the plant organs as a means of autonomous dispersal

1) **Seed as the source of autonomous dispersal**

➢ Cultivated crops are raised from seed and transmission of diseases and transport of pathogens has much importance
➢ Dormant structures
   Ex: Sclerotia of ergot fungus, smut sori
➢ Bacterial cells or spores of fungi present on the seed coat
➢ There are three types of dispersal by seed
   1. Contamination of the seed
   2. Externally seed borne
   3. Internally seed borne

1. **Contamination of the seed:**

➢ Seeds of pathogen or parasite and the host are mixed during harvest and threshing of the crop
➢ In many cases, identity of the seeds of the two entities (host and the pathogens) is difficult to separate
Ex: Smut of pearlmillet and ergot of rye

Smut of Pearlmillet & Ergot of rye
2. Externally seed borne:
- Close contact between structure of the pathogen and seeds.
- Established dormant spores or bacteria on seed coat during growth of the crop or at the time of harvest and threshing
Ex: Short smut of sorghum, bacterial blight of cotton, loose smut of barley

3. Internally seed borne:
- Pathogen may penetrate into the ovary and cause infection of the embryo while it is developing
Ex: Loose smut of wheat

3) Soil as a means of autonomous dispersal:
- Soil borne facultative saprophytes or facultative parasites may survive through soil
- Dispersal by movement of pathogen in soil or by its growth in soil or by movement of the soil containing the pathogen
It is divided into 2 categories

a) Dispersal in soil

b) Dispersal by the soil

a) **Dispersal in soil**

Three stages of dispersal in soil

i) Contamination of soil:

➢ By gradual spread of the pathogen from infested area to new area

ii) Growth and spread of a pathogen in soil:

➢ Based on its ability to multiply and spread Pathogen must be saprophytic survival ability are most important

➢ Can pass their entire life in the soil

Ex: *Pythium* sp., and *Phytophthora* sp

iii) Persistence of the pathogen in soil:

➢ Pathogens persist in soil as dormant structures like Oospores (*Pythium, Phytophthora, Sclerospora*)

b) **Dispersal by the soil:**

➢ During cultural operations like agricultural implements, irrigation water, workers feet etc.

➢ Propagules of fungi and plant debris spread throughout the field

➢ Transfer of soil from one place to another along with propagating materials

Ex: Transfer of papaya seedlings from a nursery infested with *Pythium aphanidermatum* (stem or foot rot of papaya)

➢ Similarly grafts of fruit trees transported with soil around their roots

3) **The plant and the plant organs as a means of autonomous Dispersal**

➢ Other than seed that are used for vegetative propagation, main field produce and plant debris

➢ Accumulates during course of cropping period
Ex: Late blight of potato
➢ Introduced in North America and Europe through seed tubers brought from native source of the in South America
➢ Citrus canker was introduced into California from Asia.
➢ The climatic conditions favoured its epidemic in California.

II) Passive or Indirect dispersal
It is through animate and inanimate agents
1) Animate agents
a) Insects:
➢ Insects carry plant pathogens either externally (epizoic) or internally (endozoic)
➢ They can disseminate bacteria, fungi, viruses, mycoplasmas, spiroplasmas, rickettsia,

Fungal diseases:
➢ Sum fungi produce conidia, oidia and spermatia in honey secretions having attractive odours
Ex: Sugary disease of sorghum.
➢ Ascomycetes attract insects, flies, pollinating bees and wasps which play a dual role, viz., pollination and transmission of plant pathogens
Ex: Dutch elm disease - *Ceratostomella ulmi* is transmitted internally by elm bark beetles

![Elm bark beetles](image-url)
Bacterial diseases:
- Ex: Fire blight organism - *Erwinia amylovora*
- Citrus canker bacterium - *Xanthomonas axonopodis pv. citri* are transmitted by flies (bees), ants and later by leaf miner
- Cucumber wilt bacterium - *Erwinia tracheiphila* is spread by
  - Ex: Stripped cucumber beetles - *Acalymma vittata*
  - Ex: Spotted cucumber beetle - *Diabroticundecimi punctata*

Viral diseases:
- More than 80 per cent of the viral and phytoplasmal diseases are spread by insects
- Insect which acts as specific carriers in disseminating the diseases are called insect vectors
- Order Homoptera contain largest number and most important insect vectors of plant viruses
  - Aphids (Aphididae) and leaf hoppers (Cicadellidae)

Mycoplasma diseases:
- Plant MLO’s are phloem inhabitants and those insects which are feeding on phloem of plants transfer the MLO’s
- Mycoplasmal diseases are mostly transmitted by leaf hoppers
  - Ex: Sesamum phyllody - *Orosious albicinctus*
  - Little leaf of brinjal - *Hishimonas phycitis*
Mites: *Aceria cajani* transmits Pigeonpea sterility mosaic virus

Fungi:

- Some soil borne fungal pathogens carry plant viruses in or on their resting spores and zoospores
- Tobacco necrosis virus and Cucumber mosaic virus are carried outside the fungi
- while lettuce big vein virus is carried inside the zoospores.

Nematodes:

- Nematodes act as vectors for transmission of fungi, bacteria and viruses

Bacterial diseases:

- Bacterium which causes yellow ear rot of wheat (*Corynebacterium tritici* or *Clavibacter tritici*) is disseminated by ear cockle nematode, *Anguina tritici*.
- If these two diseases appear together, a complex disease called tundu of wheat occurs.
- *Corynebacterium tritici* is not capable of dispersal and infection unless it is carried by *Anguina tritici*.

Fungal diseases:

- Root rot and wilt pathogens such as *Phytophthora, Fusarium, Rhizoctonia, Verticillium*

Viral diseases:

- Plant nematodes play a vital role in transmitting certain virus diseases
Human beings:
a). While Transportation of seeds:
   Ex: Late blight of potato, Downy mildew of grapevine, Citrus canker, Fusarium wilt of banana

b). Planting diseased seed materials:
   Ex: Vegetatively propagated plants
   Such as potato, sweet potato, cassava, sugarcane, banana, many ornamentals and fruit trees

c). During adoption of normal farming practices:
   ➢ EX: Preparatory cultivation, planting, irrigation, weeding, pruning
Transport of infective propagules during cultivation

d). By use of contaminated implements:
   Ex: Bunchy top of banana

e). By use of diseased grafting and budding material:

f) Dispersal by phanerogamic parasites:

➢ Transmit the viruses by acting as bridge between the diseased and healthy plants
   
   *Cuscuta subinclusa* - Cucumber mosaic virus
   *Cuscuta california* - Tomato spotted wilt virus
   *Cuscuta campestris* - Tomato bushy stunt virus

Cuscuta infected cucumber Tomato bushy stunt
Dispersal by birds:

- Crows feeding on fleshy, sticky and gelatinous berries of giant mistletoe (Dendrophthoe sp.) deposit the seeds on the other trees with excreta.
- Seeds of Loranthus are disseminated by birds by sticking on their beaks and also through excreta and stem segments of dodder.
- Spores of chestnut blight fungus, Endothea parasitica are disseminated by more than 18 species of birds.

h) Farm and wild animals:

- Animals while feeding on diseased fodder.
- Dung when used as manure spread in the field.

2) Inanimate agents

a) Wind:

- Dispersal of pathogens by wind is known as anemochory.
- It involves upward air currents, velocity and downward movements of the wind.
- Wind acts as a potent carrier of propagules of fungi, bacteria and viruses.
Spores carry through wind

Fungi:
- Adaptations for wind dispersal is
- Production of numerous spores and conidia
- Discharge of spores with sufficient force
- Production of very small and light spores
  Ex: Powdery mildew, downy mildew, rusts, smuts
- Spores adopted for short distance
  Ex: Uredospores of rust fungi

Uredospores

- Spores adapted to long distance
  Ex: Uredospores of *Puccinia graminis var. tritici* at 14000 feet
  *Alternaria* spores at 8000 feet
  *Puccinia recondita* and *Cronartium ribicola*
  spores at 12500 feet were reported

Nematodes:
- Ex: Cysts nematode *Heterodera major*, which causes molya disease of wheat and barley Carried by dust storms from Rajasthan to Haryana
Bacteria:

- Ex: *Erwinia amylovora* - Fire blight of apple and Pear
- Produces fine strands of dried bacterial exudates which broken off and are transmitted by wind

Viruses and phytoplasmas:

- These are not directly transmitted by wind, But through insect and mite vectors carry viruses move to different directions and distances based on the direction and speed of the air

**b) Water:**

- Transmission of plant pathogens by water is called as hydrochory. Water dissemination occurs mainly through Surface running water Rain splash
- Heavy rains or during irrigation from canals and wells carries the pathogens

Ex: Mycelial fragments, spores or sclerotia of fungi, *Colletotrichum falcatum, Fusarium, Ganoderma, Macrophomina, Pythium, Phytophthora, Sclerotium*, During irrigation carries the pathogens

**Rain splash dispersal:**

- It is one of the efficient methods of dispersal of bacterial plant pathogens
Ex: Bacterial leaf spot of rice (*Xanthomonas campestris* pv. *oryzae*), Bacterial leaf streak of rice (*Xanthomonas campestris* pv. *oryzicola*)

Spores dispersal through Rain splash wind water
11. PHENOMENON OF INFECTION/ INFECTION PROCESS

It is the third link in the infection chain
It is achieved by three ways

Establishment:
➢ Entry and colonization of pathogen in the host tissues is known as establishment

Inoculum:
➢ The infective propagules coming in contact with the host are known as inoculum

Inoculum potential:
➢ It is a function of inoculum density and their capacity

Definition: It is defined as the resultant of the action of environment, the vigour of pathogen to establish an infection, susceptibility of the host and amount of inoculum present

Success of process of infection depends on
1. Host factors
2. Pathogen factors
3. Environmental factors

1. Host factors
Susceptibility of host:
➢ It is genetically controlled by DNA
➢ It is an inheritable character transmitted from parents to off springs

Disease proneness of the host:
➢ It is by the external factors such as host nutrition, i.e. more nitrogen application makes the host more susceptible and more potash application leads to less susceptibility

2. Pathogen factors
Virulence / aggressiveness of the pathogen:
➢ It is determined by genetic material which is inheritable
High multiplication rate of the pathogen:

➢ Chances of infection increases with high rate of multiplication.
➢ High birth rate and low death rate

Proper inoculum potential:

➢ Specialized pathogens very few or even one spore is capable of causing infection successfully
➢ Non-specialized pathogens require high density of inoculum

3. Environmental factors:

➢ Such as Temperature, relative humidity, moisture,
➢ Process of infection can be grouped into three stages, i.e. pre-penetration, penetration and post-penetration

1. Pre-penetration:

➢ Depending upon the plant pathogen activity, are classified in to 2 categories

<table>
<thead>
<tr>
<th>Active Invaders</th>
<th>Passive Invaders</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Aggressive effort to gain entry into host cells</td>
<td>1. No aggressive effort</td>
</tr>
<tr>
<td>2. Do not require help of any external agency to entry into host cells.</td>
<td>2. Require help of external agencies like insect vectors or wounds caused by agricultural operations</td>
</tr>
<tr>
<td>Ex. Fungi, Phanerogamic Parasites</td>
<td>Ex. Viruses and bacteria</td>
</tr>
</tbody>
</table>
2. PENETRATION

By direct penetration or indirectly through wounds or natural openings

- Bacteria enter plants mostly through wounds and less frequently through natural openings.
- Viruses, viroids, mollicutes, fastidious bacteria enter through wounds made by vectors.
- Fungi, nematodes and parasitic higher plants enter through direct penetration and less frequently through natural openings and wounds.

1. Wounds

- Wounds caused by farm operations, hail storms, or insect punctures
  Ex. Rhizopus, Gloeosporium, Aspergillus, Penicillum, Colletotrichum, Diplodia

2. Natural openings

a) Stomata: Germ tube at the time of penetration through the stomata
  Ex. Puccinia graminis tritici, Peronospora destructor, Pseudoperonospora cubensis, Xanthomonas
Campestris, Albugo candida and Phytophthora infestans

b) Lenticels:
Ex. Sclerotinia fructicola - Brown rot of fruits
Streptomyces scabies- Scab of potato
Phytophthora arecae - Mahali disease of arecanut

c) Hydathodes:
Ex. Xanthomonas campestris pv. campestris - Black rot of crucifers

B) Direct penetration
Fungi and nematodes are direct penetration of the host by fine hypha and stretching of the epidermis

a) Breakdown of physical barriers:
➢ Fungi penetrate host plants directly through a fine hypha produced directly by the spore or mycelium or through a penetration peg produced by an appressorium by stretching of the epidermis

![Infection peg]

b) Breakdown of chemical barriers:
➢ Presence of cuticular layer on the epidermis
➢ Lack of suitable nutrients for the pathogen in the host cells
➢ Presence of inhibitory in the host cells

Through non-cutinized surfaces:
a) Seedlings:
Grain smut of jowar - Sphacelotheca sorghi
Loose smut of jowar - Sphacelotheca cruenta
Downy mildew of jowar and bajra - *Sclerospora graminicola*),
Wheat bunt disease - *Tilletia caries, Tilletia foetida*

b) Root hairs:
Wilt causing fungi - *Fusarium sp*
Club root of cabbage - *Plasmodiophora brassicae*
Root rot of cotton - *Phymatotrichum omnivorum*

c) Buds:
Pea rust fungi - *Uromyces pisi*
Witches broom of cherries - *Taphrina cerasi*

d) Flowers:
Loose smut of wheat - *Ustilago nuda tritici*
Long smut of jowar - *Tolyposporium ehrenbergi*
Ergot of rye - *Claviceps purpurea*

e) Leaves:
Basidiospores of white pine blister rust - *Cronartium ribicola*

f) Nectaries:
Fire blight of apple - *Erwinia amylovora*

g) Stalk ends: *Penicillium italicum,*

**Through cutinized surfaces:**

**Cuticle:**

Leaf spot of spinach - *Cercospora beticola*
Early blight of solanaceous plants - *Alternaria solani*
Tikka disease of groundnut - *Cercospora personata*

3. **Post penetration**

➢ In Invasion of plant tissues by the pathogen, and growth and reproduction of the pathogen (colonization) are two concurrent stages of disease development
12. ROLE OF ENZYMES IN PATHOGENESIS

Enzymes are large protein molecules which catalyze all interrelated reactions in the living cell

**Composition of the cell wall:**
Functionally cell wall is divided into 3 regions, viz.
1. Middle lamella - made of pectins
2. Primary wall - cellulose, pectic substances
3. Secondary cell wall - entirely cellulose

![Composition of cell wall](image)

The epidermis of plants is covered by cuticle, whose major chemical substance is cutin in addition to cuticular wax

**Cuticular wax:**
- Made up of long chain molecules of paraffin, hydrocarbons, alcohols, ketones and acids.
- Most of the fungi and parasitic higher plants penetrate wax layers by means of mechanical force alone

**Cutin:**
- It is an insoluble polyester of unbranched derivatives of C16 and C18 hydroxy fatty acids
- Cutin is admixed with waxes on upper side and with pectin and cellulose on the lower side
- Cutinases break cutin molecules and release monomers as well as oligomers from insoluble cutin polymer
Cutinases reaches its highest concentration at penetrating point of the germ tube and at infection peg of appressorium forming fungi
Ex: *Colletotrichum gloeosporioides, Sphaerotheca pannosa, Venturia inaequalis, Helminthosporium victoriae.*

**Pectic substances:**

- Made up of large portion of an amorphous gel filling the spaces between cellulose microfibrils
- It consisting mostly of ‘D’ galactouronic acid units with α-1,4-glycosidic bonds.
- These chains are esterified with methyl groups
- linked with other carboxyl groups in calcium and magnesium salt bridges.
- Pectic substances are of three types, namely
  a) Pectic acid (non methylated units)
  b) Pectinic acid (<75% methylated galacturonan units) and
  c) Pectin (>75% methylated units)
- The enzymes that degrade pectic substances are known as pectinases or pectolytic enzymes.
- These are types, namely
  1. Pectin methyl esterases (PME’s)
  2. Polygalactouronases (PG’s)
  3. Pectin lyases (PL’s)

1. Pectin methyl esterases:
   Breaks ester bonds and removes methyl groups from pectin leading to the formation of pectic acid and methanol (CH3OH).

2. Polygalacturonases: Split pectin chain by adding a molecule of water and breaks the linkage between two galacturonan units. These enzymes catalyze reactions that break α1,4-glycosidic bonds.
3. Pectin lyases: Split pectin chain by removing a molecule of water from the linkage, thereby breaking it and releasing products with unsaturated double bonds.

Ex: *Erwinia caratovora* subsp. *caratovora*  
*Botrytis cinerea*,  
*Sclerotium rolfsii*

**Cellulose:**
- It is made up of chains of β-D-glucopyranose units
- It is insoluble in crystalline form and soluble in amorphous form
- Enzymatic breakdown of cellulose results in final production of glucose molecules.
- Cellulose is degraded by cellulases
- Cellulase-degrading enzymes play a role in softening and degradation of cell wall material and facilitate easy penetration and spread of pathogen in the host

Ex: Basidiomycetes fungi

**Hemicellulose:**
- It is a major constituent of primary cell wall, secondary cell wall, and middle lamella
- Hemicellulases degrade hemicelluloses and depending on the monomer released from polymer on which they act, they are termed as xylanase, galactanase, glucanase, arabinase, mannose, and so on.

Ex: *Sclerotinia sclerotiorum, Sclerotinia fructigena*

**Lignin:**
- Lignin is found in the middle lamella
- It is made up of phenylpropanoid

Ex: *Xylaria, Chaetomium, Alternaria, Cephalosporium*, Basidiomycetes

**Lipids:**
- It contains phospholipids and glycolipids
- Lipolytic enzymes called lipases (phospholipases, glycolipases)
Starch:

➢ Starch is the main reserve polysaccharide found in plant cells.
➢ It is a two forms amylase and amylopectin
13. ROLE OF TOXINS IN PLANT PATHOGENESIS

**Definition:** it is a microbial metabolite excreted (exotoxin) or released by lysed cells (endotoxin) which in very low concentration is directly toxic to the cells of the susceptible (host).


- The source of origin, toxins are divided into 3 broad classes namely, pathotoxins, vivotoxins and phytotoxins.

1. Pathotoxins:
   - Most of these toxins are produced by pathogens during pathogenesis.
   - Victorin: *Cochliobolus victoriae* (*Helminthosporium victoriae*) - Victoria blight of oats
   - This is a host specific toxin

```
   HO—C—OH
   C=O
   Me
   Me
   Me
   O
   H2N
   COOH
   NH
   NH
   O
   CHCl
   HO
   HO

Victorin
```

A) Selective:
   - T- toxin: *Helminthosporium maydis race T*
   - HC-toxin: *Helminthosporium carbonum*
   - HS- toxin: *Helminthosporium sacchari*
   - Phyto-alternarin: *Alternaria kikuchiana*
   - PC- toxin: *Periconia circinata*

B) Non-selective:
   - Tentoxin: *Alternaria tenuis*
   - Tabtoxin or wild fire toxin: *Pseudomonas tabaci*
   - Phaseolotoxin: *Pseudomonas syringae* pv. *phaseolicola*
C) Plant X Pathogen interaction

Amylovorin: *Erwinia amylovora* (Fire blight of apple and pears)

2) Phytotoxins:

- These are non-specific toxin
- There is no relationship between toxin production and pathogenicity of disease causing agent
Ex: Alternilaric acid – *Alternaria solani*

![Alternari acid](image)

3) Vivotoxins:

- These are produced in the infected host by the pathogen
- It is not itself the initial inciting agent of the disease
Ex: Fusaric acid - Wilt causing *Fusarium* sp.
Lycomarasmin - *Fusarium oxysporum* f.sp. *lycopersici*
Piricularin - *Pyricularia oryzae*

![Fusaric acid](image)
Classification based on specificity of toxins

<table>
<thead>
<tr>
<th>Host specific toxin</th>
<th>Non-host specific toxin</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Only to susceptible host of the pathogen</td>
<td>1. It also affect the physiology of the host</td>
</tr>
<tr>
<td>2. Primary determinants of disease</td>
<td>2. Secondary determinants of disease</td>
</tr>
<tr>
<td>3. Produce all the essential symptoms of the disease</td>
<td>3. Produce few or none of the symptoms of the disease</td>
</tr>
<tr>
<td>Ex: Victorin, T-toxin</td>
<td>Ex: Tentoxin, Tabtoxin</td>
</tr>
</tbody>
</table>

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14. ROLE OF GROWTH REGULATORS IN PLANT PATHOGENESIS

Growth regulators are of two types
1. Growth promoting substances
2. Growth inhibiting substances
The imbalance in growth promoting and growth inhibiting substances causes
- Hypertrophy (excessive increase in cell size)
- Atrophy (decrease in cell size)

1. Growth promoting substances
A) Auxins: Indole-3-acetic acid (IAA)
- It is continuously produced in young meristematic tissue and moves rapidly to older tissues

\[
\text{Indole-3-acetic acid}
\]

Functions:
- Regulates cell elongation and differentiation
- Increases permeability of the membrane
- Increases respiration
- Promotes synthesis of mRNA

How disease is induced:
Increased IAA results in hypertrophy
Ex: *Phytophthora infestans* (Late blight of potato)
*Ustilago maydis* (Maize smut)
*Plasmodiophora brassicae* (Club root of crucifers)
*Sclerospora graminicola* (Downy mildew of sorghum)
*Agrobacterium tumefaciens* (Crown gall of apple)
*Meloidogyne* (Root knot nematode)

Decreased IAA results in atrophy.

Ex: *Ralstonia solanacearum* (wilt of Solanaceous plants)

**B) Gibberellins:**
- First isolated from Gibberella fujikuroi bakanae or foolish seedling disease of rice
- Infected seedlings show abnormal elongation due to excessive elongation of internodes
- Best known gibberellin is Gibberellic acid

![Gibberellic acid](image)

**Functions:**
- Cell, stem and root elongation,
- Promote flowering and growth of fruits.
- It also induces IAA synthesis
- Ex: *Sclerospora sacchari*, (downy mildew of sugarcane)

**C) Cytokinins:**
- Isolated from herring sperm DNA
- Cytokinins, such as zeatin and isopentenyl adenosine (IPA) have been isolated from plants

![Zeatin and Isopentenyl adenosine](image)
Functions:

- cell growth and differentiation.
- It inhibits breakdown of proteins and aminoacids
- Cytokinin activity increases in club root, in crown galls and in rust infected bean leaves.

Ex: Green islands in bean (*Phaseolus vulgaris*)

2. Growth inhibiting substances

A) Ethylene:

It effects on plants, viz., chlorosis, leaf abscission, epinasty, stimulation of adventitious roots, fruit ripening

![Ethylene](image)

<table>
<thead>
<tr>
<th>Effect of ethylene</th>
<th>Pathogen</th>
<th>Disease</th>
</tr>
</thead>
<tbody>
<tr>
<td>1).Premature ripening in banana</td>
<td><em>Pseudomonas solanacearum</em></td>
<td>Moko wilt in banana</td>
</tr>
<tr>
<td>2) leaf epinasty in tomato</td>
<td><em>Fusarium oxysporum</em> f.sp. <em>lycopersici</em></td>
<td>Wilt in tomato</td>
</tr>
</tbody>
</table>

B) Abscissic acid:

- It exerts dormancy in seeds
- Closure of stomata,
- Inhibition of seed germination and growth
- Stimulated germination of fungal spores
- It is one of the factors involved in stunting of plants

![Abscissic acid](image)
C) Dormin / Abscissin II:

- Induces dormancy
- It acts as an antagonist of gibberellins
- Masks the effect of IAA
15. PLANT DISEASE EPIDEMIOLOGY

**Epidemiology**
- Epidemiology of plant diseases is essentially a study of the rate of multiplication of a pathogen and spread of the disease caused by it in a plant population
- It deals with outbreaks and spread of diseases in a population

**Importance of epidemiology:**
- It is useful in forecasting of a disease and management of a disease
- Terms compound interest and simple interest diseases were given by Vanderplank (1963) in his book “Plant Disease Epidemics and control”

Difference between Compound interest disease & Simple interest disease

<table>
<thead>
<tr>
<th>Compound interest disease</th>
<th>Simple interest disease</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Also called as polycyclic</td>
<td>1. Also called as monocyclic</td>
</tr>
<tr>
<td>2. Disease increase as analogous to compound interest in money (interest gets interest)</td>
<td>2. Disease increase as analogous to simple interest in money (interest is added only at the end)</td>
</tr>
<tr>
<td>3. Spores produce at rapped rate</td>
<td>3. Spores produce at very slow rate</td>
</tr>
<tr>
<td>4. Disseminate by air</td>
<td>4. Dissemination by soil and seed</td>
</tr>
<tr>
<td>5. Incubation &amp; sporulation period is short</td>
<td>5. Incubation &amp; sporulation period is long</td>
</tr>
<tr>
<td>6. Several generations of the pathogen in the life of a crop</td>
<td>6. Only one generations of the pathogen in the life of a crop</td>
</tr>
</tbody>
</table>

**Ex:** Rust of cereals

**Ex:** Smut of wheat barley & Sorghum

**Disease Triangle:**
Interactions of three components of disease, i.e., host, pathogen and environment, can be visualized as a disease triangle.
**Disease Pyramid or tetrahedron**

Disease triangle can be expanded to include two more components, time and humans.

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**Essential components/conditions for an Epiphytotic**

1. Host factors
2. Pathogen factors
3. Environmental factors

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### 1. Host factors
- i) Distance of susceptible plants from the source of primary inoculum
- ii) Abundance and distribution of susceptible hosts
- iii) Disease proneness in the host due to environment
- iv) Presence of suitable alternate or collateral hosts

---

### 2. Pathogen factors
- i) Presence of virulent/aggressive isolate of a pathogen
- ii) High birth rate
- iii) Low death rate of the pathogen
- iv) Easy and rapid dispersal of the pathogen
- v) Adaptability of the pathogen

---

### 3. Weather factors

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**1. Host factors**

a) Distance of susceptible plants from the source of primary inoculum:

- Longer the distance from the source of survival of the pathogen, longer will be the time will be required more for the buildup of an Epiphytotic in a susceptible crop
b) Abundance and distribution of susceptible hosts:
   ❖ Continuous cultivation of a susceptible variety over a large contiguous area helps in the buildup of the inoculum and improves the chances of epiphytotics

c) Disease proneness in the host due to environment:
   ❖ Susceptibility is genetically controlled but it can be induced by environment and other

d) Presence of suitable alternate or collateral hosts:
   ❖ Host plants help in the survival of inoculum of different pathogens in off season
     Barbery - *Puccinia graminis tritici*
     Grass host- *Pyricularia oryzae*

2. Pathogen factors:
   a) Presence of virulent/aggressive isolate of a pathogen:
      ❖ Rapid cycle of infection is essential, and successful infection can be caused only by virulent isolates of the pathogen

   b) High birth rate:
      ❖ The capacity to produce enormous quantity of spores that are adapted to long distance dissemination in a short time

   c) Low death rate of the pathogen:
      ❖ Low death rate of the pathogens in those in which the causal agent is systemic and protected by the plant tissues

   d) Easy and rapid dispersal of the pathogen:
      ❖ Ability of a pathogen to cause dependent on its dispersal rate
        Ex: Fungal spores - wind, water
        Viruses - insect vectors
        Bacteria - rain splashes and water

   e) Adaptability of the pathogen:
      ❖ Most of the pathogens causing epiphytotics adapt themselves to various adverse conditions
3. Weather factors
   - Weather conditions such as, optimum temperature, moisture, light, are very essential for the development of an epidemics
   - Science which deals with the relationship between weather and epiphytotics is called metereopathology
16. REMOTE SENSING

**Definition:** Remote sensing is estimating an object /phenomenon without being in physical contact with it

**Objectives of remote sensing in plant Pathology**
1. Assessment of disease over a vast area
2. To know the relationship of diseases and environment
3. To know the origin and development of epidemics
4. Quantitative assessment of the disease

**Remote sensing techniques of importance to Plant Pathology**
1. Aerial photography
2. Satellite remote sensing

1. Aerial photography
   - Aerial photography can detect objects on land over a larger area
   - Colwell (1956) first used remote sensing technique for monitoring stem rust of wheat and diseases of citrus through infrared films

2. Satellite Imaging
   Weather satellites
   - Often cyclones create heavy clouds with rains and an anti-cyclone creates a cloudless sky
   - All these can be effectively monitored by weather satellites
   - Sequential pictures show the movement of these systems before they arrive in an area

**Environmental factors or non – parasitic diseases**
1. Diseases in which no animate agents or parasite is associated
2. They cannot be transmitted from one diseased plant to healthy plant called as non-parasitic diseases or physiological disorders
3. These disease are disturbance in the plant system by improper environmental conditions in air or soil.
Freezing injury:
   Ex: Tissue decay in potatoes & sweet potatoes

High temperature:
   Ex: Heat canker of flax
       Tip burn in betel vine

High soil moisture:
   Ex: Edema or swelling in cabbage

Reduced supply of oxygen to the roots:
   Ex: Dry leaf disease or Tip burn in rice
       Black heart of potato

Injurious atmosphere
   Ex: Apple scald
       Black tip of mango
Mineral deficiency:

- Red leaf of cotton (Mg)
- Khaira disease of rice (Zn)
- White bud in maze (Zn)
- Whip tail of cauliflower (Mb)
- Coconut pencil point (Micronutrient)
- Blossom end rot (Ca)

Iatrogenic disease

Effect of plant protection chemical resulted in the appearance of new disease or increase in the disease already present

Ex: Zineb controlling downy mildew in grapes but increases the incidence of powdery mildew and botrytis

Distortion in papaya and cotton due to 2, 4 D (herbicide) injury
17. PRINCIPLES OF PLANT DISEASE MANAGEMENT

Management:
It conveys a concept of continuous process which is based not only on the principle of eradication of the pathogen but mainly on the principle of minimizing the damage or loss below economic injury level

Importance:

➢ Plant diseases are important because of the losses (qualitative and quantitative) they cause
➢ At sowing of the crop and consumption of the produce
➢ Measures taken to prevent and reduce the amount of inoculum the disease and finally minimize the loss caused by the disease are called as management practices

Essential considerations in plant disease Management:

➢ Benefit-cost ratio
➢ Procedures for disease control should fit into general schedule of operations of crop production
➢ Control measures should be adopted on a co-operative basis over large adjoining areas
➢ Knowledge aspects of disease development is essential for effective economical control

Information is needed on the following aspects

a) Cause of a disease
b) Mode of survival and dissemination of the pathogen
c) Host parasite relationship
d) Effect of environment on pathogenesis in the plant or spread in plant population

➢ Prevention of disease depends on management of primary inoculum
➢ Integration of different approaches of disease management is always recommended
General principles of plant disease management

1. Avoidance:
   - Avoiding disease by planting at times when, or in areas where, inoculum is ineffective due to environmental conditions, or is rare or absent

2. Exclusion of inoculum:
   - Preventing the inoculum from entering or establishing in the field or area where it does not exist

3. Eradication:
   - Reducing, inactivating, eliminating or destroying inoculum at the source

4. Protection:
   - Preventing infection by chemical toxic barrier between the plant surface and pathogen

5. Disease resistance (Immunization):
   - Preventing infection or reducing effect of infection by improvement of resistance in it by genetic manipulation or by chemical therapy
GENERAL PRINCIPLES OF PLANT DISEASE MANAGEMENT

1. Avoidance
   a) Proper selection of geographical area
   b) Proper selection of the field
   c) Time of sowing
   d) Disease escaping varieties
   e) Proper selection of seed and planting material

2. Exclusion
   a) Seed inspection and certification
   b) Plant quarantine regulation

3. Eradication
   a) Domestique quarantine
   2. Foreign quarantine
   3. Total embargoes

4. Protection

5. Disease resistance

I. Avoidance of the pathogen:
   a) Proper selection of geographical area:
      ➢ Many fungal and bacterial diseases are more severe in wet areas than in dry areas.
      ➢ Cultivation of bajra in wet areas is not profitable due to the diseases, smut (Tolyposporium penicillariae) and ergot (Claviceps microcephala)

b) Proper selection of the field:
   ➢ Raising of a particular crop year after year in the same field makes the soil sick, where disease incidence and severity may be more.
   Ex: Wilt of redgram,
   Late blight of potato - Phytophthora infestans
   Green ear of bajra - Sclerospora graminicola
c) Time of sowing:
   - Alteration of date of sowing can help in avoidance of favourable conditions for pathogen
     Ex: *Rhizoctonia* root rot of redgram is more severe in the crop sown immediately after the rains

d) Disease escaping varieties:
   - Certain varieties of crops escape the disease damage because of their growth characteristics
     Ex: Early maturing varieties of wheat or pea escape the damage due to *Puccinia graminis tritici* and *Erysiphe polygoni*

e) Proper selection of seed and planting material:
   - Material from healthy sources will effectively manage the diseases
   - Potato seed certification or tuber indexing is followed for obtaining virus free seed tubers
   - Citrus bud wood certification programme will help in obtaining virus free planting material

II. Exclusion of the pathogen:
These measures aim at preventing the inoculum from entering or establishing in the field or area where it does not exist.

a) Seed inspection and certification:
   - Crops grown for seed purpose are inspected periodically for the presence of diseases that are disseminated by seed
   - Necessary precautions are to be taken to remove the diseased plants in early stages, and then the crop is certified as disease free

b) Plant quarantine regulation:
   - It is “a legal restriction on the movement of agricultural commodities for the purpose of exclusion, prevention or delaying the spread of the plant pests and diseases in uninfected areas
Plant quarantine laws were first enacted in France (1660), followed by Denmark (1903) and USA (1912).

In India, plant quarantine rules and regulations were issued under Destructive Insects and Pests Act (DIPA) in 1914. In India, 16 plant quarantine stations are in operation by the “Directorate of plant protection and quarantine” under the ministry of food and agriculture, government of India.

Plant quarantine measures are of 3 types.

**Domestic quarantine:**
- Rules and regulations issued prohibiting the movement of insects and diseases and their hosts from one state to another state in India is called domestic quarantine.
- Domestic quarantine in India exists for Two pests (Rooted scale and Sanjose scale) and Three diseases (Bunchy top of banana, banana mosaic and wart of potato).

Bunchy top of banana: It is present in Kerala, Assam, Bihar, West Bengal and Orissa.
Banana mosaic: It is present in Maharashtra and Gujarat.
Wart of potato: It is endemic in Darjeeling area of West Bengal, therefore seed tubers are not to be imported from West Bengal to other states.

**2. Foreign quarantine:**
- Rules and regulations issued prohibiting the import of plants, plant materials, insects and fungi into India from foreign countries by air, sea and land.

**1. Airports:**
- Bombay (Santacruz), Calcutta (Dum Dum), Madras (Meenambakam), New delhi (Palam, Safdarjung) and Tiruchurapally.
2. **Sea ports:**

➢ Bombay, Calcutta, Vishakapatnam, Trivandrum, Madras, Tuticorin, Cochin and Dhanushkoti.

3. **Land frontiers:**

➢ Hussainiwala (Ferozpur district of Punjab), Kharla (Amritsar district of Punjab) and Sukhiapokri (Darjeeling district of West Bengal)

3. **Total embargoes:**

➢ Total restriction on import and export of agricultural commoditie

**Phytosanitary certificate:**

It is an official certificate from the country of origin, which should accompany the consignment without which the material may be refused from entry

**III. Eradication:**

These methods aim at breaking the infection chain by removing the foci of infection and starvation of the pathogen (destruction of sources of primary and secondary inoculum)

It is achieved by

a) Rouging:

➢ Removal of diseased plants or their affected organs from field

Ex: yellow vein mosaic of bhendi, khatte disease of cardamom

b) Eradication of alternate and collateral hosts:

➢ Eradication of alternate hosts will help in management of many plant diseases

Ex: Barbery eradication programme in France and USA reduced the severity of black stem rust of wheat

Ex: Eradication of _Thalictrum_ species in USA to manage leaf rust of wheat caused by _Puccinia recondita._
c) Crop rotation:
- Continuous cultivation of the same crop in the same field helps in the perpetuation of the pathogen in the soil
- Soils which are saturated by the pathogen are often referred as sick soils
- To reduce the incidence and severity of many soil borne diseases, crop rotation is adopted
  Ex: Panama wilt of banana (long crop rotation)
  - Wheat soil borne mosaic (6 yrs) and
  - Club root of cabbage (6-10 yrs)

d) Crop sanitation:
- Collection and destruction of plant debris from soil will help in the management of soil borne facultative saprophytes as most of these survive in plant debris
- Collection and destruction of plant debris is an important method to reduce the primary inoculum

e) Manures and fertilizers:
- The deficiency or excess of a nutrient may predispose a plant to some diseases
- Excessive nitrogen application aggravates diseases like stem rot, bacterial leaf blight and blast of rice
- Phosphorous and potash application increases the resistance of the host Addition of farm yard manure or organic manures such as green manure, 60-100 t/ha, helps to manage the diseases like cotton wilt, Ganoderma root rot of citrus, coconut

f) Mixed cropping:
- Root rot of cotton (*Phymatotrichum omnivorum*) is reduced when Cotton is grown along with sorghum
- Intercropping sorghum in cluster bean reduces the incidence of root rot and wilt (*Rhizoctonia solani*)
g) Summer ploughing:
   ➢ Ploughing the soil during summer months expose soil to hot weather which will eradicate heat sensitive soil borne pathogens

h) Soil amendments:
   ➢ Application of organic amendments like saw dust, straw, oil cake, will effectively manage the diseases caused by *Pythium*, *Phytophthora*, *Verticillium*,
   Ex: Application of lime (2500 Kg/ha) reduces the club root of cabbage by increasing soil pH to 8.5
   Ex: Application of Sulphur (900 Kg/ha) to soil brings the soil pH to 5.2 and reduces the incidence of common scab of potato (*Streptomyces scabies*).

i) Changing time of sowing:
   ➢ Pathogens are able to infect susceptible plants under certain environmental conditions
   ➢ Alternation in date of sowing can help avoidance of favourable conditions for the pathogens.
   Ex: Rice blast can be managed by changing planting season from June to September/October

j) Seed rate and plant density:
   ➢ Close spacing raises atmospheric humidity and favours sporulation by many pathogenic fungi.
   ➢ A spacing of 8’X8’ instead of 7’X7’ reduces sigatoka disease of banana due to better ventilation and reduced humidity.

k) Irrigation and drainage:
   ➢ The amount, frequency and method of irrigation
   ➢ High soil moisture favours root knot and other nematodes and the root rots
   Ex: *Sclerotium*,
      *Rhizoctonia*, *Pythium*,
      *Phytophthora*, *Phymatotrichum*,

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Physical methods

a) Soil solarization:
- Soil solarization or slow soil pasteurization is the hydro/thermal soil heating accomplished by covering moist soil with polyethylene sheets as soil mulch during summer months for 4-6 weeks.
- Soil solarization was developed for the first time in Israel (Egley and Katan) for the management of plant pathogenic pests, diseases and weeds.

b) Soil sterilization:
- Soil can be sterilized in greenhouses and sometimes in seed beds by aerated steam or hot water
- At about 50°C, Nematodes, Oomycetous
- At about 60 and 72°C, fungi and bacteria are killed
- At about 82°C, weeds, bacteria and insects are killed
- Heat tolerant weed seeds and TMV are killed at boiling point (95-100°C)

iii. Hot water or Hot air treatment:
- Hot water treatment or hat air treatment will prevent the seed borne and sett borne infectious diseases
- Hot water treatment of seeds, bulbs and nursery stock
- Hot water treatment is used for controlling sett borne diseases of sugarcane [whip smut, grassy shoot and red rot of sugarcane (52°C for 30 min)] loose smut of wheat (52°C for 10 min)

Biological methods

Definition:
Biological control is the reduction of inoculum density or disease producing activity of a pathogen or a parasite in its active or dormant state by one or more organisms accomplishing naturally or through manipulation of the environment of host or antagonist by mass introduction of one or more antagonists
Hyperparasitism:
➢ Direct parasitism or lysis and death of the pathogen by another micro-organism when the pathogen is in parasitic phase is known as hyperparasitism.
Ex: *T. harzianum* parasitize and lyse the mycelia of *Rhizoctonia* and *Sclerotium*

Hyperparasitism

**Important fungal biocontrol agents:**
Species of Trichoderma, viz., *T. harzianum, T. viride, T. virens (Gliocladium virens)* are used as biocontrol agents against soil borne diseases, such as, root rots, seedling rots, collar rots, damping off and wilts caused by the species of *Pythium, Fusarium, Rhizoctonia, Macrophomina, Sclerotium, Verticillium,*

Formulations of biocontrol agents available:
➢ *T. viride* (Ecofit, Bioderma in India)
➢ *G. virens* (GlioGard in USA)
➢ *T. harzianum* (F-Stop in USA)
➢ *T. polysporum* (BINABT)

**Important bacterial biocontrol agents:**
➢ *Pseudomonas fluorescens* (Dagger-G against damping off of cotton seedlings in USA)
➢ *Bacillus subtilis* (Kodiak against damping off and soft rot in USA)
➢ Agrobacterium radiobacter K-84 (Gallex or Galltrol against crown gall of stone fruits caused by *Agrobacterium tumefaciens*)
PROTECTION
The prevention of the pathogen from entering the host or checking further development in already infected plants by the application of chemicals is called protection and the chemicals used are called protectants

Therapy
Means cure of a disease, in which fungicide is applied after the pathogen is in contact with the host. Chemicals used are called therapeutants

Fungicide
Any agent (chemical) that kills the fungus

Fungistat
Some chemicals which do not kill fungi, but simply inhibit the fungus growth Temporarily

Antisporulant
The chemical which inhibits spore production without affecting vegetative growth of the fungus

Fungicides are classified into three categories
1. Protectants:
   - Effective only when used before infection of pathogen
     Ex: Zineb, sulphur, captan, Thiram (Contact fungicides)
2. Eradicants:
   - Eradicate the dormant or active pathogen from the host
     Ex: Lime sulphur, Dodine
3. Therapeutants:
   - Inhibit the development of a disease syndrome in a plant when applied after infection by a pathogen
     Ex: Systemic fungicides
CLASSIFICATION OF FUNGICIDES

Copper fungicides
- preparatory copper fungicides
  - 1. Bordeaux mixture
  - 2. Bordeaux paste
  - 3. Burgundy mixture
  - 4. Cheshunt compound
  - 5. Chaubattia paste

Sulphur fungicides
- Proprietary copper fungicides
  - 1. Copper oxychloride
  - 2. Cuprous oxide
  - 3. Copper hydroxide

Heterocyclic nitrogenous compounds
- 1. Captan
- 2. Folpet
- 3. Captanil
- 4. Iprodione
- 5. Vinclozolin

Miscellaneous fungicides
- 1. Chlorothalonil
- 2. Dinocap
- 3. Dine

Systemic fungicides

SULPHUR FUNGICIDES

Inorganic sulphur fungicides
- 1. Lime sulphur
- 2. Sulphur dust
- 3. Wettable sulphur

Organic sulphur compounds
- Dialkyl Dithiocarbamates
  - 1. Ziram
  - 2. Ferbam
  - 3. Thiram

Monoalkyl dithiocarbamates
- 1. Nambam
- 2. Zineb
- 3. Vapam
- 4. Maneb

SYSTEMIC FUNGICIDES

1. Acylalanines
   - Metalaxyl
   - Benalaxyl

2. Aromatic hydrocarbons
   - Chloroneb

3. Benzimidazoles
   - Carbendazim
   - Benomyl
   - Thiabenazole

4. Aliphatics
   - Prothiocarb
   - Propamocarb

5. Oxathins or carboximides
   - Carboxin
   - Oxycarboxin

6. Imidazoles
   - imazalil
   - Fanapanil

7. Morpholines
   - Tridemorph

8. Organophosphate
   - Iproxynphos
   - Ediphenphos

9. Alkylphosphonates
   - Aluminium Tris

10. Pyrimidines
    - Fenarimol

11. Thiophanates
    - Thiophanate
    - Thiophanate methyl

12. Triazoles
    - Triadimefon
    - Tricyclazole
    - Bitertanol
    - Hexaconazole
    - Propiconazole
    - Mycelbutanil

13. Strobilurins
    - Azoxystrobin
    - Kresoxim methyl
Classification of fungicides based on method of application

1. Seed protectants:
   Ex. Captan, thiram, carbendazim, carboxin
2. Soil fungicides (preplant):
   Ex. Bordeaux mixture, copper oxy chloride, Chloropicrin, Formaldehyde, Vapam,
3. Soil fungicides:
   Ex. Bordeaux mixture, copper oxy chloride, Captan, PCNB, thiram
4. Foliage and blossom:
   Ex. Capton, ferbam, zineb, mancozeb, chlorothalonil
5. Fruit protectants:
   Ex. Captan, manebl, carbendazim, mancozeb
6. Eradicants:
   Ex. Lime sulphur
7. Tree wound dressers:
   Ex. Boreaux paste, chaubattia paste
**Host Plant Resistance (Immunization)**

**Disease resistance:**
It is the ability of a plant to overcome completely or in some degree the effect of a pathogen or damaging factor

**Susceptibility:**
The inability of a plant to resist the effect of a pathogen

**Advantages of resistant varieties:**
- Most simple, practical, effective and economical method of plant disease management.
- Save time, energy and money spent on other measures of control
- Non-toxic to human beings, animals and wild life
- Do not pollute the environment
- Effective only against the target organisms
- It is inherited and therefore permanent at no extra cost

**Disadvantages:**
- Breeding of resistant varieties is a slow and expensive process
- Resistance of the cultivar may be broken down with the evolution of the pathogen

**Types of resistance:**

1. **Vertical resistance:**
   - When a variety is more resistant to some races of the pathogen than others, is called vertical resistance (race-specific resistance)
   - Vertical resistance is usually governed by single gene
   - It is unstable

2. **Horizontal resistance:**
   - When the resistance is uniformly spread against all the races of a pathogen, is called horizontal /generalized /non specific /field /qualitative resistance.
   - Horizontal resistance is usually governed by several genes
   - It is more stable
3. **Monogenic resistance:**
   ❖ When the defense mechanism is controlled by a single gene pair, is called monogenic resistance

4. **Oligogenic resistance:**
   ❖ When the defense mechanism is controlled by a few gene pairs, is called oligogenic resistance

5. **Polygenic resistance:**
   ❖ When the defense mechanism is controlled by many genes is called polygenic resistance
18. INTEGRATED PLANT DISEASE MANAGEMENT

IPDM involve management systems which utilize compatible combinations of all the available techniques to keep the pathogen population below the economic threshold level (ETL)

**Main components of IPDM:**
1. Cultural practices
2. Regulatory measures (quarantine)
3. Chemical methods
4. Biological methods
5. Physical methods
6. Genetic engineering

**Main strategies of IPDM**
1. Need based application of pesticides
2. Encouragement and enhancement of biocontrol agents
3. Use of resistant or tolerant cultivars of plants
4. Modification of cultural practices
5. Use of any other strategies that interrupts host-pathogen interactions

**Advantages of IPDM**
1. Avoids chemical pollution of soil, water, air and food products
2. Avoids development of resistance in the plant pathogens against fungicides
3. It is an eco-friendly strategy for management of plant diseases
4. It is an economically feasible approach
5. It is a multipronged strategy for efficient management of plant diseases
References


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