Plant Pathology

Introduction:

Plants are the sources of food for the man, animals and the microorganisms in this world. To meet the food requirements for the growing population of the world men are trying to protect the plants specially the crops from the damage or use by the insects and microorganisms. With the development of human knowledge about those microorganisms the science of plant pathology has been developed. Plant pathologists are the plant doctors just like human doctor. The major objective of plant pathologist is to reduce the losses caused by the plant diseases.

Importance of Plant Pathology:

Plant diseases are important because of the losses caused by them. The loss can occur in the field or in the store. On an average, diseases do 1/3 rd loss of food grain from the total loss caused by various means like insects, weeds, rodents etc. There are several evidences that the apple orchards of 10-15 years old are destroyed by collar rot otherwise survived and produced food for 25 to 30 years in India. Similarly in Nepal citrus decline is a serious problem and the orange orchards of 5-8 years are completely killed by root rot.

Irish Famine in 1845 - 49 was due to late blight of potato - *Phytophthora infestans*. It reduced the population from 80 to 60 lacs in Ireland. Many of them died of hunger, many of them faced malnutrition and some of them migrated to other country.

Wheat rust has been another disease that has appeared in epiphytotic form from time to time in many countries. This disease forced the farmers in many parts of the world to change the cropping pattern. Bengal Famine in 1943 was due to brown spot of rice - *Helminthosporium oryzae*. In Ceylon (1871 - 1893) the export of coffee was reduced by 93% because of coffee rust - *Hemileia vastatrix*. They had to cut the coffee plants and started planting tea. In Europe, downy mildew attacked the grape plants, grape yield was reduced greatly, and many grape wine factories were closed All these affected the economy of the country.

There are indirect losses caused by the pathogens. Some of the fungi when attack the food grains they produce toxin affecting the human and animal health. They may cause abortion, paralysis, bronchitis, stomach trouble etc.

Plant Pathology:

Plant pathology is a branch of agricultural, botanical or biological science that deals with the cause, etiology, resulting losses and management of plant diseases.
It has four major objects;

to study the living, non-living and environmental causes of plant diseases,
to study the mechanism of disease development by pathogens,
to study the interactions between the plant and the pathogen,
to develop the methods of controlling the disease and reducing the losses caused by diseases.

Plant disease:

Disease is a condition in which the functions of the organism are not properly discharged (Ward, 1901).

Plant Disease is defined as "any variation from the normal, as expressed either by the checking or by the interruption of physiological activities or by structural changes, which are sufficiently permanent to check development, cause abnormal formations or lead to premature death of a par of the plant or of the entire plant (Held, 1933)".

Disease is a malfunctioning process that is caused by continuous irritation (Horsfall and Dimond, 1959).

Causes, classification and general symptoms of plant diseases

A. Inanimate (non-living) causes:
1. Soil conditions
2. Atmosphere
3. Chemical injuries

I. Soil:
1. Soil moisture deficit or excess - It depends upon the nature of plants. Under water logging condition maize becomes yellow but rice can grow well.
2. Compaction of soil - Plants with tap root system will be affected. The roots may be ramped or the plants may be sick looking due to hard pan in the soil.
3. Soil crust - In case of heavy soil, after rain if there is drought crust is formed blocking the seedling to come out and the seedling looks sick.

Deficiency in nutritional level
Nitrogen deficiency is problem mainly on cereals which is expressed by yellowing of plants.
Boron deficiency is problem in vegetables and fruits. Browning of cauliflower, rotting of radish, fruit dropping and cracking.
Zinc deficiency is common problem in all types of crops. Khaira disease of rice is well known to all.

II. Atmosphere

Effect of high temperature - Seedlings collapse, sun scorch, sunburn, leaf burning.

Effect of low temperature - leaf discoloration to yellow, red, and brown; stem cankers and cracks because of intra-cellular ice formation.

Cold injury - If the winter is severe the banana leaves become black and dead due to protein denaturation of the cells.

Air pollutants:

1. Sulphur dioxide - The chief source is coal, other sources are refining of copper, led, zinc and nickel. The black tip of mango is caused because of the smokes coming from brick kilms containing So_2.
2. Hydrogen floride - It is highly toxic. It is released from different industries like aluminium, phosphatic fertilizer, and steel and petroleum refinery.

3. Ozone (O_3) - The sources of ozone are upper atmosphere, electrical storms, and photochemical reactions. It is also coming because of automobiles. Most of the No_2 reacts photochemically withO_3 and cause pollutants.

III. Chemicals injuries

Application of more amounts of agrochemicals including fertilizers causes toxicity. eg. 2,4-D kills chinopodium but high dose will affect the wheat also.

Faulty and improper application of fungicides and insecticides causes injuries to the plants. eg. cucurbits are very sensitive to chlorinated hydrocarbon group of insecticides, copper ion is toxic to plants so high dose application of copper fungicide may cause injury to the plants.

B. Animate (living) causes:

1. Mycoplasma-like organisms
2. Plant pathogenic bacteria
3. Fungi
4. Algae
5. Nematodes
6. Phanerogamic plant parasites

C. Viruses - neither living nor non-living entities

Classification of plant diseases:

On the basis of causes of plant diseases

1. Noninfectious diseases:
   They cannot be transmitted from the infected plants to the healthy plants because there is no involvement of living pathogens to cause the disease. eg. deficiency diseases
2. Infectious diseases:
   They are transmitted from infected plant to healthy plants and from one field to another field. There is involvement of pathogens such as fungi, bacteria, virus, nematodes etc.

On the basis of mode of spread and severity of infection

1. Sporadic diseases:
   When the diseases are occurring at very irregular intervals and locations and in relatively few instances, they are called sporadic diseases.
2. Endemic diseases:
   When the diseases are constantly occurring in a locality year after year from mild to severe form, they are called endemic diseases.
3. Epidemic or epiphytotic diseases:
   When the diseases are occurring periodically in a widespread area in severe form causing heavy damage, they are known as epidemic diseases.
4. Pandemic diseases:
   When the diseases are occurring in epidemic proportions over a very extensive region causing devastating damage in short period of time, they are called pandemic diseases.

On the basis of chief source of inoculum
1. Seed-borne diseases
2. Soil-borne diseases
3. Air-borne diseases

On the basis of parts of the plants infected
1. Foliar diseases
2. Fruit diseases
3. Root diseases

On the basis of plant species or crops
4. Rice diseases
5. Wheat diseases
6. Maize diseases
7. Millet diseases
8. Vegetable diseases, etc

General symptoms:

Symptoms are the changes in the morphological features of the plant that could be recognize by visual observation. eg. chlorosis, stunting, leaf spots, gall formation

Singns are the visible structures of the pathogen on the diseased part of the plants. eg. loose smut, powdery mildew

Symptoms due to visible pathogens:

1. **Mildew**: In this, the pathogen is seen as white, gray, brownish or purplish growth on the host surface.
Downy mildews - the superficial growth is cottony or downy growth likes a day old chicken feather eg. downy mildew of grape – *Plasmopara viticola*
Powdery mildews - enormous numbers of spores are formed on superficial growth of the fungus giving the host surface a dusty or powdery appearance. Eg. powdery mildew of pea – *Erysiphe polygoni*
2. **Rusts -** They appear as relatively small pustules of spores, usually breaking through the host epidermis. The pustules may be yellow, brown, or black in color. Boown rust of wheat – *Puccinia recondita*
3. **Smuts -** They appear as sooty or charcoal like powder usually on floral organs. Loose smut of wheat – *Ustilago tritici*
4. **White blisters -** They are found mainly on crucifers as white blister-like pustules, which break open the epidermis and expose powdery masses of spores. White blister of mustard – *Albugo candida*
5. **Sclerotia -** It is a compact, often hard, mass of dormant fungus mycelium looking black or dark brown in color. Sclerotia rot of vegetables – *Sclerotinia sclerotiorum*
6. **Scab -** It refers to roughened or crust like lesions which is scabby, dirty appearance. Eg. powdery scab of potato – *Spongospora subterranea*

Symptoms due to some effect or change in the host plant:

Hypertrophy - increase in size of the organ due to increase in size of cell, whereas hyperplassia - in crease in size of organ due to increase in number of cells. They are expressed as;

1. **Galls -** These malformations are more or less globose, elongated, or irregular in shape. They may be fleshy or woody. Smaller galls are called warts and larger galls are called knot. Stem gall of coriender – *Protomyces macrosporus*

2. **Leaf curl** - Leaves are twisted, curled, distorted due to over growth of tissues in localized areas of the leaves. Eg. peach leaf curl – *Taphrina deformance*
3. **Witches' broom** - Numerous slender branches arise fron a limited region in rather close cluster appearing like a broom. Eg. Witches broom - Mycoplasm

Atrophy or hypoplassia or dwarfing - Inhibition of growth resulting in stunting or dwarfing of the plant.

Necrosis - is the condition in which the death of cells, tissues, or organs has occurred as a result of parasitic activity of pathogens. They are expressed as;

Spots - are the localized lesion on host leaf consisting of dead and collapsed cells. Eg. leaf spot of broad leaf mustard – *Alternaria brassicae*
Anthracnose - necrotic and sunken ulcer like scattered lesions on the leaves, flowers, fruits and stems. Eg. mango anthracnose – *Colletotrichum sp*.
Canker - a localized necrotic lesion sunken beneath the surface or a dead area in the bark or cortex of stem especially on woody plant. Eg. citrus canker – *Xanthomonas campestris pv. citri*
Blight - rapid burning of leaves, branches, twigs or floral organs resulting their death. Eg. late blight of potato – *Phytophthora infestans*
Damping off - The stems of the seedlings near the soil surface become constricted, weak, and unable to bear the load of the upper part and they topple down. Eg. damping off of seedlings – *Pythium spp*.
Rots - maceration and disintegration of roots, fruits, tubers etc. root rot – Rhizoctonia solania

Symptoms caused by plant viruses

1. Stunting - the multiplication of cells may be reduced.
2. Local lesions - formation of small, usually necrotic lesions at the point of entry of viruses.
3. Mosaic - alternate patches of green and yellow color of leaves.
4. Ring spot - distinct chlorotic or necrotic rings on the leaves or fruits.
5. Rosette - short branching habit of plant growth.
6. Enation - tissue malformation or overgrowth.
7. Stem pitting - below the bark pits on the stem develop on citrus due to tristeza virus.

Definition, importance and general morphological characters of fungi

Fungi – are eukaryotic, spore bearing, achlorophyllous organisms that generally reproduce sexually and asexually, and whose usually filamentous, branched somatic structures are typically surrounded by cell walls containing chitin or cellulose, or both of these substances, together with many other complex organic molecules.

Importance of fungi:

Beneficial effects:

1. Many varieties of mushrooms are used for their nutritional and delicious food value.
2. Many fungi are important for decomposition of plant debris because they can use cellulose.
3. Fungi are used for many industrial processes involving fermentation e.g. bread, wines, beers, cheeses.
4. They are also used to produce organic acids, some drugs, vitamins and antibiotics.
5. Fungi are used as an important research tools by geneticists, cytologists and biochemists.

Harmful effects:

1. They cause the majority of known plant diseases; they also cause some disease to animals and man.
2. Many fungi are responsible for destruction of food, fabrics, leather and other goods manufactured from raw material subject to fungal attack.

General characteristics:

1. Fungi are the living organism devoid of chlorophyll. They look like a simple plant but do not possess stems, roots, leaves, and vascular system. They are usually thread like, multi-cellular and reproduce by means of spores.
2. The fungal thallus consists of microscopic threads or filaments that branch in all directions, spreading over or within the substratum utilized for food. The single filament is known as hypha, which mostly has cross walls at regular interval, which are called septa, but the vigorously growing hypha is coenocytic. The septa have central pore through the protoplasm moves from one cell to another.
3. The chemical composition of cell wall is not same in all fungi but mostly it contains polysaccharides together with protein, lipids, and other substances.
4. The mass of hyphae is called mycelium. The mycelium of parasitic fungi grows on the surface of the host either spreading between the cells (intercellular) or penetrating into the cells (intracellular). They send haustoria into the host cell to draw nutrients. The haustoria may be knob-like, elongated or branched.
5. Most fungi grow at 20 to 30 degrees Celsius. They obtain their food either by infecting living organism as parasites or by attacking dead organic matter as saprobes. They may be facultative parasites or facultative saprophytes or obligate parasites.
6. Fungi reproduce asexually i.e. without union of two nuclei and sexually i.e. By the union of two nuclei. The entire thallus may be converted into one or more reproductive structure, they

are known as holocarpic fungi but in most of the cases, only a portion of the thallus develops into reproductive organs, they are known as eucarpic fungi.

Asexual and sexual reproduction and types of fruiting bodies

Asexual reproduction:

It takes place in various ways.

1. Fragmentation – the hyphae breakup into their component cells, they are called arthrospores. If the cells get enveloped in a thick wall before they separate, then they are known as chlamydospores.
2. Fission – splitting of a cell into two daughters cells by constriction and formation of a cell wall.
3. Budding – production of small outgrowth from a parent cell which grows and gets separated, it is called blastospore
4. Production of spores – This is the most common method and found in many fungi. The spores may be hyaline to green, yellow, orange, red, brown and black. Their shape may vary from globose to oval, oblong and needle shaped. The spores produced in a sporangium (a sac like structure) are called sporangiospores. They may be motile i.e. zoospores or nonmotile i.e. aplanospore. The spores produced at the tip or sides of conidiophores are called conidia.

Sexual reproduction:

The process of sexual reproduction consists of three distinct phases.

Plasmogamy – union of two protoplasts which brings the haploid nuclei close together within the same cell.

Karyogamy – fusion of the two haploid nuclei resulting into one diploid zygote nucleus.

Meiosis – reduction division resulting into four haploid nuclei.

There are various methods by which the compatible nuclei are brought together in the process of plasmogamy, which are often known as methods of sexual reproduction. They are;

1. Planogametic copulation – Fusion of two naked gametes one or both of which are motile. There may be isoplanogametic copulation or anisoplanogametic copulation.

2. Gamentagial contact – Two gametangia of opposite sex come in contact and either dissolving the wall or by production of fertilization tube at the point of contact the nuclei are transferred from one cell to other cell (from antheridium to oogonium).

3. Gemetangial copulation – Fusion of the entire content of two contacting gamentangia.

4. Spermatization – Some fungi bear numerous, minute, uninucleate, spore-like male structures called spermatia, which are carried to female gamentagia special recessive hyphae to which they become attached.

5. Somatogamy – The two somatic hyphae come closer and exchange of nuclei etc. take place. Here the somatic cell taking the sexual function.

Types of fruiting bodies:

Fungi produce various types of fruiting bodies on / in which the fungal spores are produced. They may be asexual or sexual fruiting bodies.

Asexual fruiting bodies:

i) Pucnidium - It is spherical to oval-shaped more of less closed or with an opening, hollow fruiting body lined inside with conidiophores bearing conidia. Eg. *Phoma* sp.

ii) Acervulus – A mat of hyphae giving rise to short conidiophores closely packed together forming a bed like mass on which the conidia are produced. Eg. *Collectotrichum* spp.

iii) Synnema – A group of conidiophores cemented together and forming an elongated structure bearing conidia at their tips or along the length of the conidiophores. Eg. *Graphium* sp.

iv) Sporodochium – A cushion-shaped stroma covered with conidiophores bearing conidia at their tips. Eg. *Epicoccum* sp.

Sexual fruiting bodies

i) Cleistothecium

It is a completely closed ascocarp in which asci and ascospores are produced. Eg. *Erysiphae polygoni.*

ii) Perithecium

It is more or less closed ascocarp with an opening called ostiole at maturity in which asci and ascospores are produced. Eg. *Venturia inequalis*

iii) Apothecium

It is an open ascocarp lined with asci producing ascospores. Eg. *Agaricus bisporus, Pleurotus sajorcaju.*

iv) Ascostroma

It is a cavity (locule) formed by hyphal arrangement within a stroma. Eg.

Classification of fungi with their diagnostic characters

Superkingdom – Eukaryonta
Kingdom – Myceteae

Division 1 - Gymnomycota
Sub-division 1 – Acrasiogymnomycotina
Class - Acrasiomycetes
Sub-division 2 – Plasmodiogymnomycotina
Classes - 1. Protosteliomycetes
2. Myxomycetes

Division 2 – Mastigomycota
Sub-division - 1. Haplomastigomycotina
Classes - 1. Chytridiomycetes
2. Hypochytridiomycetes
3. Plasmodiophoromycetes
Sub-division - 2. Diplomastimycotina
Class - Oomycetes

Division 3 - Amastigomycota
Sub-division -1. Zycomycotina
Classes - 1. Zygomycetes
2.Trichomycetes
Sub-division - 2. Ascomycotina
Class - Ascomycetes

Sub-division -3. Basidiomycotina
Class - Basiomycetes
Sub-divisoion - 4. Deuteromycotina
Form-class - Deuteromycetes

1. Acrasiomycetes

No flagellated cells are produced except in one species. Formation of pseudoplasmodia takes place after an aggregation of myxamoebae, with lobose or filose pseudopodia. Sorocarp is usually stalked.

2. Protosteliomycetes

Myxamoebae forming sorocarp directly or after developing into plasmodia. Plasmodial streaming is unidirectional. Sexual reproduction is unknown.

3. Myxomycetes

They are having flagellated cells, fused to form zygote and develop into plasmodia with reversible streaming. They form various types of sporophores.

4. Chytridiomycetes

Aquatic, holocarpic, reproducing asexually through zoospores with uniflagellate whiplash type located posteriorly.

5. Hypochytridiomycetes

Similar to chytridiomycetes but the flagellum is tinsel type and located anteriorly.

6. Plasmodiophoromycetes

The somatic structure consists of plasmodium and asexual reproduction is through sporangia liberating zoospores with two flagella, both whiplash types located anteriorly and are unequal.

7. Oomycetes

Well-developed coenocytic mycelium, branched, asexual reproduction is through sporangia liberating the zoospores having two flagella growing in opposite direction. Of which one is whiplash and another is tinsel type.

8. Zygomycetes

Asexual reproduction is by aplanospores borne singly or in groups within sporangial sacs. Sexual reproduction is fusion of usually equal gamentangia resulting in the formation of zygosporangium containing a zygospore.

9. Trichomycetes

They are the parasites of arthropods. Asexual reproduction is by amoeboid cells and sexual reproduction is similar to zygomycetes.

10. Ascomycetes

They have well-developed mycelium but some are unicellular. Asexual reproduction is mainly by conidia. Sexual reproduction takes place by various ways. They produce ascospores in a sac like structure called ascocarps.

11. Basidiomycetes

They have well-developed mycelium with a long dikaryotic phase that give rise to various types of sporophores in which basidia bearing basidiospores are produced.

12. Deuteromycetes

They have either lost their sexual process because of evolution or unknown to us. Reproduce by producing various types of asexual spores the conidia.

Characteristics of some of the genera of fungi

Division	Mastigomycota
Sub-division	Haplomastigomycotina
Class	Chytridiomycetes
Order	Chytridiales
Family	Synchytriaceae

Genus *Synchytrium:*

It consists of more than 100 species that are parasitic on plants. The fungus is holocarpic, endobiotic and obligate parasite producing hypertrophy of the host plant. *Synchytrium endobioticum* causes black wart of potato. The fungus produce zoospores with single flagellum, whiplash type, located anteriorly. The zoospores when come in contact with the host surface, encyst, loose their flagella and penetrate the host, form sorus in the host cell and germinate producing zoospores in the vesicle. The zoospores fuse to develop zygote, which can also penetrate, the host and develop resting spore in the host get released in the soil. It survives for 3-4 years in the soil and when it germinates it produces zoospores.

Division	Mastigomycota
Sub-division	Haplomastigomycotina
Classes	Plasmodiophoromycetes

Order Plasmodiophorales
Family Plasmodiophoraceae

Genus ***Plasmodiophora*:**

The fungus is endoparasitic of vascular plant. It causes hypertrophy and hyperplassia of the host plant. *Plasmodiophora brassicae* causes club root diseases of brassicas. The fungal body is simply a plasmodium, which is capable of producing the zoospores each having two unequal flagella of whiplash type. The zoospores get attached with the rooot hair of the brassicas, encyst, germinate and penetrate the host. The interaction of host and pathogen will result in swelling of the roots forming a club shaped structure. The plasmodium is transformed into a mass of resting spores, which are released after decaying the infected roots, and survives in the soil for several years.

Genus *Spongospora***:**
Most of the characters of Spongospora are similar to that of the *Plasmodiophor*a but there are two main differences i) the primary and secondary zoospores are of same size but in *Plasmodiophora* the secondary zoospores are smaller in size and ii) the spores form spongy balls but they are free in *Plasmodiophora*. The.*Spongospora subterranea* causes the disease powdery scab of potato. The fungus upon germination form single amoeba like which penetrates through the eyes or root hair of potato. After penetration they may develop into zoospores or balls of resting spores.

Division Mastigomycota
Sub-division Diplomastimycotina
Class: Oomycetes
Order Peronosporales
Family Pythiceae

Genus *Pythium*
The *Pythium* spp. are soil-inhabitants. They cause seed rots, damping off, root rot and fruit rots. They can live as saprophyte or parasite on several plant species. The fungi produce slender, coenocytic hyphae. They grow inter and intracellularly in the host plant. They reproduce asexually producing sporangia and zoospores in the vesicle. The zoospores have two flagella, tinsel type long located anteriorly and whiplash type short located posteriorly. The mycelium produces antheridium and oogonium for sexual reproduction. The nucleus is passed from antheridium to oogonium, which is fused to form zygote, and the oosphere develops thick walled oospores.

Genus ***Phytophthora***

The *Phytophthora* spp. cause disease on large number of host plant. *P. infestans* causes the late blight of potato. The main differences between *Pythium* and *Phytophthora* are formation of indeterminate sporangiophores and sporangial germination. No vesicle is formed in *Phytophthora*. They produce sporangia or chlamydospores capable of germinating directly by germ tube or indirectly by producing zoospores. They produce oospores in their sexual cycle.

Division Mastigomycota
Sub-division Diplomastimycotina
Class: Oomycetes
Order Peronosporales
Family Peronosporaceae

Genus ***Sclerospora, Plasmopara and Peronospora***

They are also known as downy mildew fungi because the species of those genera are responsible to cause downy mildew diseases on various crop plants. Those genera are differentiated mainly on the basis of the sporangiophores. The sporangiophores of Sclerospora are rigid tout hyphae, branced upwards at the tips bearing sporangiospores. In *Plasmopara*, the sporangiophores are branched at right angle and in *Perenospora* the sporangiophores are branched at acute angle, tapering towards the tip, gracefully curved bearing sporangia at their tips.

Division Mastigomycota
Sub-division Diplomastimycotina
Class: Oomycetes
Order Peronosporales
Family Albuginaceae

Genus ***Albugo,***

It produces short, club-shaped, indeterminate sporangiophores, which bears chains of globose sporangia at their tips. The species of *Albugo* are obligate parasite causing the disease white rust or white blister. A. candida causes white rust of crucifers.

Division Amastigomycota
Sub-division Ascomycotina
Class Ascomycetes
Order Taphrinales
Family Taphrinaceae

Genera: *Taphrina*

The mycelium of this fungus is composed of septate hyphae growing intercellularly or subcuticularly or sub epidermally in the host. The asci are formed in a layer on the host surface from subcuticular mycelium that bursts through the cuticle. Each ascus consists of generally eight ascospores. *T. deformans* causes peach leaf curl and *T. maculans* causes leaf spot of turmeric.

Genus *Protomyces*

It is similar to *Taphrina* but it produces the resting spores called chlamydospores very commonly in the host.

Division	Amastigomycota
Sub-division	Ascomycotina
Class	Ascomycetes
Order	Erysiphales
Family	Erysiphaceae

Genus *Erysiphe*

The species of Erysiphe are obligate pathogen causing powdery mildew diseases on the host plants. The whitish appearance of the plant surface is due to the presence of conidiophores and conidia of the pathogen. They reproduce sexually producing ascospores in the asci borne in ascocarp, which is completely closed (cleistothecium). They parasitize more than 40,000 plant species. *E. polygoni* alone has been recorded on 352 host plants.

Division	Amastigomycota
Sub-division	Ascomycotina
Class	Ascomycetes
Order	Clavicipitales
Family	Clavicipitaceae

Genus *Claviceps*

It produces black hard compact body known as sclerotia, which is a resistant structure to survive the fungus under unfavourable environmental conditions. *C. purpurea* causes ergot disease of rye and *C. microcephala* causes ergot of bajra. When the scleria germinates they produce perithecial head consisting of many perithecia. The perithecia consist ascus in which needle shaped ascospores are produced.

Division Amastigomycota
Sub-division Basidiomycotina
Class Basiomycetes
Order Uredinales
Family Pucciniaceae

Genera: *Puccinia*

The species of *Puccinia* are obligate parasites of crop plants. Many species of *Puccinia* are macrocyclic heteroecious rust, which need more than one host to complete their life cycle. They have different stages.

Stage 0 Spermagonia bearing spermatia and receptive hyphae
Stage I Aecia bearing aeciospores
Stage II Uredinia bearing urediniospores
Stage III Telia bearing teliospores
Stage IV Basidia bearing basidiospores

The urediniospores are single celled, stalked and echinulated but the teliospores of these fungi have double celled and stalked. The diseases stem rust, brown rust, and yellow rust are caused by *P. graminis-tritici*, *P. recondite* and *P. striiformis*, respectively.

Genus Melampsora

The teliospores of these fungi are sessile, single –celled and formed in layers. *M. lini* causes flax rust. They are the autoecious rust completing their life cycle in a single host.

Genus *Uromyces*

It is also an aetoecious rust. *Uromyces fabae* causes rust of pea.

Division Amastigomycota
Sub-division Basidiomycotina
Class Basiomycetes
Order Ustileginales
Family Ustilaginaceae

Genus *Ustilago*

It has more than 300 species, many of them are parasitic on crop plants. *Ustilago maydis* – smut of maize, *U. tritici* – loose smut of wheat, *U. hordai* – covered smut of barley. The black powdery mass formed on the host are the teliospores of the fungi. They germinate by producing septate promycelium bearing sporidia. Secondary sporidia are formed by budding.

Division Amastigomycota
Sub-division Basidiomycotina
Class Basiomycetes
Order Ustil;eginales

Family Tilletiaceae

Genus *Tilletia*

The species of *Tilletis* differ from the species of *Ustilago* in the method of teliospores germination. The promycelium remains asepted. Typically 8 basidiospores are formed at the tip of promycelium. *Tilletia caries* and *T. foetida* causes wheat bunt, *T. indica* causes karnal bunt of wheat.

Division	Amastigomycota
Sub-division	Deuteromycotina
Form-class	Deuteromycetes
Form-order	Melanconiales
Form-family	Melanconiaceae

Genus *Colletotrichum,*

The species of *Colletotrichum* are facultative parasites, causing anthracnose diseases on leaves, young twigs and fruits of many plant species. Their mycelium is branched, septate, and hyaline. They produce the fruiting bodies called acervuli on the host bearing lot of sickle-shaped conidia. Their perfect stage is *Glomerell*a. Some of the important plant pathogenic species are;

Colletotrichum capsici – dieback and ripe fruit rot of chillies
C. falcatum – red rot of sugarcane
C. gloeosporioides – anthracnose of mango, citrus and apple
C. lindemuthianum – bean anthracnose

Division	Amastigomycota
Sub-division	Deuteromycotina
Form-class	Deuteromycetes
Form-order	Melanconiales
Form-family	Dematiceae

Genera Alternaria, Helminthosporium, (Drechslera, Bipolaris) , Cercospora, Pyricularia

Alternaria,

The fungi generally grow as a saprophyte on the decaying plant parts and in the soil. Some species are parasitic on higher plants. Leaf spots with concentric rings are produced by this fungus on the crop plants.. Some of the common species parasitic on plants are;

Alternaria brassicae – leaf spots of crucifers
A. brassiccicola – leaf spot of cole crops

A. solani – leaf spot of potato and tomato
A. porri – purple blotch of onion
A. triticina – leaf blight of wheat

Helminthosporium (Drechslera or Bipolaris)
They cause leaf spot and leaf blight on several crop species. Their conidiophores and conidia are brown in color. The conidia have pseudo septa. The end cells will germinate giving rise to mycelium. Their perfect stage is known as *Cochliobolus*. Some of the common species are;
Drechslera maydis – southern leaf blight of maize
D. turcicum – northen leaf blight of maize
Bipolaris. oryzae – brown leaf spot of rice
B. sorokiniana – leaf blight of wheat

Cercospora,
This genus includes about 700 species, which are parasitic on plants causing leaf spot or leaf blotch. Their perfect stage is known as Mycospherella. The conidia of *Cercospora* are hyaline and septate. Some of the important species are;
Cercospora arachidicola – leaf spot of ground nut
C. personata – learf spot of ground nut
C. cruenta – leaf spot of mung
C. spinosa – leaf spot of spinach

Pyricularia,
P. oryzae causes blast of rice. Its perfect stage is *Magnaporthe grisea*. The *Pyricularia* produces hyaline, pyriform two septed conidia with the basal papilla.

Division	Amastigomycota
Sub-division	Deuteromycotina
Form-class	Deuteromycetes
Form-order	Melanconiales
Form-family	Tuberellaceae

Fusarium,
The Fusarium species can live in the soil saphrophytically. They are weak parasites causing the disease like wilt in many crop plants under suitable conditions. They can produce macro and micro conidia and chlamydospores. Some of the important species are:
Fusarium solani – root rot of many plants

F. moniliforme – wilt of maize
F. oxysporum – wilt of many plants

Division	Amastigomycota
Sub-division	Deuteromycotina
Form-class	Deuteromycetes
Form-order	Agonomycetales

Genus *Sclerotium,*
Sclerotium rolfsii causes wilt of lentil, chickpea, collar rot of ground nut. Their mycelium is shining silvery white. They produce brown , spherical, mustard seed like sclerotia. The sclerotia can survive in the soil during off-season of the crop plants.

Genus *Sclerotinia*
The fungus is cottony white growing on the host surface. In later stages they produce black sclerotia *for* their survival in the soil or remained mixed with the seeds of crop plants. *Scerotinia sclerotiorum* causes white blight of mustard, brinjal, chilli and many other crop plants.

Genus *Rhizoctonia*
The mycelium of this fungus is brown and they have slight constriction and septation near the branching. They produce brown sclerotia, which is the survival structural. The sclerotia can germinate to cause infection. *Rhizoctonia solani* has unlimited host plants.

Division	Amastigomycota
Sub-division	Deuteromycotina
Form-class	Deuteromycetes
Form-order	Melanconiales
Form –family	Moniliceae

Genus *Aspergillus* and *Penicillium*
They are mostly saprophytic fungi growing on woods, leather, bread etc placed in dampy places. *Aspergillus* may be yellow, green, brown, black in color whereas *Penicillium* is either green or blue in color. Their perfect stages are *Eurotium* and *Talaromyces* belonging to Ascomycetes group. They are used for various industrial products. Various acids, antibiotics are manufactured from them.

Bacteria

Baceteria are prokaryotic, unicellular organisms, which multiply by binary fission. The genetic materials are transferred from one cell to another bacterium by conjugation, transformation and transduction.
Bacteriophages are the group of viruses that infect specific bacteria, usually killing them. Morphologically, they are three types such as tadpole-shaped, spherical and filamentous.

The bacterial cells are of mainly three shapes, spherical, rod, and spiral, also referred as coccus (Pl. cocci), bacillus (bacilli), and spirillum (spirilla), respectively. Most of the pathogenic bacteria are rod shaped.
A typical bacterial cell consists of; cell wall, slime layer, protoplasm, chromosome, mesosome, plasmid, ribosome, vacuole and flagellum.
The bacteria move with the help of flagella. Based on number and arrangement of flagella the bacteria can be grouped into four groups.

1. Monotrichous - a single flagellum at one end of the cell.
2. Lophotrichous - two or more flagella at one or both ends of the cell.
3. Amphitrichous - one flagellum at each end.
4. Peritrichous - large number of flagella surrounding the cell.

Classification and characters of Plant Pathogenic bacteria

Several methods of classifications have been tried from time to time. Such as conventional taxonomy, numerical taxonomy and molecular taxonomy.

Kingdom – Prokarytae		
Class – Proteobacteria	Firmibacteria	Thallobacteria
Genus – *Erwinia*	*Bacillus*	*Streptomyces*
Pseudomonas	*Clostridium*	
Xanthomonas		
Xylella		

Characters of *Xanthomonas*
Straight rods of 0.1 – 0.7 x 0.7 – 1.8 um, motile with one polar flagellum, gram –ve, obligately aerobic, and strictly respiratory type of metabolism

Characters of *Pseudomonas*
They are straight or slightly curved rods, 0.5 – 1.0 x 1.5 – 5.0 um, gram –ve, motile with one to several polar flagella and aerobic. Strictly respiratory type of metabolism.

Characters of *Erwinia*
Straight rods, 0.5 –1.0 x 1.0 – 3.0 um, gram –ve, motile with peritrichous flagella except E. stewartii, facultative anaerobic, oxidase negative and catalase positive

Characters of *Agrobacterium*

Gram negative rods, 0.6 – 1.0 x 1.5 – 3.0 um, motile by 1 –6 peritrichous flagella, aerobic.

Characters of Streptomyces

Extensively branched vegetative hyphae, 0.5 – 2.0 um in diameter, forms chains of spores, aerobic, highly oxidative.

Some of the plant pathogenic bacteria and the diseases caused by them are;

Ralstonia solanacearum – Bacterial soft rot of tobacco, tomato, and potato

Pseudomonas syringe pv. glycinea – blight of soybean

Xanthomonas campestris pv. malvacearum – blight of cotton

Agrobacterium tumefaciens – crown gall of apple and pear

Erwinia amylovora – fire blight of apple and pear

Xylella fastidiosa – phony peach, citrus leaf blight

Streptomyces scabies – powdery scab of potato

Clavibactor spp. - ring rot of potato

Fastidious Vascular Bacteria – Fastidious phloem-limited bacteria were first observed in 1972 in the phloem of clover and later in citrus plant affected with the greening disease. In 1973 fastidious xylem-limited bacteria were observed in grape affected with pierce's disease.

Bacteria	**Fungi**	**Algae**
Mostly non-filamentous unicellular organisms.	Mostly filamentus multi-cellular organisms.	Mostly multicellular organism
Mostly lack chlorophyll or other pigments.	Always lack chlorophyll.	Mostly posses chlorophyll or other pigments.
Cell wall present	Cell wall present in true fungi,absent in slime mold.	Cell wall always present.
Nucleus absent	Nucleus always present.	Nucleus always present.
Multiplication by binary fission.	Multiplication by division or budding or production of asexual or sexual spores.	Multiplication by asexual or sexual methods.

Mycoplasma-like organisms:

Mycoplasmas have following main characters;

1. They are very small, unicellular, usually non-motile, prokaryotic organisms.

2. They can be grown in cell-free media forming typical 'fried egg' shaped colonies.
3. They are highly pleomorphic (various shape and size) showing small coccoid bodies, ring forms, and fine filaments, which may be branched.
4. They are bounded by a triple layer unit membrane without a rigid cell wall and lack the ability to synthesize cell wall material.
5. They are filterable through bacterial filters.
6. They are highly resistant or insensitive to penicillin but are inhibited by tetracyclines.
7. They are inhibited by specific antibody.
8. They usually require sterol for growth.

They cause the diseases like aster yellows, mulberry dwarf, potato witches' broom, little leaf of brinjal, small leaf of cotton, grassy shoot of sugarcane, rice yellow dwarf, pigeon pea sterility etc. They are transmitted by the leafhoppers.
Phytoplasmas (MLOs) – pear decline

Spiroplasma-like organisms:

It was reported from the citrus stubborn (Stunting, excessive proliferation of axillary buds, bunchy up-right growth, swelling and mottling of leaves, heavy flowering, excessive fruit drop and bitter flavor of fruits) from USA.
The Spiroplasms are similar to MLOs but the wall has about 20nm width (only 10nm in MLO). They may be helical, spiral, spherical, or ovoid in shape. They are temporarily checked by penicillin.
Spiroplasma citri – stubborn of citrus

Rickettsia-like organisms:

They are the obligate intracellular parasites in certain arthropods without causing disease on them but they cause several diseases in plants. They cannot be grown in cell free medium. Taxonomically they are very close to bacteria. The plant diseases suspected to be caused by them are; Xylem-limited group - Pierce's disease of grape, alfalfa dwarf, almond leaf scorch, and plum leaf scald. Phloem-limited group - rugose leaf curl of clover, citrus greening, and potato leaflet stunt. Non-tissue restricted - apple and carrot proliferations.

Virus

It has both living and non-living characters such as multiplication, infectiveness, mutations are living characters and particle, and precipitation are non-living characters.
W. M. Stanley (1938) could get the crystals form of TMV, which is still infectious.

Lwoff (1957) defined virus as "strictly intracellular, potentially pathogenic entities with an infectious phase and possessing only one type of nucleic acid either RNA or DNA, surrounded by protein coat, and multiplying in the form of their nucleic acid only and unable to grow or undergo binary fission".

The virus multiplies by replication or duplication using host ribosome. About 600 virus diseases of plants have been reported. All those plant viruses were reported to contain RNA except cauliflower mosaic virus and dahlia mosaic virus. They are the DNA virus. The particle shape of virus may be of rigid rod (TMV), flexible rod (Cowpea mosaic virus), spherical (Squash mosaic), polyhedral (Tulip yellow mosaic).

Viroid is only a fragment of RNA without protein coat. Viroid is a single stranded covalently closed circular RNA of low molecular weight that can infect plant cells, replicate and cause diseases.

Transmission of plant viruses:

The viruses are transmitted by sap, grafts, vectors, dodders etc under natural conditions.

1. Mechanical transmission

It is basically the manual transfer and deposition of biologically active virus to suitable sites in the living cells by sub lethal wounding or abrasion. The infected plant sample is grinded with phosphate buffer and the extract is taken mixed with carborundum powder and with the help of cotton swab the extract is absorbed and gently rubbed on the leaf surface of the susceptible host, then washed the leaf with distilled water dropping the water through wash bottle.

2. Graft transmission

Through grafting stock and scion some viruses are transmitted. The time required for the virus to get established in the healthy partner may vary from several days to a few weeks in herbaceous plants while in woody plants it may take several months to express symptoms. Some virus, which is not transmitted through graft are transmitted through dodder.

3. Seed transmission

Different parts of seeds may carry different types of viruses but those carried in the embryo is the most efficient one and regarded as the true seed transmission. Some of the seed transmitted viruses are also transmitted through pollen. Eg. bean common mosaic, squash mosaic, cucumber mosaic, soybean mosaic etc.

4. Vector transmission

There are different vectors transmitting viruses, however insect vectors are the most efficient one. Aphids, the most efficient one *Myzus persicae* alone can transmit more than 100 different types of viruses. White flies *Bemisia tabaci* is quite common vector which can transmit at least 25 different viruses. Mealybugs, Leafhoppers, plant hoppers, thrips, beetles, mites also transmit viruses. There are other vectors also such as nematodes (Xiphinema, Longidorus and Trichodorus) and fungi (*Olpidium brassicae*, *Polymyxa graminis* and *Spongospora subterranea*

Nematodes:

Nematodes are triploblastic, bilaterally symmetrical, unsegmented, pseudocelomate and vermiform animals. The body of nematode may be elongated, spindle shaped, fusiform tapering towards the ends, but the cross-section is always circular.
There are two groups of nematodes, plant parasitic and saprophytic. The parasitic nematodes have stylet with which they punctured the host cell. They may be ectoparasite, endoparasite, sedantary or migratory.

Classification of nematodes:
Phylum – Nematoda
Orders – Tylenchida and Dorylaimida

Family – Anguinidae	Genus – Anguina
Criconematidae	Criconemella
Pratilenchidae	Pratilenchus
Tylenchidae	Tylenchulus, Pratilenchus
Belonolaimidae	Belonilaimus
Hoplolaimidae	Hoplolaimus
Heterodoridae	Globodera, Meloidogyne
Longidoridae	Longidorus, Xiphinema
Trichodoridae	Trichodorus

Life cycle:
The life cycle plant parasitic nematode is usually very simple, with five distinct stages. The female nematodes lay eggs, which under goes a series of cell divisions, forming the first stage larvae. The first molt takes place in the egg, and the second stage larvae emerge

from the eggs. They will try to find proper host to feed. When they start feeding, they pass through three additional molts. Between 3rd and 4th molt, the sexual organs begin to develop.

After 4th molt the males do not feed on the host but they live as free living in the soil but the female continue to feed and become adult to lay eggs.

Characteristics of Anguna, Heterodera, Meloidogyne and Hirshmaniella

Anguna, spp. are found to attack all the above ground parts of the plants. They are never found in the roots. The second stage larvae remain in dormant stage in the seed. *A. tritici* causes whaet gall or ear cockle disease. The adult nematode measures 1.5 – 4 mm long. They have stylet with basal bulb.

Heterodera, spp. are known as cyst nematodes. They are parasitic on many plants such as sugarbeet, oats, clover, soybean etc. *H. avenae* causes molya disease of barley and wheat. The female nematodes are found attached on the host inserting their head inside the host plant and the body remains outside but the males and cyst are found in soil. Males are slender 1- 2 mm long, female lemon shaped 0.5 – 0.8 mm in length and 0.5 mm width. Cysts are dark brown and lemon shaped.

Meloidogyne spp. are called as root knot nematodes. They are parasitic on many plants such as tomato, brinjal, lady's finger, papaya etc., causing root knot disease. Females and 3rd or 4th stage larvae are sedentary parasites on many plants. Males and 2nd stage larvae are migratory and found in soil. Males are cylindrical 1 –2 mm long but females are saccate or spherical 0.8 mm long and 0.5 mm width.

Hirshmaniellia sp. It is rather large nematode measuring 1 –4 mm in length. It has stylet with basal bulb and the tail is generally pointed. *H. oryzae* causes root rot in rice. They are also found in soil.

Phanerogamic Plant Parasites:
A number of flowering plants are parasitic on economic plants and cause considerable damage.Based on parasitic nature they may be grouped as;

Stem parasites: a) entirely dependent (holoparasite) eg. *Cuscuta* on clover, alfalfa, flax, sugarbeet and onion.
b) partially dependent (semiparasite) eg. *Loranthus* on mango, fig and citrus.

2. Root parasites a) entirely dependent eg. *Orobanche* in tobacco, mustard, broad leaf mustard etc.
b) partially dependent eg. *Striga* in corn sugarcane, cereals, tobacco etc.

Principles of Plant Pathology

Saprophytes are those organisms, which grow on dead or decaying tissues of the plants or aniamals. eg. saprophytic fungi , saprophytic bacteria

Parasites are those organisms, which are dependent on other living organisms for their growth and existence. eg. parasitic fungi and bacteria

Obligate parasites are those organisms, which are strictly dependent on other living organisms for their growth and development. eg. *Erysiphe*, *Puccinia*, *Ustilago*

Facultative parasites are those organisms which, are ordinarily living as saprophytes but sometime they can live as parasites. eg., *Fusarium, Rhizoctonia, Scerotium*

Facultative saprophytes are those organisms which, are living mostly as parasites but sometimes they live as saprophytes. eg. *Phytophthora*, *Alternaria*, *Helminthosporium*

Pathogen is an organism, which cause disease in a particular host or a range of hosts.

Pathogenicity is the ability or capacity of a pathogen to cause disease in a particular host or a range of hosts. It can also be defined as general deposition of an organism sufficient to cause infection and produce the symptom of disease on the host/hosts.

In 1876 the bacteriologists Louis Pasteur and Robert Koch had proved that anthrax disease of cattle was caused by a specific bacterium. Soon after, in 1878 T.J. Burill for the first time proved that fire blight of apple and pear was caused by a bacterium.
Koch's postulate is followed to prove the Pathogenicity. It includes;
Constant association of the organism with the diseased host.
Isolation of the suspected pathogen from the diseased host and establishment of pathogen in pure culture.
Inoculation of disease free host with the pure culture of the suspected pathogen, with the resulting reproduction of the disease.
Reisolation of the pathogen in pure culture from the inoculated plant matching with the original culture isolated from the original diseased host.

Pathogenesis
When a pathogen attacks the plant, the development of disease is not a sudden effect. Chains of events are responsible for causing any disease. These stages, reactions, and interactions are arranged in sequence, which lead to disease development. The entire chain of events leading to disease development is known as pathogenesis or disease cycle. Therefore, pathogenesis includes inoculation, penetration, infection, incubation period, invasion, reproduction, dissemination, and over wintering or over summering of the pathogen.

1. **Inoculation -** is the process by which pathogens or their reproductive units are brought into contact with plants.

   Inoculum -The part of the pathogen population that encounters the host plant. In case of bacteria and virus they are carried as such but spores in case of fungi, eggs in case of nematode and seeds of parasitic plants as inoculum.
2. **Penetration -** is the entrance of the pathogen into the host.
   It may involve in penetration cuticle alone eg. Apple scab; penetration into the epidermal cells only eg. Powdery mildew; in most of the pathogens penetration go deep into the epidermal cells or intercellular spaces further progressing into the inner cells and tissue of the plants.
   Direct penetration takes place by the mechanical pressure of the pathogen or they may secrete enzymes to soften or dissolve the host surface and then apply the pressure.
   Indirect penetration takes place through the natural openings such as stomata, lenticels, and hydathodes.
3. **Infection -** is the process by which the pathogen establishes contact with the susceptible cells or tissues of the host and gets their nutrients from them.
   For infection to take place, the pathogen must be virulent, host must be susceptible, and the environment must be favorable.
4. **Incubation period -** is the time interval between infection of the plant and the first appearance of the disease symptoms on the plant. The length of incubation period varies with the type of pathogen and the environmental conditions from few days to weeks, months, or even years.
5. **Invasion -** refers to the later stages of infection during which the pathogen spreads more or less extensively into the tissue of the host. Invasion follows the establishment of infection. It is sometime called as colonization.
6. **Reproduction** - Once the pathogen established well with the host, they reproduce very fast in great numbers. Bacteria reproduce with in 20-30 minutes and produce millions within 10 hours. Virus multiplies by replication or duplication, which is even faster than bacteria. Fungi multiply by asexual and sexual spores. They are also very prolific, one smutted wheat seed consists of about 10 million spores.
7. **Dissemination -** Few pathogens have autonomous movement, which may vary from few millimeters to few meters. They are disseminated passively by wind, water, insect, human beings, and other animals.
8. **Over wintering or over summering -** The pathogen usually survives in the vegetative form in the host. In absence of crop host, they survive in the weed or other collateral hosts. Some of them produce resting spores such as oospores, sclerotia and survive during either summer or winter in absence of their hosts.

Disease forecasting and Principles of disease management

Survival and dissemination of plant pathogens

In absence or their cultivated host, animate pathogen must find some alternate source of their survival. The sources of survival can be grouped as.

I. Infected host as reservoir of inoculum.
II. Saprophytic survival outside the host.
III. Dormant spores and other structures in or on the host or outside the host.

I. Infected host as reservoir of primary inoculum:

They can be considered in three groups;

1. the cultivated host,
2. wild hosts of same family (collateral hosts)
3. wild hosts of different family (alternate hosts)

The fruit plants being perennial the pathogen infecting them can survive in active form year after year. eg. citrus canker (*Xanthomonas campestris*). In red rot of sugarcane caused by *Colletotrichum falcatum* survives on the infected sugarcane sets. In case of blat of rice (*Pyricularia grisea*), the pathogen survives in the weeds of Graminae family. In case of wheat rust (*Puccinia graminis tritici*) the pathogen survives in the barbery plant.

II.Saprophytic survival outside the host:

The facultative parasites are capable of surviving as saprophyte in absence of the crop host. Species of *Pythium, Rhizoctonia, and Sclerotium* survives in the soil and in the plant debris. Depending upon the type of pathogen the saprophytic survival may vary. Some of them survive for short period eg. *Fusarium, Verticillium*, others may survive for long time.

III.Dormant organs of pathogen as source of survival:

Plant virus and bacteria do not produce resting stage so they do not have dormant organs. The fungi, nematode, and phanerogams survive through their dormant or resting structures. Phanerogams produce seeds eg orobanche, striga. Nematodes can survive through their dormant structures like eggs, cysts, and galls. In case of fungi, they produce different dormant organs or structures for their survival and become a primary source of inoculum. Some of them produce conidia, chlamydospores, oospores, sclerotia which can survive in the soil. In some seed borne fungi, the dormant mycelium survives in the embryo of the seed and some of the dormant spores survive on or in the seed coat.

Dissemination - meaning and mode of dissemination

Dispersal of the inoculum for long or short distance is called dissemination. It is important not only for spread of the plant diseases but also for the continuity of the life cycle of the pathogens. The dispersal of plant pathogens may take place as;

Direct or Active or autonomous dispersal

Indirect or Passive dispersal

Direct or active or autonomous dispersal:

The autonomous dispersal of fungi, bacteria, viruses, and nematodes is accomplished through the agency of soil, seed, and plant organs during various agronomic operations.

Soil, as a means of autonomous dispersal - The soil-borne facultative parasites may grow to some distance in the soil. eg. *Rhizoctonia solani, Sclerotium rolfsii*. Some of them may produce zoospores, which can travel for some distance in the film of soil water eg. *Pythium, Phytophthora*. This may help them to find the host for infection. The pathogens may also be disseminated through the infested soil along with the farm equipment.

The seeds also serve for autonomous dispersal of the pathogens. The pathogens may be externally or internally seed-borne and they are carried along with the seed. Some pathogens may get concomitant contamination and disseminated along with the seed. eg. seeds of orobanche, striga, sclerotia etc. The vegetatively propagated plant organs may carry the pathogen. Virus, bacteria, and fungi are carried with the plant organs and get disseminated.

Indirect or Passive dispersal:

The passive dispersal of plant pathogens is accomplished through the agency of animal kingdom (human being, animals, insects, nematodes etc.), air , and water.

The human beings are the most important means for dispersal of pathogens from limited to far distance in the world. Vegetative propagation of fruits, ormentals, sugarcane, potato etc. helps in dispersal of pathogens. Export and import of seed or other planting material from one state to other state, from one country to another country helps in dissemination of plant pathogens. Insects are very efficient in disseminating the pathogens particularly virus and bacteria. The fire blight of apple (*Erwinia amylovora*) is transmitted by honeybees. Mainly the sucking insects like aphids and hoppers are responsible for transmitting virus diseases. Nematodes *Xiphinema, Longidorus* and *Trichodorus* transmit the virus. The nematode transmitted viruses have been divided into two groups on the basis of their particle shape. i) Nepo virus - are the polyhedral particles eg. tobaco and tomato ring spot. They are transmitted by *Xiphinema* and *Longidorus*. ii) Netu virus - are the tubular particles eg. pea early browning and tobacco rattle. They are transmitted by *Trichodorus*.

Dispersal through air:
The bacteria and virus are taken by air current along with the infected tissues of the host. Spores of many fungi are carried by the wind. The distance covered by these spores depends upon the velocity of the wind and the height attended by the spores. The uredospores of *Puccinia graminis tritici* carried from South America to North America.

Dispersal through water:
The spores are disseminated by rain splash to local areas. eg. Fire blight of apple. The seeds of phenerogams, nematode cysts, fungal mycelium, spores, and other resistant structures are taken to longer distance by water current.

Epidemiological studies

Epidemology - concept, analysis and use

Epidemology is mainly concerned with the spread of the disease. To establish the disease in epidemic or epiphytic form, there must be i) host plant at susceptible stage, ii) presence of virulence pathogen, and iii) presence of suitable environment for the pathogen.

Host plant - The susceptibility of host plant depends upon the;

i) Age of the plant - Depending upon the type of the pathogen, the susceptible age of the plant vary. eg. susceptible stage of rice to blast (*Pyricularia oryzae*) is the seedlings of about 21 days and at tillering stage. The susceptible stage of wheat to leaf blotch (*Bipolaris sorokiniana*) is milk to dough stage. Similarly, susceptibility of powdery mildew is increased with the increase of age of plant such as lettuce, pea, cucurbits.

ii) Virulence of the pathogen - The pathogen must have virulent genetic character. The other characters, which help the pathogen to become virulent, are high sporulation, active liberation, short life cycle etc.

iii) Suitable environment - Temperature and moisture play an important role for the development of disease to epiphytic condition. eg. Late blight of potato develops in epiphytic proportion when the night temperature is 10^0C, day temperature 18-20^0C, light rainfall followed by cloudy weather. Severe winter ie. temp. 10-12^0C and prolonged cloudy weather will favor for the development of white stem blight (*Sclerotinia sclerotiorum*) to develop in epiphytic condition on vegetables and rape seed and mustard. In general, high humidity above 90% is required for the development of disease. *Erysiphe polygoni* spores can germinate even at 0% humidity whereas *E. graminis* requires 100% humidity for the germination of the spores. Mineral nutrition also affects the pathogen to develop in epiphytic condition. High nitrogenous fertilizer supports the development of blast disease and low nitrogenous fertilizer favors the brown spot of rice.

Use of epidemology in control of diseases:
A compound interest type of disease is expressed by the following equation.

$x = X_0e^{rt}$ where, x = the amount of disease at a given time,
X_0 = the initial inoculum,
r = the average infection rate,
t = time during which the infection has occurred, and
e = natural log (value 2.7182818).

Based on the above equation control measures should be targeted to;
reduce X_0 , by sanitation, vertical resistance, and chemicals and other methods.
reduce r, by horizontal resistance, chemical protectants, and some cultural control measures.
reduce t, by sanitation, short duration varieties, early harvesting.

Pre-exposed and post-exposed defense mechanisms

Defense mechanism - structural (pre- and post-infection), physiological and biochemical (pre- and post-infection

The plants have tremendous ability to defend themselves from the attack of the pathogens. In nature, the plant is visited by a large number of pathogens but only very few of them are able to cause disease. It depends upon the genetic make-up of the host and that of the pathogen. There are strains of the pathogen that show a differential ability to attack the same host.

Structural defense:
Structures that affect the ability of the pathogen to penetrate the host may be existed before the entry of the pathogen or it may be formed after the entry in response of infection.
The pre-existing defense structures are waxes and cuticle, structures of epidermal cell wall, structures of natural openings, and internal structures.

Waxes and cuticle - Cuticle is the noncellular wax and cutin which covers the host surface. Wax being hydrophobic will not allow germinating the spores. The thickness

of the wax layer is important in developing resistance because it will be difficult to penetrate the thick wax by the germinating pathogen.
Structure of epidermal cell wall - The thickness and toughness of the cell wall is important. It may vary in different plants due to relative lignification or deposition of silicic acid. The

Pyricularia oryzae is unable to penetrate the lignified cell wall but they can penetrate the motor cells.

Structure of natural openings - Many fungi and bacteria enters through the natural openings such as stomata, hydathodes, lenticels. The fungus *Puccinia graminis tritici* can enter only through the stomata. In wheat variety Hope, the stomata open late and by that time, the water dry out and the germ tube die. Similarly, in the mandarin variety Szinkum, the stomata have very narrow entrance surrounded by elevated lips, which prevents water and bacteria from getting entrance. In apple due to small size of lenticels prevents the entry of bacteria *Pseudiomonas papulosum*.

Internarnal structures - The thickness and toughness of internal cell walls determines the growth of the pathogen. In case of angular leaf spot of cotton, the infection is limited in between the veins.

The post infection defense structures are histological defense, cellular defense, cytoplasmic defense, and necrotic or hypersensitive reactions.

1. Post infection histological defense - This structural defense consists of limiting the spread of pathogen in tissues by creating barriers through tissue differentiation and accumulation of chemical substances. These structures consist of cork layers, development of abscission layers, formation of tyloses, and deposition of gums, etc.

   When the plants are attacked by fungi, bacteria, some virus and nematodes the diseased cells becomes surrounded by cork layers. The cork layers are mostly formed in stem, roots, and unripe fruits. This will prevent further growth of the pathogens. eg. potato scab (*Streptomyces scabis*).

   The usual function of abscission layers is to separate the ripe fruits and old leaves from the plant. The abscission layers are formed surrounding the infected tissues, and the pectin material between the middle lamellae dissolved and the infected part will be cut off. eg. peach leaf spot (*Xanthomonas pruni*).

   Tyloses are outgrowths of the protoplasts of adjacent parenchyma in the xylem vessels. They create obstruction to the development of the pathogen in the vascular tissues. eg. wilt of sweet potato disease (*Fusarium oxysporum f.sp. batatas*).
   Gum deposition along the border of diseased tissues often serves as protective barrier against some viruses infecting stone fruits and the leaf spot and blast of rice.

2. Cellular defense structures - These structures include callus-like swellings of the cell wall and sheathing of penetrating hyphae of the pathogen. eg. scab of cucumber (*Cladosporium cucumerinum*). However, these are not strong defense structures.

3. Cytoplasmic defense - This is the last line of defense after penetration by the pathogen. The nucleus of the host cell enlarges divide into two and disintegrates which will slow the growth of the pathogens.

Sometimes the nucleus moves towards the tip of the hypha, encircles, and acts as defense. eg. wheat rust (*Puccinia graminis tritici*).

4. Necrotic or hypersensitive defense - When a pathogen penetrate the cell wall and come in contact to the protoplasm of host the nucleus moves towards the zone of infection and enlarges. Browning of the protoplasm takes place covering the whole cell and the cytoplasm disintegrates resulting in the death of the cell. Sometimes the cytoplasmic material is thickened and cut off from the healthy tissue and the growth of the pathogen is checked. eg. late blight of potato (*Phytophthora infstans*).

Biochemical defense:

Pre-existing biochemical defense -

1. Inhibitors released by the plant in its environment - The leaf and root exudates have great effect on the phyllosphere and rhizosphere microflora and fauna. The exudates contain different biochemicals such as amino acids, sugars, glycosides, organic acids, enzymes, alkaloides, nucleotides etc. These exudates may be ideal food for some of the microorganisms and some of them will inhibit the growth of other microorganisms. Tomato leaves secret chemicals that protect from the attack of *Botrytis cinerea*. Red scales of onion contain protocatechuic acid and catechol, the phenolic compounds, which protect from *Colletotrichum circinans*. Some linseed is resistant to wilt (*Fusarium oxysporum f.sp. lini*) due to the presence of hydrocynide in their root exudates.
2. Inhibitors present in the plant cell - Anti microbial substances are present in almost all plant species. However, only in few cases it has been observed providing resistance to disease. The resistant variety of potato against scab disease (Streptomyces scabies) contains high amount of chlorogenic acid. This phenolic compound is also toxic to *Meloidogyne* and *Verticillium*.
3. Lack of essential substances for growth of the pathogen - The fungus *Rhizoctonia solani* forms a cushion on the host surface from where a infection peg develops to penetrate the host. Certain chemical is required for the formation of the hyphal cushion. The chemical, not identified yet is absent in resistant variety.
4. Absence of common antigen - The plants do not produce antibody against the foreign antigen as does by the animal. However, serological studies with linseed rust (*Melampsora lini*) and angular leaf spot of cotton (*Xanthomonas malvacearum*), presence

of the pathogen protein (antigens) in the host ensures susceptibility and in their absence forms antibody-like substance providing resistance.

Post-infection biochemical defense reactions:

Defense through toxic materials produced in response to infection

a) Phenolic compounds and their role in defense - Aromatic amino acids found in higher plants serve as precursors for the synthesis of phenolic compounds. Some of the phenolic compounds produced in response to infection by the pathogens are caffeic acid, umbelliferon, scopoletin, and chlorogenic acid in sweet potato; phloretin in apple; hydroquinone in pear. Phytoalexins are complex phenolic compound produced by the plant in response to infection. eg. isocoumarin in carrot inoculated with *Ceratocystis fimbriata*, pisatin and phaseolin in pea inoculated with *Monilia fructicola*

b) Defence through induced synthesis of proteins and enzymes - In tristeza virus, inoculation with mild isolate will protect from severe isolate due to the synthesis of proteins and enzymes.

c) Formation of substrates resistant to enzymes of the pathogen - The pectinolytic enzymes such as pectin methyl esterase, pectin glycosidase, polygalacuronase and polymethyl galacuronase produced by the pathogen dissolve the pectic substances present in the middle lamellae. The plants may form polyvalent cations of pectin-protein, which is not affected by these enzymes, and this will check the tissue disintegration.

Defense through detoxification of pathogen toxins - The toxic substance victorin (*Helminthosporium victoriae*) in oat and piricularin (*Pyricularia oryzae*) in rice is detoxified in the resistant varieties.

Defense through altered biosynthetic pathways - The infected plant cells contain more RNA and protein without affecting DNA. Such alteration finally led to synthesis of biochemicals that provides either resistance or susceptible reactions.

Defense through hypersensitivity- Strong reaction by the host cells causes death of cells at the site of infection and thus check the obligate parasites.

Toxin:

A toxin can be defined as a product of microorganism that acts directly on living host protoplasm to influence either the course of disease development or symptom expression. These toxins are frequently called as antimetabolites because they suppress the metabolic activities of host.

Name of the disease	Causal organism	Toxic compound
Early blight of tomato	*Alternaria solani*	alternaric acid
Leaf spot of rice	*Helminthosporium oryzae*	cochbolin
Chestnut blight	*Endothia parasitica*	diaporthin, skyrin
Blast of rice	*Pyricularia oryzae*	piricularin
Wilt diseases	*Fusarium spp.*	fusaric acid, lycomarasmin
Anthracnose	*Colletotrichum sp.*	colletotin
Wild fire of tobacco	*Psudomonas tabaci*	wild fire toxin
Victoria blight of oats	*Helminthosporium victoriae*	victorin
Blight of toxin	*Periconia circinata*	periconia toxin
Brown rot or wilt of potato	*Pseudomonas solanacearum*	polysacchride
Tomato wilt	*F. oxysporum f. lycopersici*	ethylene

Toxins are given different names based on their contribution to disease production.

1. Pathotoxin - The toxin, which plays a causal role in disease development and produces all the characteristic of disease symptoms, is known as pathogen. eg. victorin.
2. Vivotoxin - The compound, which can produce at least a portion of disease syndrome, is known as vivotoxin. eg. piricularin, fusarial wilt toxins.
3. Phytotoxin - The toxin, which does not produce any disease syndrome of the pathogen but they kill the host cells is known as phytotoxin. eg. alternaric acid.

.Effect of diseases on physiological functioning of plants

Effect on photosynthesis -

The carbohydrates are synthesized by chloroplasts in green parts of the plant through the process of photosynthesis. They are degraded by respiration to release carbon dioxide, water, and energy.

$$C_6H_{12}O_6 + 6O_2 \underset{\text{Photosynthesis}}{\overset{\text{Respiration}}{=\!=\!=\!=\!=\!=}} 6O_2 + 6H_2O + \text{energy}$$

The affected plants produce different symptoms such as chlorosis by many viruses, necrotic lesions, dwarfing, leaf spots, leaf blight etc , which reduce the photosynthetic area by reducing the green portion or chlorophyll content of the plant. The pathogen affects photosynthesis by the destruction of chlorophyll including the chloroplast and by decreasing the efficiency of the photosynthetic process per mole of chlorophyll.

In certain cases, the diseased plants show an increased ability of photosynthesis, such plants are categorized as tolerant.

Effect on uptake and translocation of water and nutrient -

Plants absorb water and inorganic nutrients from the soil through their root system and translocated upward through xylem vessels of the stem and into the vascular bundles of the petiole and leaf vein ultimately entering into the leaf cells. The organic nutrient prepared in the leaf is translocated to other parts of plants through phloem.

Many pathogens, such as damping off, root rotting fungi and bacteria, most nematodes and some virus cause an extensive destruction of the roots before showing the symptoms on the foliage. Root injury will directly affect the absorption of water. The pathogen also inhibits the root hair formation and thus reduces the water and inorganic nutrient absorption. Some of the fungal mycelium, spores, and bacterial cells may plug the vessel. The pathogenic polysaccharides in the vessel also block the water and nutrients. Gels or gums released by the plants as pathogen attacks them also block the water and nutrient. Tyloses are the overgrowth of parenchyma cell adjacent to xylem which also block the movement of water and nutrients.

Effect on transpiration -

In general, transpiration is increased in infected plants because of;

1. destruction of cuticle as in case of rusts,
2. increase in permeability of leaf cell, and
3. defunction of stomata.

Beside these, the suction force of excessive transpiring leaves is abnormally increased that may lead to collapse of underline vessels.

Effect on movement of organic nutrients -

The organic nutrients prepared in the leaf move through plasmadesmata into the adjoining phloem and to phloem sieve tubes through osmotic pressure. The pathogen may interfere the transport in any stages. Obligate pathogen such as rust fungi, powdery mildew fungi cause accumulation of photosynthetic product as well as inorganic nutrients in the invaded zone that cause reduced photosynthesis and increased respiration. The level of cytokinins is higher in the diseased cell than in healthy cells. The cytokinins attrack water and nutrient. Therefore, the movement of minerals and organic nutrients occurs from healthy to infected cells.

Effect on respiration -

The rate of respiration is generally increased in the infected plants. Increased in respiration is observed shortly after inoculation continue during the time of symptom production and multiplication of pathogen reach to maximum at spore production by the pathogen and after that respiration is decreased. In resistant variety, respiration was increased more rapidly but for short time and in susceptible variety, respiration increased slowly reaching to high level and continued high level for longer time.

The mechanisms by which the respiration increases in the diseased plants are mainly two.

1. Uncoupling of oxidative phosphorilation - Phosphorilation of ADP may not take place. It has been seen that certain substance like 2,4 dinitrophenol (DNP) prevents phosphorilation of ADP to ATP that will stimulate respiration. This results in decreased energy output.
2. Stimulation of metabolism - Increased respiration is due to increase metabolism like growth stimulation, protoplasmic streaming and translocation and accumulation of materials in the diseased area will utilize more ATP resulting more ADP and inorganic phosphate which will further stimulate respiration.

Forecasting of diseases and estimating disease incidence

Forecasting can be defined as ascertainment and notification to the growers of a commodity about the favorable conditions of certain disease so that control measures could be applied for economic return.

Forecasting will have practical value in case of the following conditions.

1. Disease causes economically significant damage in terms of quality and quantity,
2. Time of disease appearance its development and epidemic depends on weather conditions directly or indirectly,
3. Information on weather-disease relationships is fully known
4. Practical, effective, and economical control measures are available, and
5. All the growers of a commodity are ready to act as suggested by the forecasting service and the government of the country concerned.

Methods of forecasting

In general, definite environmental relationships with the disease are found from laboratory experiments. Then it is verified with the actual field data in different regions. Major and critical weather factors determining the amount of disease are identified. A tentative model is developed and verified with the field macroclimate and microclimate data and the disease pattern and then it is used for forecasting. However, the actual methods of forecasting for a disease depends on the type of disease cycle which mat differs from place to place or country to country.

Simple bio-climatic models

In Holland, Everdingen (1926) framed Duch rules to forecast late blight of potato.

i) night temperature below dew point for at least 4 hours,

ii) minimum temperature of 10^0C or above,

iii) cloudiness on the subsequent day, and

iv) at least 0.1 mm of rain during the subsequent 24 hours.

In England, Beaumont (1947) gave similar rules with slight modifications. The RH should not fall below 75% and temperature below 10^0C for at least 46 hours. Blight is expected after 2-3 weeks. Smith (1956) further modified that the temperature not below 10^0C and

RH is 90% or above for at least 11 hours on each day. These simple models are elaborated and improved.

1. Mechanical model and zero date:

Simple mechanical models are used considering the zero dates. Zero date means the date before which the disease can not be expected even the weather conditions are suitable. It may be due to host may not be in susceptible stage or pathogen may not be sufficiently multiplied.

2. Synoptic weather chart:

It was first used in Ireland in 1952 and it is continued. Once a link has been established between a plant disease and certain synoptic weather pattern, it becomes more simple to forecast the disease.

3. Negative forecast:

This involves an arithmetical weighing of weather conditions if they favor or hinder a plant disease. A cumulative rating is maintained which automatically indicates when an outbreak is possible.

4. Computer programming to simulate plant disease:

The computer is used to facilitate arithmetical work. Computer programming moders are developed. eg. EPIDEM for Alternaria blight of tomato, EPIMAY for southrn leaf spot of maize, EPISEPT for Septoria in wheat, MYCOS for Aschochyta blight of Chrysanthemum, and BLIGHTCAST for late blight etc.

5. Medium and long-range strategical warnings:

It is predicted by studying the weather pattern of a particular country and the weather requirement for a disease. It is warned not to allow to get enter in the country stating the potential danger of the disease in the new area or country.

Principles of plant disease control

Principles of plant disease control include

I) Prophylaxis i) Exclusion (Quarantine and other legislative measures)

ii) Eradication (Cultural eradication and chemical eradication)

iii) Protection (Cultural manipulation, Physical and chemical protections)

II) Immunization i) Genetic resistance

ii) Therapy (Physical therapy and chemical therapy)

1. Avoidance of pathogen: Avoiding disease by planting at times when or where inoculum is absent or ineffective due to unfavorable environmental conditions.
   i) Choice of geographic area
   ii) Selection of field
   iii) Choice of time of sowing
   iv) Disease escaping varieties
   v) Selection of seed and planting stock
   vi) Modification of cultural practices

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

   ii) Inspection and certification
   iii) Quarantine
   iv) Eradication of insect vectors

3. Eradication: Reducing, inactivating, eliminating, or destroying inoculum at the source, either from a region or from an individual plant in which is it already established.
   i) Biological control of plant pathogens
   ii) Crop rotation
   iii) Removal or destruction of diseased plant or plant organs
   iv) Rouging
   v) Eradication of alternate and collateral hosts
   vi) Sanitation
   vii) Heat and chemical treatment of diseased plants
   viii) Soil treatments

4. Protection: Preventing infection by creating a chemical toxic barrier between the plant and the pathogen.
   i) Chemical treatment
   ii) Chemical control of insect vectors
   iii) Modification of environments

5. Disease resistance: Altering the effectiveness of the pathogen by selection or introduction of resistant genes in the plant.
   Selection and hybridization for disease resistance
   Resistance through chemotherapy
   Resistance through host nutrition

6. Therapy: Reducing severity of disease in an infected individual.
   Chemotherapy
   Heat therapy
   Tree surgery

Methods of disease control

Cultural methods:
Crop rotation with non-host will help to control some of the pathogens. eg. Ahrar wilt *Fusarium oxysporium f. udum* can be controlled by rotation of crop rice, groundnut etc.
Summer ploughing will expose the pathogen to direct sun and kill them. *Meloidogyne* can be reduced by summer ploughing.
Flooding will create anaerobic condition and is helpful to reduce the diseases of angular leaf spot of cotton - *Xanthomonas malvacearum* and banana wilt - *Fusarium oxysporium f. cubense*.
Sanitation - collection and destruction of infected parts of the plant after harvest of the crop is useful to reduce many plant diseases.
Time of sowing is important for checking soil-borne pathogen.
Depth of sowing - Seed sown too deep in the soil will get infection and cause pre emergence damping off.
High seed rate creates suitable environment for post emergence damping off.

Use of fertilizers - High nitrogen favors rice blast disease but suppress brown spot and vice-versa.
Addition of organic amendments is the easy and cheap method of managing the plant diseases. **Green manuring** will reduce the nematode problem.
Mixed cropping is sometime useful to control the disease. eg. Ahrar and Jawar when grown together, Jawar secrets HCN that kills the ahrar wilt pathogen.

Physical methods:
Dry heat treatment, hot water treatment, and firing will kill indiscriminately the microorganisms living in the soil. They may be harmful or useful. It is practiced to controlled *Sclerotium rolfsii* causing root rot in many crops.

Regulatory method

Plant quarantine is the legal restriction on the movement or interchange of plant or plant products between countries, states, and communities for the purpose of preventing or the introduction and establishment of plant pathogens where they do not exist. There are domestic quarantine and international quarantine established.

Plant quarantine actions are grouped into 5 major groups;

1. Embargo - Absolute prohibition on the movement of infected materials from a quarantined area to a protected area.
2. Detention - A delay in the release from a period when the plant material are held under careful observation until freedom from the parasite have been assured or organism has been eliminated.
3. Inspection - Plant material examined either on the source of produce or at the point of entrance.
4. Disinfection - If the material is found diseased, then either seed treatment or hot air or sorting is done.
5. Unrestricted entry - When it is considered that there is no harmful disease it is allowed to enter everywhere.

Biological method:

Introduction or inactivation of less harmful or saprophytic microorganisms to check more harmful or pathogenic organisms is known as biological control method. The fungi *Trichoderma* and *Gliocladium* are used to control soil-borne pathogens like *Rhizoctonia*, *Sclerotium*, *Sclerotinia* and *Fusarium*. Similarly, saprophytic bacteria are used to control the fungal or bacterial disease.

Classification and formulation of chemicals used in disease control:

Fungicide means a chemical, which are able to kill the fungi. However, all the fungicides do not kill the fungi, they may check the growth of the fungi temporarily or they may check the germination of fungal spores. Therefore, they can be classified as i) Protectants and ii) Therapeutants

Protectants are those fungicides, which are used to protect the plants from the attack of pathogens. They should be applied before infection. eg. Zineb, Maneb, Sulfur etc.

Therapeutants are those chemicals, which are capable of eradicating the pathogen even after causing the infection. eg. vitavax, hinosan, antibiotics etc.

Based on mode of action they can also be classified as i) Systemic and ii) Nonsystemic
Systemic fungicides are those, which act by entering the system of the plants. They are the therapeutants.

Nonsystemic fungicides are those, which cannot enter the system of the plants but act on the surface of the plants. They are generallty protectants.

Based on general use the fungicides are classified as;
Seed protectants - organomercurials, captan, thiram
Foliage fungicides - zineb, maneb, captan, ferbam
Soil fungicides - PCNB, thiram, captan, vitavex
Fruit protectants - benomyl, captan

Based on chemical nature the fungicides are classified as;

Sulfur fungicides
- Inorganic - Elemental sulfur, Lime sulfur
- Organic - Dithiocarbamates eg. zineb, maneb, ziram, nabam, vapam, thiram

Copper fungicides
- Copper sulfate - Bordeaux mix., Burgundy mix., Chesnut compound
- Copper carbonate - Chaubattia paste, Masuadia paste
- Copper oxychloride - Blitox-50, Fytolan, Cupramar
- Cuprous oxide - Perenox, Fungimar

Mercurial fungicides
- Inorganic – Mercuric chloride, mercurous chloride
- Organic – Agrosan, Ceresan, Herbasan, Lunasan

Quinone – Chloranil, Diclone
Heterocyclic nitrogenous – Captan, Folpet
Oxathiin – Vitavax, Plantvax
Bendimidazole – Benomyl, Thiobandazole, Bavistin, Derosal
Petachloronitrobenzene – Brassicol
Antibiotics – Aureofungin, Agrimycin, Streptomycin, Streptocycline

Formulation of fungicides:

Water dispersible or Wettable powders – This is the most commonly available formulation. They have the capacity to wet or disperse in the water. Generally wetting agent is present in each WP. Frequent agitation is necessary if spreader or dispersing agent is not added while spraying the fungicides.

Dusts – They have generally 4-10% active ingredient and the rest is inert material. They are applied as dry or dust form. The particle size should be 200-300 mesh size.

Suspension or Slurries – Very limited fungicides are available in this form. Some of the systemic fungicides are found in the form of suspension.

Integrated Pest Management (IPM)

IPM is a new conceptual approach, which is based on ecological principles and integrates multidisciplinary methodologies in agroecosystem management strategies that are practical, effective, economical and protective of both public health and environment. Various control measures that can be incorporated in IPM includes, Judicious use of chemicals preferably botanical pesticides, Biological control , Plant Quarantine , Seed certification , Resistant cultivars , Genetic engineering

Application of Plant Bio-technology to Disease

Shoot-Tip Culture: This technology is applied mainly to get free from virus but it also enabled plants to get free from viroids, mycoplasma, bacteria and fungi.

Thermotherapy: Potato virus-x, Cucumber mosaic virus can be eliminated by combined application of heat treatment either before or after meristim shoot-tip culture.

Chemotherapy: Chemicals used for inactivation or suppression or elimination of plant viruses

Compound	Viruses	Host
Ribovirin	PVy, PVx, PVs, PVm	potato
	Mottled Crinkle virus	eggplant
Malachite green	PVx	potato
Actinomycin-D	TMV	Chinese cabbage

Use of somachlonal variation: Examples where plants with heritable resistance have been obtained from unselected tissue cultures.

Host	Pathogen	Tissue source
Potato	*Alternaria solani*	Mesophyll, protoplast
	Phytophthora infestans	Mesophyll
Tomato	*Fusarium oxysporum* f.sp.	Callus from cotyledon

	lycopersici Race 2	and protoplast

Selection of potato against pathogen toxin resulted heritable resistance against the pathogen eg. exposing the cells of tomato in furasic acid and selection made to get resistance to *Fusarium oxysporum* f. sp. *lycopersici* Race 2. Similarly *Brassica napus* exposed to culture filtrate of *Phoma lingum*.

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