Plant Pathogens & Principles of Plant Pathology

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ICAR e-Course

For

B.Sc (Agriculture) and B.Tech (Agriculture)

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Lecture 01 - Introduction

Definition and History of Plant Pathology

Plant Pathology

Plant pathology or phytopathology is the science, which deals with the plant diseases. It is concerned with health and productivity of growing plants. Phytopathology (Greek *Phyton* = plant + *pathos* - disease, ailments + *logos* = discourse, knowledge) is the branch of agricultural, botanical or biological science which deals with the cause, etiology (aetiology), resulting in losses and management methods of plant diseases.

Plant pathology can also be defined as the study of the nature, cause and prevention of plant diseases. Plant pathology is related to most of the old and new sciences like biology, physics, chemistry, physiology, mathematics, genetics, soil science, biochemistry, biotechnology etc. Plant pathology has the following major objectives.

1. To study biotic (living), mesobiotic and abiotic (non-living and environmental) causes of diseases or disorders
2. To study the mechanisms of disease development by pathogens
3. To study the plant (host)-pathogen interaction in relation to environment
4. To develop methods of management of plant diseases

Plant diseases

Plant diseases are recognized by the symptoms (external or internal) produced by them or by sick appearance of the plant. The term plant disease signifies the condition of the plant due to disease or cause of the disease. Plant disease is mainly defined in terms of the damage caused to the plant or to its organ. The other definitions for the term disease are:

1. Disease is a malfunctioning process that is caused by continuous irritation, which results in some suffering producing symptoms. This definition is accepted by both American Phytopathological Society and British Mycological Society.

2. Disease is an alteration in one or more of the ordered sequential series of physiological processes culminating in a loss of coordination of energy utilization in a plant as a result of the continuous irritation from the presence or absence of some factor or agent.

3. A plant is said to be ‘diseased’ when there is a harmful deviation from normal functioning of physiological process (Federation of British Plant Pathologists, 1973).

4. The disease can also be defined as 'any disturbance brought about by a living entity or non-living agents or environmental factors which interfere with manufacture, translocation or utilization of food, mineral nutrients and water in such a way that the affected plant changes in appearance with or without much loss in yield than that of a normal healthy plant of the same variety. In general disease is an interaction among the host, parasite and the environment.

Man became painfully aware of plant diseases in the early times of antiquity. This is evidenced by the inclusion of blasting and mildew in the Old Testament. Our ancient religious literature gives informations on plant diseases much before their mention by the Greek philosopher, Theophrastus. *Rigveda, Atharvanaveda* (1500-500 B.C.), the *Artha Shashtra* of *Kautilya* (321-186 B.C.), *Sushrute Samhita* (200-500 A.D.), *Vishnu Puran* (500 A.D.), *Agnipuran* (500-700 A.D.) and *Vishnudharmottar* (500-700 A.D.) are some of the ancient books from India where diseases and other enemies of plants are mentioned. In *Rigveda*, classification of plant diseases and germ theory of disease were discussed.

The learned men during Vedic period were aware that the diseases are caused by microbes. The book *"Vraksha Ayurveda"* written by *Surapal* in ancient India contained information on plant diseases. This is the Indian book, which gave first information on plant diseases. He divided plant diseases into two groups *viz.*, internal and external. Plant diseases like rust, smut, downy mildew, powdery mildew and blight were mentioned in the Bible.

The Greek Philosopher, *Theophrastus* (370-286 B.C.) was the first to study and write about the diseases of trees, cereals and legumes. In his book *'Enquiry into plants'* Theophrastus has recorded his observations, imaginations and experiences but they were not based on any experiments. He had mentioned that plants of different groups have different diseases, which are autonomous or spontaneous *i.e.*, no external causes were associated with the plant diseases.

The history in several aspects of plant pathology is given as below.

Mycology

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

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

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

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

1821 - E. M. Fries published Systema Mycologicum for naming of fungi; he was named as Linnaeus of Mycology.

1821 - Robertson of England stated that sulphur is effective against peach mildew.

1845 - Irish Potato famine due to *Phytophthora infestans* caused starvation of million and immigration of 1.5 million people.

1858 - J. G. Kuhn published first textbook in Plant Pathology – The Diseases of Cultivated Crops, their Causes and their Control.

1861 -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.

1865 – Anton de Bary reported heteroecious nature of wheat stem rust.

1869 – England loses coffee production to coffee rust, forced to grow tea.

1874 -Robert Hartig published a book entitled, "Important Diseases of Forest Trees".

1875-1912 - 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.

1877 – M. S. Woronin discovered and named the Club root of Cabbage pathogen as *Plasmodiophora brassicae.*

1878 – M. S. Woronin found out the life cycle of potato wart disease.

1878 -Downy mildew of grapevine was introduced into Europe from America. The disease almost ruined the wine industry.

1881 -H.M. Ward worked out the life cycle of coffee leaf rust. He is called as Father of Tropical Plant Pathology.

1882 -Robert Hartig published a textbook -Diseases of Trees. He is called as "Father of Forest Pathology".

1885 -Pierre Marie Alexis Millardet accidentally discovered the Bordeaux mixture for the control of downy mildew of grapevine.

1885 – A. B. Frank defined and named mycorrhizal associations in plant roots.

1887 -Burgundy mixture was introduced by Mason of France.

1894 -Swedish scientist Eriksson described the phenomenon of physiologic races in cereal rust fungus, *Puccinia graminis*.

1899 – 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.

1904 – A. F. Blakeslee, American Geneticist founded heterothallism in *Rhizopus*

1904 – R. H. Biffen was the first to show that resistance to pathogens in plants can be inherited as a Mendelian character; pioneer in genetics of plant disease resistance.

1912 – H. Burgeff reported that within a cell of a fungus, fusion between dissimilar nuclei can occur. He called this phenomenon as heterokaryosis.

1917 -E. C. Stakman demonstrated physiologic forms in stem rust of wheat.

1918 -E.J.Butler published book on *Fungi and Disease in Plants*; he made exhaustive study on Indian fungi and the diseases caused by them. He is called as the Father of Modern Plant Pathology in India; He joined as the first Director of Imperial Bureau of Mycology (Commonwealth Mycological Institute, CMI) now CAB International Mycological Institute in Kew, England in 1920. He began the journal *Review of Applied Mycology*; with S.G. Jones he wrote, *'Plant Pathology'* in 1949.

1929 -Sir Alexander Fleming isolated the antibiotic, Penicillin from the fungus, *Penicillium notatum*.

1932 – H. N. Hansen and R. E. Smith were the first to demonstrate the origin of physiologic races through heterokaryosis.

1934 -W. H. Tisdale and I. Williams studied the organic fungicides by discovering alkyl dithiocarbamates.

1938 – H. N. Hansen found out dual phenomenon in Fungi Imperfecti.

1942 – H. H. Flor developed gene-for-gene hypothesis in flax rust.

1943 – Great Bengal Famine due to *Helminthosporium oryzae* caused death of 2 million people in India.

1943 -Dimond, Heuberger and Horsfall discovered the ethylene bis dithiocarbamates.

1945 -J. G. Horsfall explored the mechanism of fungicidal action.

1948 -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.

1951-57 -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.

1952 -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.

1953 – Pontecorvo and his associates demonstrated parasexualism in fungi.

1956 -J. G. Horsfall published a book entitled "Principles of Fungicidal action"

1957 – E. C. Stakman with J. G. Harrar wrote a book *Principles* of *Plant Pathology.*

1963 - J. E. Van der Plank found out vertical and horizontal types of resistance in crop plants.

1966 -van Schmeling and Marshall Kulka were the first to find out systemic fungicides (oxathiin compounds – carboxin and oxycarboxin).

1970 -S. D. Garrett investigated the management of root diseases and he is the pioneer worker in the field of biological control. 1972 – G. Rangaswami wrote a book on Diseases of Crop Plants in India.

Plant Bacteriology

1683 – Anton von Leeuwenhoek first observed bacteria.

1876 -Louis Pasteur and Robert Koch -They proved that anthrax disease of cattle was caused by specific bacterium.

1876 -Robert Koch of Germany described the theory called "Koch's postulates." He established the principles of pure culture technique.

1876 -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.

1882 -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*).

1901-1920 E.F.Smith of U.S.A gave the final proof of the fact that bacteria could be incitants of plant diseases. He also worked on the bacterial wilt of cucurbits and crown gall disease. He is also called as "Father of Phytobacteriology". Chilton and his coworkers demonstrated that crown gall bacterium transforms plant cell to tumour cell by introducing into them a plasmid.

1910 -C. O. Jensen related crown gall of plants to cancer of animals.

1952 -J. Lederberg coined the term plasmid 1952 – S. A. Waksman won Nobel prize for the discovery of streptomycin.

1952 – Zinder and J. Lederberg discovered transduction in bacteria 1962 – H. Stolp discovered bdellovibrios.

1972 – P. B. New and A. Kerr success in biological control of *A. radiobacter* strain K.

1972 – I. M. Windsor and L. M. Black observed a new kind of phloem inhabiting bacterium causing clover club leaf disease.

1974 – I. Zanen et al. demonstrated Ti plasmid in *Agrobacterium tumefaciens*.

1980 – D. W. Dye et al. introduced the pathovar in the taxonomy of plant pathogenic bacteria.

Plant Virology

1886 -Adolf Mayer described a disease of tobacco called mosaikkranheit (tobacco mosaic). Adolf Mayer demonstrated the sap transmission of Tobacco Mosaic Virus disease.

1892 -Dimitri Ivanowski demonstrated that the causal agent of tobacco mosaic could pass through bacterial filter.

1895 -E.F. Smith of U.S.A. showed the peach yellows was a contagious disease.

1898 -M.W. Beijerinck -a Dutch microbiologist and founder of virology proved that the virus inciting tobacco mosaic is not a microorganism. 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.

1929 -F. O. Holmes provided a tool by which the virus could be measured by showing that the amount of virus present in a plant sample preparation is proportional to the number of local lesions produced on appropriate host plant leaves rubbed with the contaminated sap.

1935 -W. M. Stanley proved that viruses can be made as crystals. He got Nobel Prize in 1946.

1936 -F. C. Bawden and, N.W. Pirie (Britain) found that the crystalline nature of the virus contains nucleic acid and protein.

1939 -Kausche and colleagues first time saw the TMV virus particles with the help of Electron microscope.

1956 -Gierer and Schramm proved that the nucleic acid fraction of the virus is actually the infectious agent.

1959 -Munday succeeded in inducing TMV mutations.

1966 -Kassanis discovered the satellite viruses.

1971 -T. O. Diener discovered viroids, which only consist of nucleic acids. Smaller than viruses, caused potato spindle tuber disease (250-400 bases long of single-stranded circular molecule of infectious RNA).

Phytoplasma

1967 – Doi *et al* and Ishiie *et al*, the Japanese scientists found that mycoplasmalike organisms (MLO) could be responsible for the disease of the yellows type. Doi observed that MLO's are constantly present in phloem while Ishiie observed MLO's temporarily disappeared when the plants are treated with tetracycline antibodies.

Spiroplasma

1972-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.

Lecture 02

Important plant pathogenic organisms- different groups- fungi, bacteria, fastidious vesicular bacteria, phytoplasmas, spiroplasmas, viruses, viriods, algae, protozoa and phanerogamic parasites with examples of diseases caused by them

Plant diseases are classified on the basis of type of pathogenic or non-pathogenic causes of the disease. The classification is based on the plant pathogenic organisms as follows.

A. Parasites: They include both biotic and mesobiotic agents. The diseases are incited by parasites under a set of suitable environment. Association of definite pathogen is essential with each disease.

i. Biotic agents: They are also called as animate causes. They are living organisms.

Biotic agents include

1. Prokaryotes

a. True bacteria or bacteria (Facultative parasites) e.g. Citrus canker.

b. Rickettsia-like bacteria (RLB) e.g. Citrus greening, Pierce's disease of grape

c. Mollicutes or wall-less prokaryotes

i. Mycoplasma-like organism (MLO) e.g. Sesame phyllody, egg plant little leaf.

ii. Spiroplasma e.g. Corn stunt, Citrus stubborn

2. Eukaryotes

a. Protists (Unicellular, coenocytic or multicellular with little or no differentiation of cells and tissues).

i. Fungi e.g. wilt of cotton

ii. Protozoa e.g. heart rot of coconut

iii. Algae e.g. red rust of mango

b. Plants - Parasitic flowering plants or phanerogamic parasites - Broomrape of tobacco.

c. Animals (Multicellular, extensive differentiation of cells and tissues) e.g. Nematodes -Root knot nematode.

ii. Mesobiotic agents: They include viruses and viroids. They are infectious agents. They can be crystallized and are considered non-living. But their multiplication in the living plants ensures that they are living. Hence they are called as mesobiotic agents.

Viruses e.g. yellow mosaic of blackgram

Viroids e.g. spindle tuber of potato

B. Non-parasites or Abiotic agents: They are also called as non-infectious or physiological disorders. When no pathogen is found, cultured from or transmitted from a diseased plant, then the disease is said to be caused by a non-living or environmental factor. These diseases occur because of disturbances in the plant system by the improper environmental conditions in the air or soil or by mechanical influences. They are listed below.

i. Too low or too high temperature

ii. Lack or excess of soil moisture

iii. Lack or excess of light

iv. Lack of oxygen

v. Air pollution (Toxic gases in the atmosphere etc.)

vi. Mineral deficiencies or toxicities

vii. Soil acidity or alkalinity

viii. Toxicity of pesticides

ix. Improper agricultural practices.

a. FUNGI

Fungi are eukaryotic, achlorophyllous organisms that may reproduce sexually and asexually and whose filamentous branched somatic structures are typically surrounded by cell walls containing chitin or cellulose.

b. BACTERIA

Bacteria are microscopic, unicellular prokaryotes, which lack chlorophyll. These microorganisms are with a primitive nucleus lacking a clearly defined membrane. The bacteria are smaller than fungi and measure about 0.5 to 1.0 x 2.0 to 5.0 μm in size. More than 1,600 bacterial species are known. Majority of them are saprophytes. Several species cause diseases in human beings and animals. About 200 species of bacteria cause diseases in plants. First report of plant disease by bacteria was made by T.J. Burrill of the University of Illinois. He showed that fire blight of apple and pear is caused by a bacterium, *Erwinia amylovora*. Bacteria have been defined by Clifton as "extremely minute, rigid essentially unicellular organisms, free of true chlorophyll and generally devoid of any photosynthetic pigments; most commonly multiplying asexually by simple transverse fission, the resulting cells being of equal or nearly equal size".

Fastidious vascular bacteria (Rickettsia-like bacteria – RLB)

Fastidious vascular bacteria are otherwise called Rickettsia - Like bacteria, Rickettsia like organisms (RLO), or fastidious prokaryotes or rickettsia -like walled bacteria. They are small bacteria with a cellular ultrastructure of typical gram- negative bacteria. They are very exacting in their nutritional requirements, refusing to grow on routine bacteriological media. They have a cell wall unlike MLO and spiroplasma. MLO is restricted to phloem tissues where as RLB are restricted mostly to xylem or phloem. A common habit for both is the insect body fluid (haemolymph). Both the groups are dependent on insect vectors for transmission. Non-tissue restricted RLB have also been observed in plant diseases. They reproduce by binary fission. Mostly insect vectors transmit them. Nematode *(Xiphinema index)* also helps in transmission of RLB (yellow disease of grapevine). Mechanical inoculations (as in Pierce's disease of grapevine, almond leaf scorch and alfalfa dwarf) or vegetative propagation also reproduce disease symptoms. They produce phytoalexins, which induce characteristic symptoms of the disease. They are cultured in artificial media e.g., Pierce's disease of grapevine, almond leaf scorch, phony disease of peach and plum leaf scald. Xylem restricted RLB can be more successfully cultured than limited-limited bacteria.

Penicillin is effective against RLB. Sulpha drugs also inhibit them. The RLB can be divided into three groups.

1 Xylem-limited RLB

2 Phloem-limited RLB and

3 Non-tissue restricted RLB

1. Phloem-limited RLB

Phloem limited bacterium was first recognized by D.Lefleche and J.M.Bowe in 1970. Twelve phloem-restricted RLB have been identified Examples of phloem limited RLB include citrus greening, clover club leaf (CCL), white clover disease, clover rugose leaf curl, potato leaflet stunt, little leaf of *Sida cordifolia* and stunting of dodder.

a. Symptoms: Stunting, yellowing of young leaves, virescence of floral parts, premature death of the entire plant.

b. RLB: They are mostly rigid rods and Gram-negative and sensitive to penicillin. The cells measure 0.2 to 0.5 x 1.0 to 2.0 (0.3 x 1.3) µm and are bound by a double membrane or a cell wall and cytoplasmic membrane. RLB have not been cultured *in vitro* and Koch's postulates

proved. Therefore, not much is known about their nature, taxonomy and serological relationships.

Transmission: Transmission is by leafhoppers, dodder and grafting. Citrus greening is transmitted by citrus psylla (*Psyllina* sp.) and by vegetative propagation. Clover clubleaf multiplies in its vector, *Agalliopsis novella.* The vector retains infectivity throughout its life cycle and the RLB is transovarially transmitted.

2. Xylem-limited RLB

Pierce's disease of grapevine, almond leaf scorch, phony disease of peach, wilt of periwinkle, Sumatra disease of cloves, elm leaf scorch, alfalfa dwarf, plum leaf scald. The RLB causing phony disease of peach is named as *Xylella fastidiosa*. **Symptoms:** Symptoms include marginal necrosis of leaves, stunting of plants, decline in vigour and reduction in yield.

RLB: In general xylem-limited Gram-negative bacteria have elongated cells of 0.2 to 0.5 into 1.4 μm size (Davis *et. al.,* 1981). The cells usually have well defined cell wall and plasma membrane. Both are triple layered in structure. The walls are ridged or ripped due to periodic infolding of the outer membrane of the wall. These width of the ridges is about 45 to 75 nm. The cell wall ultrastructure is typical of Gram negative bacterial. In culture, the cells of Pierce's disease of grapevine and almond leaf scorch are non-motile, gram negative, oxidase negative and catalase positive.

They are susceptible to tetracyclines but not to penicillin. The G+C content of the DNA is about 53.1 moles per cent.

Transmission

Transmission of RLB takes place mostly through xylem feeding insects. Sap transmission and transmission through vegetative propagation have been reported. The insect vectors belong to sharp shooter leafhoppers (Cicadellidae) and spittle bug or froghoppers (Cercopidae). Pierce's disease of grapevine is spread by *Homaladisca coagulata, Oncometopia undulata, Cuerna costalis, Draeculacephala portola, D.minerva, Corneocephala fulgide* and *Graphocephala atrapunctata.* RLB of Pierce's disease of grapevine is transmitted by the vector in a non-circulative but persistent manner. There is no incubation period in the body of the vector and infectivity is lost after moulting. This is because the RLB accumulate only in the salivary syringes where they appear to attach in a polar orientation. The transmission is accompanied by

regurgitation of the bacteria into the xylem stream. The RLB are not pathogenic to the vector. There is no transovarially transfer of RLB.

3. Non-tissue restricted RLB: They are also found in parenchyma and meristematic cells of yellows of grapevine, chlorosis and Aspermy of wheat, apple proliferation, carrot proliferation and necrosis of grapevine. A yellow of grapevine is transmitted by a nematode, *Xiphinema index.* Not much is known about RLB of these diseases.

PHYTOPLASMA

Phytoplasma lack cell wall and are bounded by a unit membrane. They are pleomorphic. They lack cell wall. They have fried egg appearance of colony. They are filterable through 450 nm membrane. They have both DNA and RNA. They cannot be grown on artificial media. They produce symptoms like little leaf, phyllody, spike, yellows, stunting, witches' broom etc. They are mostly transmitted by leafhoppers. They are insensitive to penicillin and sensitive to tetracycline. e.g. phyllody of sesame, little leaf of brinjal.

SPIROPLASMA

Spiroplasma is helical, wall-less prokaryotes requiring cholesterol for growth and cause diseases in plants, insects and rats. They are insensitive to penicillin and sensitive to erythrocin and tetracycline. e.g. corn stunt, citrus stubborn.

VIRUS

Viruses are ultramicroscopic, nucleoprotein entities, which are infectious agents and obligately parasitic pathogens, which are less than 200 mμ in size. They are devoid of enzymes and depend on the host protein synthesis machinery (ribosomes). They have only one type of nucleic acid viz., RNA or DNA. Most of the plant virus is having RNA. e.g. TMV. Few viruses contain DNA. e.g. Cauliflower mosaic virus, banana bunchy top virus, maize streak virus and sugar beet curly top virus.

VIROIDS

Viroids are small low molecular weight ribonucleic acids that can infect plant cells replicate themselves and cause disease. They are also called as mini viruses. e.g. Potato spindle tuber, Chrysanthemum stunt, Coconut *Cadang cadang.*

ALGAE

Algae are eukaryotic, unicellular or multicellular organisms and mostly occur in aquatic environments. Many algae thrive as terrestrial or subterranean algae. The size of algae ranges

from 1.0mm to many centimetres in length. They contain chlorophyll and are photosynthetic. They reproduce by asexual and sexual processes. The study of algae is called phycology or algology.

PROTOZOA

Protozoa (trypanosomatid flagellates) belonging to the class Mastigophora, order Kinetoplastida and family Trypanosomatidae have been known to parasitize plants. Protozoa attacking plants move by flagella. Protozoa or trypanosomatid flagellates belonging to the class Mastigophora, order: Kinetoplastida and family Trypanosomatidae have been known to parasitize plants. The Mastigophora, or flagellates, are characterized by one or more long slender flagella at some or all stages of their life cycle. The flagella are used for locomotion and food capture. They are also used as sense organs. The body of the flagellates has a definite long, oval or spherical form, which is maintained by a thin, flexible membrane cover.

In some groups it may be armoured. Flagellates reproduce by longitudinal fission. Flagellates apparently cause the phloem necrosis disease of coffee, the heart rot disease of coconut palm and the Marchitez suppressive (sudden wilt or wither) disease of oil palm, Marchitez suppressive is one of the important diseases in oil palm. *Phytomonas staheli* was described from sieve tubes of coconut and oil palm.

PHANEROGAMIC PARASITES

Phanerogamic parasites are flowering plants or seed plants, which lead a parasitic life on other living plants. They parasitize a great number of economic plants and cause considerable loss in yield. The phanerogamic parasites invade stem or root of the host plants. Some of these parasites possess chlorophyll, which manufacture carbohydrates to a limited extent and depend on the host for mineral, salts and water.

These are generally called as semi or partial parasites. Some of the parasites, which do not have chlorophyll, depend entirely on the host plants for their food materials. They are called holo or total parasites. Nearly 2,500 species of phanerogamic parasites in 11 families have been recorded throughout the world. Among them Orobanchaceae, Scrophulariaceae, Loranthaceae, Convolvulaceae and Lauraceae are important.

Classification of plant diseases

There are thousands of diseases, which attack crop plants. Classification can be made based on several criteria. The various ways of classifying diseases of plants are given below.

1. Type of infection

a. Localized diseases: These diseases are limited to a definite area of an organ or part(s) of a plant. e.g. leaf spots and anthracnoses caused by different fungi.

b. Systemic diseases: In these diseases the pathogen spreads from a single infection point so as to infect all or most of the host tissues. e.g. Downy mildews caused by fungi and mosaics and leaf curls caused by viruses.

2. Type of perpetuation and spread

a. Soil-borne diseases: The causal agents perpetuate and spread through soil. e.g. Damping off caused by fungi like *Pythium* sp. and root rot caused by *Rhizoctonia* spp.

b. Seed-borne diseases: Seed or seed materials help in the perpetuation and spread of this disease. The disease causing agents may be internally seed-borne or externally seed-borne e.g. Loose smut of wheat caused by *Ustilago nuda tritici* (internally seedborne) and blast of rice caused by *Pyricularia oryzae* (externally seed-borne).

c. Air-borne diseases: In these type of diseases the causal agents are spread by wind (air). e.g. Early leaf spot and late leaf spot of groundnut caused by *Cercospora arachidicola* and *Phaeoisariopsis personata* respectively.

3. Extent of occurrence and geographic distribution

a. Endemic diseases: It is also known as enphytotic disease. When a disease is more or less constantly occurring year after year in a moderate to severe form in a country or locality then it is called as an endemic disease. e.g. Wart disease of potato caused by *Synchytrium endobioticum* is endemic in Darjeeling, citrus canker caused by *Xanthomonas campestris* pv. *citri* is endemic in Asia and sorghum rust caused by *Puccinia purpurea* is endemic in India.

b. Epidemic or epiphytotic diseases: An epidemic or epiphytotic refers to sudden outbreak of a disease periodically over a widespread area in a devastatingly severe form causing extensive losses or complete destruction. Epidemic disease may be present constantly in the locality but assumes a severe form only on occasions. This is because of the occurrence of favourable environment responsible for the rapid development of the disease. But the pathogen may be irregular in appearance or there may be lack of sufficient inoculum to cause the disease. e.g. wheat stem rust (*Puccinia graminis tritici*) and powdery mildew (*Erysiphe graminis* var. *tritici*), late blight of potato (*Phytophthora infestans*), sugarcane red rot *(Physalospora*

tucumanensis), downy mildew of grapevine (*Plasmopara viticola*) and rice blast *(Pyricularia oryzae).*

c. Sporadic diseases: Sporadic diseases are those, which occur at irregular intervals over limited areas or locations. They occur in relatively few instances. e.g. *Fusarium* wilt of cotton (*Fusarium oxysporum* f.sp. *vasinfectum*), grain smut of sorghum (*Sporisorium = Sphacelotheca cruenta*) and wheat loose smut (*Ustilago nuda tritici*).

d. Pandemic diseases: 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.

4. Multiplication of inoculum

Based on the multiplication of inoculum, diseases are classified as

a. Simple interest disease and

b. Compound interest disease.

a. In simple interest disease (monocyclic epidemics) the disease increase is just like simple interest in money. Here inoculum comes from a reservoir and hence amount of inoculum for a given season's crop is fixed. So there is no repetition of the disease cycle within the crop season. Hence the disease spread will be slow. e.g. Soil inhabiting pathogens like *Pythium* sp., *Rhizoctonia* sp. and *Sclerotium* sp.

b. In compound interest disease (polycyclic epidemics) the disease increase is just like compound interest in money. Inoculum is multiplied several times (every 7 to 15 days for wheat rust) during crop growth in a season. So the disease spread will be fast. e.g. Wheat stem rust, rice blast, powdery mildew diseases of different crops.

Lecture 03

General Characters of fungi - Definition of fungus, somatic structures, types of fungal thalli, fungal tissues, modifications of thallus, reproduction in fungi (asexual and sexual)

General characters of fungi

Fungi are the eukaryotic, achlorophyllous, and unicellular or multicellular organisms, which may reproduce by asexual and sexual spores.

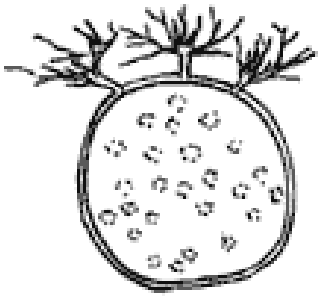
1. All are eukaryotic - Possess membrane-bound nuclei (containing chromosomes) and a range of membrane-bound cytoplasmic organelles (e.g. mitochondria, vacuoles, endoplasmic reticulum).
2. Most are filamentous - Composed of individual microscopic filaments called hyphae, which exhibit apical growth and which branch to form a network of hyphae called a mycelium.
3. Some are unicellular - e.g. yeasts.
4. Protoplasm of a hypha or cell is surrounded by a rigid wall - Composed primarily of chitin and glucans, although the walls of some species contain cellulose.
5. Many reproduce both sexually and asexually - Both sexual and asexual reproduction often result in the production of spores.
6. Their nuclei are typically haploid and hyphal compartments are often multinucleate - Although the oomycota and some yeast possess diploid nuclei.
7. All are achlorophyllous - They lack chlorophyll pigments and are incapable of photosynthesis.
8. All are chemoheterotrophic (chemo-organotrophic) - They utilise pre-existing organic sources of carbon in their environment and the energy from chemical reactions to synthesize the organic compounds they require for growth and energy.
9. Possess characteristic range of storage compounds - e.g. trehalose, glycogen, sugar alcohols and lipids.
10. May be free-living or may form intimate relationships with other organisms i.e. may be free-living, parasitic or mutualistic (symbiotic).

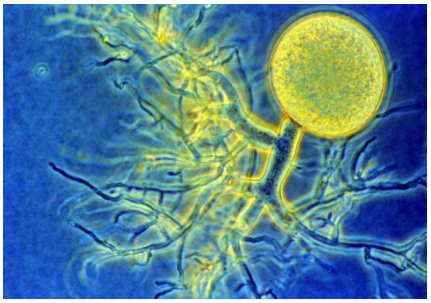
Thallus

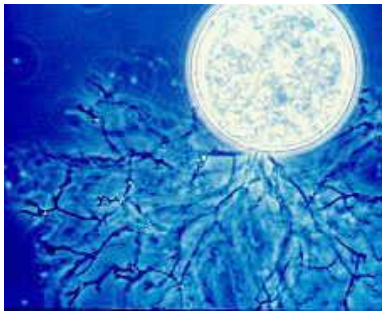
The body of the fungus is called as 'thallus'.

Eucarpic thallus

The thallus is differentiated into vegetative part, which absorbs nutrients, and a reproductive part, which forms reproductive structure. Such thalli are called as eucarpic. e.g. *Pythium aphanidermatum.*

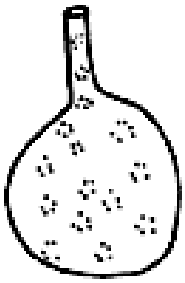


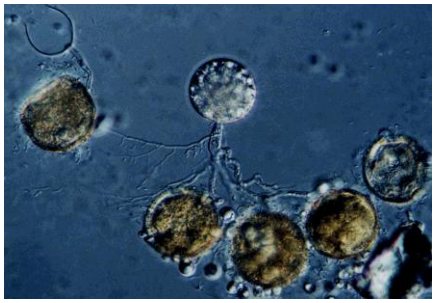




Holocarpic thallus

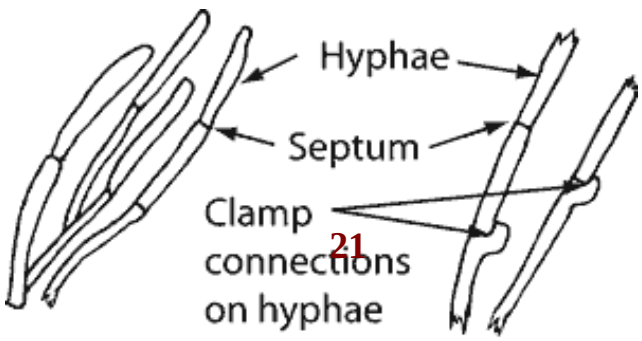
The thallus does not show any differentiation on vegetative and reproductive structure. After a phase of vegetative growth, it gets converted into one or more reproductive structures. Such thalli are called as *'holocarpic'* e.g. yeast, *Synchytrium endobioticum*

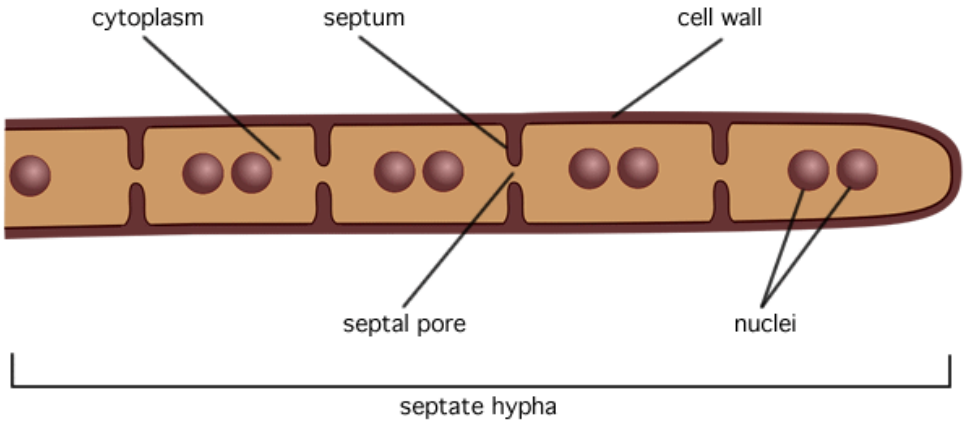




Hyphae

Hyphae is a tubular, transparent filament, usually branched, composed of an outer cell wall and a cavity (lumen) lined or filled with protoplasm including cytoplasm. Hyphae are divided into compartments or cells by cross walls called septa and are generally called as septate (with cross wall) or coenocytic (aseptate -without cross wall). Hyphae of most of the fungi measure 5-10 µm across.





Mycelium (pl. Mycelia)

The hyphal mass or network of hyphae constituting the body (thallus) of the fungus is called as mycelium. The mycelium of parasitic fungi grows on the surface of the host and spread between the cells and it is called intercellular mycelium. The mycelium of parasitic fungi, which grows on the surface of the host and penetrates into the host cells and is called intracellular mycelium. If the mycelium is intercellular, food is absorbed through the host cell walls or membrane. If the mycelium penetrates into the cells, the hyphal walls come into direct contact with the host protoplasm. Intercellular hyphae of many fungi, especially of obligate parasites of plants (fungi causing downy mildews, powdery mildews and rusts) obtain nutrients through haustoria.

Monokaryotic mycelium (uninucleate)

Mycelium contains single nucleus that usually forms part of haplophase in the life cycle of fungi.

Dikaryotic mycelium (binucleate)

Mycelium contains pair of nuclei (dikaryon), which denotes the diplophase in the life cycle of fungi.

Homokaryotic mycelium

The mycelium contains genetically identical nuclei.

Heterokaryotic mycelium

The mycelium contains nuclei of different genetic constituents.

Multinucleate

The fungal cell contains more than 2 nuclei.

Septa

Transverse septa occur in the thallus of all filamentous fungi to cut off reproductive cells from the rest of the hypha, to separate off the damaged parts or to divide the hypha into regular or irregular compartments or cells. There are two general types of septa in fungi viz., primary and adventitious. The primary septa are formed in association with nuclear division and are laid down between daughter nuclei. The adventitious septa are formed independently of nuclear division and are especially associated with changes in the concentration of the protoplasm as it moves from one part of the hypha to another.

Transverse septa

Septa vary in their construction septa have biological importance in the lifecycle of fungi. Some are simple whereas others are complex. All types of septa are formed by centripetal growth from the hyphal wall inward. In some septa, the growth continues until the septum is a solid plate. In others the septum remains incomplete, leaving a pore in the centre that may often be plugged or occulted.

Some groups of Basidiomycetes like Auriculariaceae, Tremellaceae, Aphyllophorales, Agaricales etc (except Ustilaginales and uredinales) have more complex septa. Surrounding the central pore in the septum is a curved flange of wall material, which is thickened to form a barrel-shaped or cylindrical structure surrounding the pore. Septa of this type are termed dolipore septa (L. *dolium* = a large jar or cask i . e., barrel).

These septa are often overlaid by perforated cap, which is an extension of the endoplasmic reticulum. This cap is known as parenthosome or pore cap. Despite these apparent barriers, there is a good cytoplasmic continuity between adjacent cells. The septal pore may vary in width from 0.1 to 0.2 μm. Dolipore septa are found in both monokaryotic and dikaryotic mycelia.

Fungal cell structure

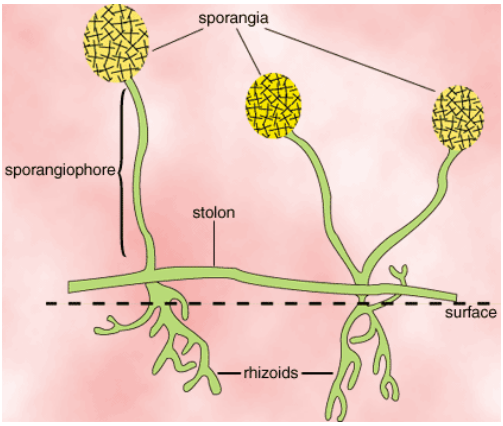
Fungal cells are typically eukaryotic and have distinguished characteristics than that of bacteria, and algae. The chief components of cell wall appears to be various types of carbohydrate or their mixtures (upto 80-90%) such as cellulose, pectose, callose etc., cellulose predominates in the cell wall of mastigomycotina (lower fungi) while in higher fungi chitin is present. The living protoplast of the fungal cell is enclosed in a cell membrane called as plasma membrane or plasmalemma. Cytoplasm contains organelles such as nucleus, mitochondria, Golgi apparatus, ribosomes, vacuoles, vesicles, microbodies, endoplasmic reticulum, lysosomes and microtubules.

The fungal nucleus has nuclear envelope comprising of two typical unit membrane and a central dense area known as nucleolus, which mainly consist of RNA. In multinucleate hyphae, the nuclei may be interconnected by the endoplasmic reticulum. Vacuoles present inside the cell provide turgor needed for cell growth and maintenance of cell shape. Beside the osmotic function, they also store reserve materials. The chief storage products of fungi are glycogen and lipid. The apex of the hyphae are usually rich in vesicles and are called as apical vesicular complex (AVC) which helps in the transportation of products formed by the secretary action of golgi apparatus to the site where these products are utilized.

Specialized Somatic Structures

Rhizoid

A rhizoid (Gr. *rhiza* = root + *oeides* = like) is a short, root-like filamentous outgrowth of the thallus generally formed in tufts at the base of small unicellular thalli or small porophores. Rhizoid serves as anchoring or attachment organ to the substratum and also as an organ of absorption of nutrients from substratum. Rhizoids are short, delicate filaments that contain protoplasm but no nuclei.

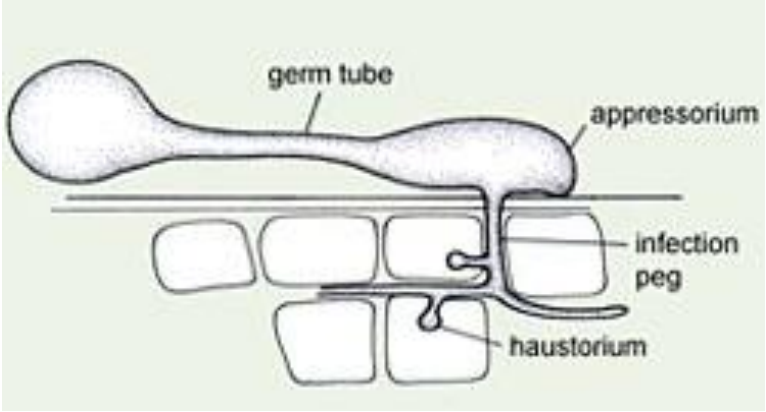


Rhizoids are common in lower fungi like Chytridiomycetes, Oomycetes and Zygomycetes. Some species produce a many-branched rhizomycelium. This is an extensive rhizoidal system that usually do not contains nuclei, but through which nuclei migrate. e.g.

Cladochytrium sp. On rhizomycelium numerous sporangia develop. Such thalli are polycentric, that is, they form several reproductive centres instead of a single one where the thallus is termed monocentric.

Appressorium

Appressorium (p1. appressorium; L. *apprimere* = to press against) is a simple or lobed structure of hyphal or germ tube and a pressing organ from which a minute infection peg usually grow and enter the epidermal cell of the host. It helps germ tube or hypha to attach to the surface of the host or substrates. These appressoria are formed from germ tubes of Uredinales (rust fungi), Erysiphales (powdery mildew fungi) and other fungi in their parasitic or saprophytic stages. In addition to giving anchorage, appressoria help the penetrating hyphae, branches to pierce the host cuticle. In fungi like *Colletotrichum falcatum*, germ tubes from conidia and resulting hyphae form appressoria on coming in contact with any hard surface like soil etc. These appressoria are thought to function as resting structures (chlamydospores) also.

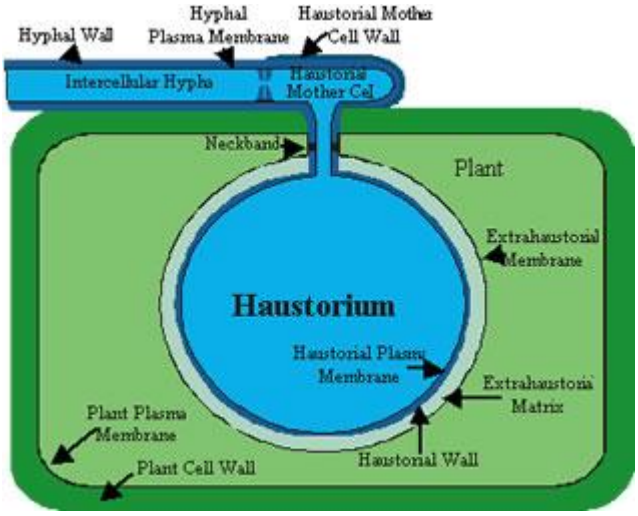


Haustoria

Haustoria (sing. haustorium; L. *haustor* = drinker) are special hyphal structures or outgrowths of somatic hyphae sent into the cell to absorb nutrients. The hyphal branch said to function as haustorium becomes extremely thin and pointed while piercing the hast cell wall and expands in the cell cavity to form a wider, simple or branched haustorium. Haustoria may be knob-like or balloon – like in shape, elongated or branched like a miniature root system.

The hyphae of obligate parasites of plants like downy mildew, powdery mildew or rust fungi late blight fungus etc ., produce haustoria. Hyphopodia: Hyphopodium (pl. hyphopodia Gr. *hyphe* = web + *pous* = foot) is a small appendage with one or two cells in length on an external hypha and function as absorbing structures. The terminal cell of hyphopodium is expanded and rounded or

pointed. Sometimes it produces a haustorium. e.g. Ectophytic fungi (*Meliola aesariae*) attacking leaves of green plants.



Aggregations of hyphae and tissues

a. Mycelial strand

Mycelial strands are aggregates of parallel or interwoven undifferentiated hyphae, which adhere closely and are frequently anastomosed or cemented together. They are relatively loose (e.g. *Sclerotium rolfsii* growth on culture medium) compared to rhizomorph. They have no well-defined apical meristem. Mycelial strand formation is quite common in Basidiomycetes, Ascomycetes and Deuteromycetes. Mycelial strands form the familiar 'spawn' of the cultivated mushroom, *Agaricus bisporus.* Mycelial strands are capable of translocating materials in both the directions. They are believed to afford means by which a fungus can extend an established food base and colonize a new substratum, by increasing the inoculum potential of the fungus at the point of colonization.

b. Rhizomorph

Rhizomorph (Gr. *rhiza*=root + *morphe* = shape) is the aggregation of highly differentiated hyphae with a well defined apical meristem, a central core of larger, thin walled, cells which are often darkly pigmented. These root-like aggregation is found in the honey fungus or honey agaric *Armillariella mellea (=Armillaria mellea)*. They grow faster than the mycelial strands. The growing tip of rhizomorph resembles that of a root tip. The fungus may spread underground from one root system to another by means of rhizomorph.

c. Fungal tissues

During certain stages of the life cycle of most fungi, the mycelium becomes organized into loosely or compactly woven tissues. These organized fungal tissues are called plectenchyma (Gr. *plekein* = to weave + *encyma* = infusion i.e., a woven tissue). There are two types of plectenchyma viz., prosenchyma and pseudoparenchyma. When the tissue is loosely woven and the hyphae lie parallel to one another it is called prosenchyma (Gr. *pros* = toward + *enchyma* = infusion, i.e., approaching a tissue). These tissues have distinguishable and typical elongated cells. Pseudoparenchyma (Gr. *Pseudo* = false) consists of closely packed, more or less isodiametric or oval cells resembling the parenchyma cells of vascular plants. In this type of tissues hyphae lose their individuality and are not distinguishable. Cells in prosenchyma are thin-walled and cells in pseudoparenchyma.

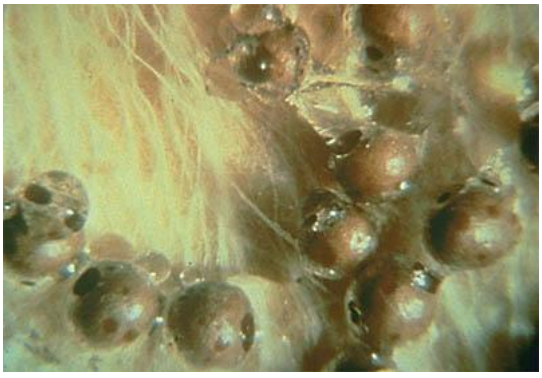
Stroma and sclerotium

Stromata and sclerotia are somatic structures of fungi.

i. Stroma (pl. stromata; Gr. *stroma* = mattress)

A stroma is a compact, somatic structure or hyphal aggregation similar to a mattress or a cushion, on which or in which fructifications of fungi are usually formed. They may be of various shapes and sizes. Hyphal masses like acervuli, sporodochia, pionnotes etc. are the fertile stromata, which bear sporophores producing spores.

ii. Sclerotium (pl. sclerotia; Gr. *skeleros* = hard)



A sclerotium is a resting body formed by aggregation of somatic hyphae into dense, rounded, flattened, elongated or horn-shaped dark masses. They are thick-walled resting structures, which contain food reserves. Sclerotia are hard structures resistant to unfavourable physical and chemical conditions. They may remain dormant for longer periods of time, sometimes for several years and germinate on the return of favourable conditions. The sclerotia on germination may be myceliogenous and produce directly the mycelium e.g. *Sclerotium rolfsii, Rhizoctonia solani* and *S. cepivorum* (white rot of onion).

They may be sporogenous and bear mass of spores. e.g. *Botrytis cinerea*. They may also be carpogenous where in they produce a spore fruit (ascocarps or basidiocarps) bearing stalk. e.g. *Sclerotinia sp. Claviceps purpurea* (ergot of rye). Development of ascocarps is seen in *Sclerotinia*, where stalked cups or apothecia, bearing asci, arise from sclerotia. In *Claviceps purpurea*, sclerotia germinate and give rise to drumstick like structures called perithecial stromata, which contain perithecia, flask-shaped cavities within which the asci are formed.

Mycorrhizae

Mycorrhiza (pl. mycorrhizae; Gr. *mykes* = mushroom + *rhiza* = root) is the symbiotic association between higher plant roots and fungal mycelia. Many plants in nature have mycorrhizal associations. Mycorrhizal plants increase the surface area of the root system for better absorption of nutrients from soil especially when the soils are deficient in phosphorus.

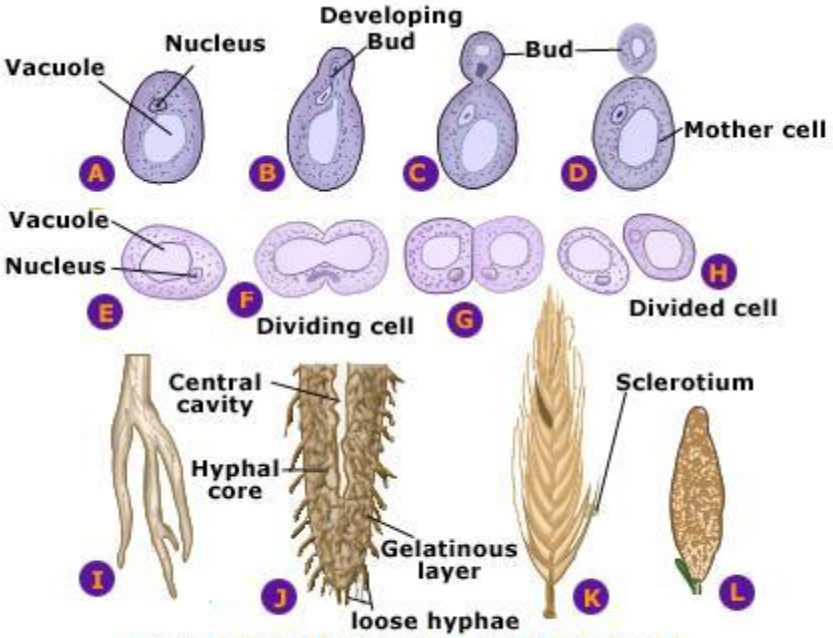
The nature of association is believed to be symbiotic (mutualism), non-pathogenic or weakly pathogenic. There are three types of mycorrhizal fungal associations with plant roots. They are ectotrophic or sheathing or ectomycorrhiza,. endotrophic or endomycorrhiza and ectendotrophicmycorrhiza.

REPRODUCTION

Reproduction is the formation of new individuals having all the characteristics typical of a species. The fungi reproduce by means of asexual and sexual or parasexual reproduction. Asexual reproduction is sometimes called somatic or vegetative and it does not involve union of nuclei, sex cells or sex organs. The union of two nuclei characterizes sexual reproduction.

ASEXUAL REPRODUCTION

In fungi, asexual reproduction is more important for the propagation of species. Asexual reproduction does not involve union of sex organs (gametangia) or sex cells (gametes) or nuclei. In fungi the following are the common methods of asexual reproduction.



Modes of vegetative reproduction in fungi.
A-D. Budding. E-H. Fission. I-J. Rhizomorph; K-I. Sclerotia

1. Fragmentation of mycelium

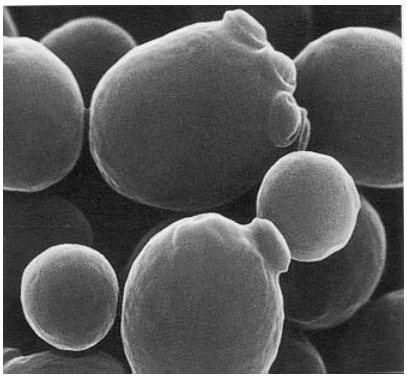
Mycelial fragments from any part of the thallus may grow into new individuals when suitable conditions are provided.

2. Fission of unicellular thalli

It is also known as transverse cell division. Reproduction by the method of fission is are in fungi. Fission is simple splitting of cells into two daughter cells by constriction and the formation of a cell wall. It is observed in *Schizosaccharomyces* spp

3. Budding

Budding is the production of a small outgrowth (bud) from a parent cell. As the bud is formed, the nucleus of the parent cell divides and one daughter nucleus migrates into the bud. The bud increases in size, while still attached to the parent cell and eventually breaks off and forms a new individual. It is common in yeasts.(*Saccharomyces* sp. *).*



Scanning electron micrograph of the budding yeast *Saccharomyces cerevisiae*.

4. Production of asexual spores

Reproduction by the production of spores is very common in many fungi.

SPORES

The term 'spore'(Gr. spora=seed, spore) is applied to any small propagative, reproductive or survival unit, which separates from a hypha or sporogenous cell and can grow independently into a new individual. Spores may be unicellular or multicellular. Multicellular spores are mostly with transverse septa and in some genera like *Alternaria* a spore will have both transverse and longitudinal septa. Each cell of a multicellular spore may be uninucleate, binucleate or multinucleate depending on the fungal species. The spores may be in different shapes and sizes.

They may be spherical, oval or ovate, obovate, pyriform, obpyriform, ellipsoid, cylindrical, oblong, allantoid, filiform or selecoid, falcate or fusion. The spores may be with or without simple or branched appendages. The spores may be motile or nonmotile. If the spores are motile they are called planospores (Gr. Planets = wanderer) and non-motile spores are called aplanospores. Spores may be thin or thick-walled, hyaline or coloured, smooth or with ornamented walls. The following types of ornamentations are found on the walls.

Asexual spores

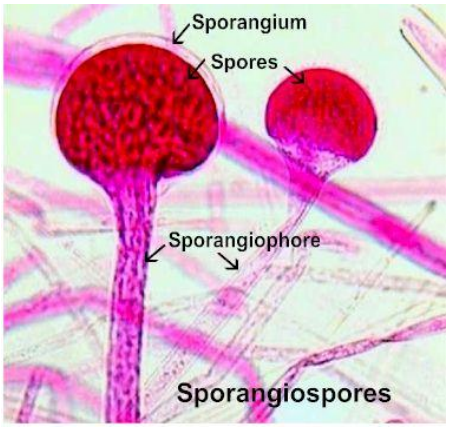
The spores produced asexual means are:

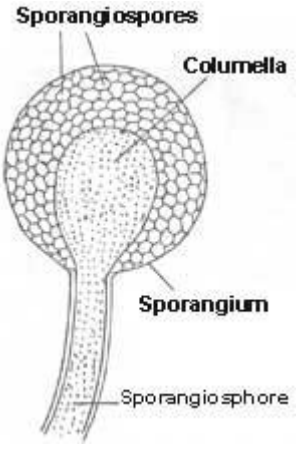
a. Sporangiospores

b. Conidia

c. Chlamydospores

a. Sporangiospores





Sporangiospores may be motile (planospores) or non-motile spores (aplanospores). In simpler fungi sporangiospores are usually motile and are called zoospores. These spores are produced in lower fungi, which inhabit aquatic or moist terrestrial substrates. sporangiospores are formed in globose or sac-like structure called sporangium (pl. sporangia; Gr. Spora = *seed*, spore + *angeion* = vessel). In the zygomycetes and especially in the

Mucorales, the non-motile asexual spores called aplanospores are contained in globose sporangia surrounding a central core or columella. Sporangia are also known in which there is no columella, or where the spores (aplanospores) are arranged in a row inside a cylindrical sac termed a *Merosporangium* (e.g. *Syncephalastrum* spp. Mucorales).

These aplanospores may be uni or multinucleate and are unicellular, generally smooth-walled, globose or ellipsoid in shape. When aplanospores mature, they may be surrounded by mucilage and rain splash or insects usually disperse such spores. When aplanospores are dry then are dispersed by wind currents. The sporangiospores for sporangium may vary from several thousands to only one. In some fungi few-spores sporangia are called *Sporangiola*. *Sporangiola* are dispersed as a unit. e.g. *Choanephora* sp. and *Blakeslee* sp. in Choanephoraceae of Mucorales. In holocarpic thalli, the entire thallus (without differentiation of a sporophore) becomes a sporangium. Its contents cleave into a number of segments which round off and become zoospores. In eucarpic thalli, a part of the thallus, or special branches from thallus, function as or produce sporangia.

In terrestrial and plant parasitic forms of lower fungi, the sporangium may function as spore and no zoospores are formed. In others zoospores are formed within the sporangium itself or the inner wall of the sporangium may grow out into a short or long tube which swells to form a vesicle. The contents of the sporangium move into a vesicle and the zoospores are differentiated. E.g. *Pythium aphanidermatum.*

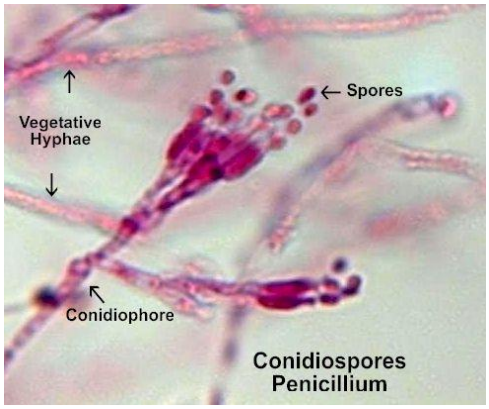
Zoospore (Gr. *Zoon* = animal + *spora* = seed, spore)

It is an asexually produced spore, which is motile by means of flagellum or flagella. Zoospore is naked and its covering is only a hyaloplasm membrane. Normally, zoospores are uninucleate and haploid. Zoospores may be spherical, oval, pyriform, obpyriform, elongate or reniform in shape. The zoospores are provided with one or two flagella (sing. flagellum, L. *flagellum*=whip) for its movement in the surrounding film of water. Flagellum is a hair-or tinsel-like structure that serves to propel a motile cell.

These flagella may be anterior, posterior or laterally attached to a groove in the body. There are two types of flagella in zoospores. They are whiplash and tinsel types. The whiplash flagellum has a long rigid base composed of all the eleven fibrils and a short flexible end formed of the two central fibrils only. The tinsel flagellum has a rachis, which is covered on all sides along its centre length with short fibrils. In uniflagellate zoospores the flagellum may be anterior

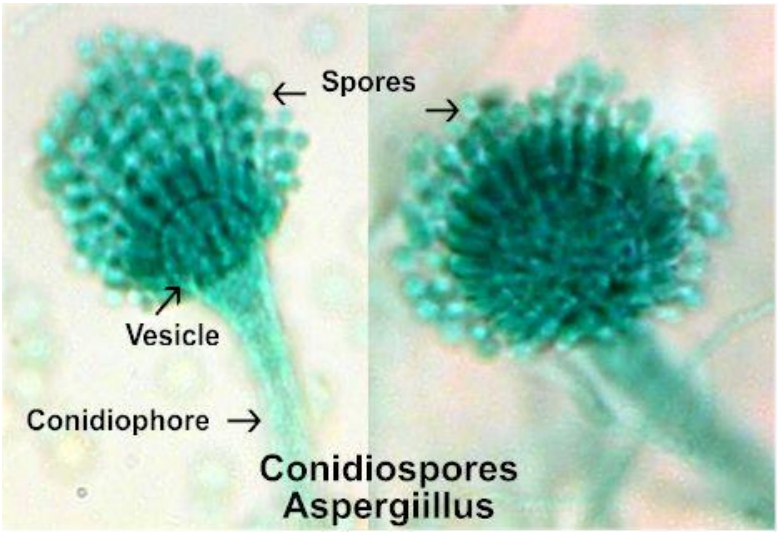
or posterior. But in biflagellate zoospores one is whiplash and the other is tinsel type and one points forward and the other backward. But in Plasmodiophorales fungi flagella are of whiplash type and unequal.

Zoospores pass through the three phases viz., motility, encasement and germination. The length of their motility depends on available moisture, temperature and presence of stimulatory or inhibitory substances in the environment. Later the zoospores become sluggish, spend or cast their flagella (except in chytridiacious fungi and primary zoospores in Saprolegniales where flagella are shed but withdrawn into its body become spherical and secrete thin wall around itself and become encysted. The encysted zoospores germinate. The functions of zoospores include initiation of new generation and acting as gametes.



b. Conidiospores

Conidiospores or conidia (sing. Conidium) are asexual reproductive structures borne on special spore bearing hyphae conidiophores. They are found in many different groups of fungi, but especially in ascomycotina, Basidiomycotina and Deuteromycotina. In Deuteromycotina conidia are the only means of reproduction. Conidia may be borne singly or in chains or in cluster. They vary from unicellular (e.g. *Colletotrichum),* bicellular, microconidia of *Fusarium* spp. and multicellular (*Pestalotiopsis*, *Cercospora*). One-celled spores are called amerospores, two celled spores are didymospores and multicellular spores are called phragmospores. The multicellular conidia may be divided by the septa in one to three planes. In *Alternaria* spp., conidia are with both transverse and longitudinal septa are called dictyospores.



The shape of the conidium may vary. They may be globose, elliptical, ovoid, cylindrical, branched or spirally coiled or star-shaped (staurospores). The colour of the conidia may be

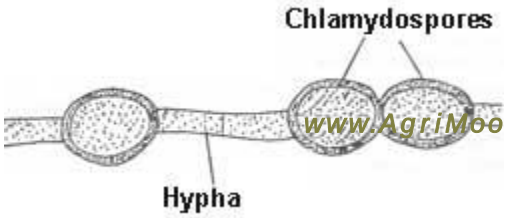
hyaline (hyalospore) or coloured (phaeospore) pink, green, or dark. The dark pigments are probably melanins. The colour of the conidia and conidiophores are important features used in classification. In the order Entomophthorales (e.g. *Basidiobolus, Pilobolus*) asexual reproduction is by means or forcibly discharged uninucleate or multinucleate primary conidia. On germination primary conidia develops uninucleate or binucleate secondary conidia. In species of Fusarium one or two-celled microconidia and many-celled macroconidia are common.

Conidia may be formed in acropetal (oldest conidium at the base and the youngest at the apex) or basipetal (oldest conidium at the apex and youngest at the base) succession. Generally the term 'conidia'is used for any asexual spores other than sporangia and spores formed directly by hyphal cells. When the spore is not much differentiated from the cells of the conidiophore in shape the term oidium is often used for conidia. A distinction between sporangiospores and conidia is that, before germination of sporangiospores a new wall, eventually continuous with the germ tube, is laid down within the original spore wall whilst in conidia there is no new wall layer laid down. Conidiophores are also known as sporophores. They are special hyphae bearing conidia.

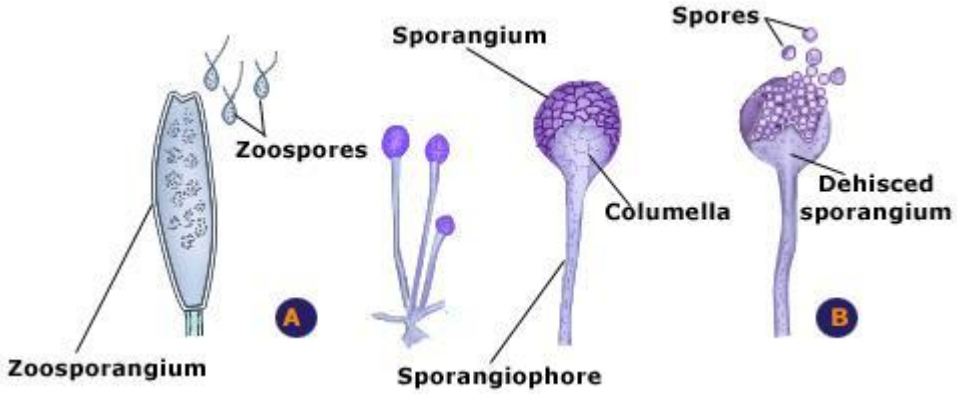
They may be free, simple or branched. They may be distinct from each other or may be aggregated to form compound sporophores or fruiting bodies such as synnemata, sporodochia, acervuli and pycnidia. They may be provided with sterigmata or specialized branches on which they bear conidia. Some conidial spores are inflated at the tips (e.g. *Aspergillus*); others are inflated at intervals, forming kneelike structures on which the conidia are grouped (*Gonatobotrys*); still others have many branches, which are characteristically arranged, in whorls (*Verticillium*) or in sympodium (*Monopodium*). They are generally produced on the surface of the host. The sporogenous part of the conidiophore is commonly apical but may be laterally placed. The apical zone of differentiation of conidiophore may give rise to a single conidium or more often, to a succession of conidia in chains, false heads.

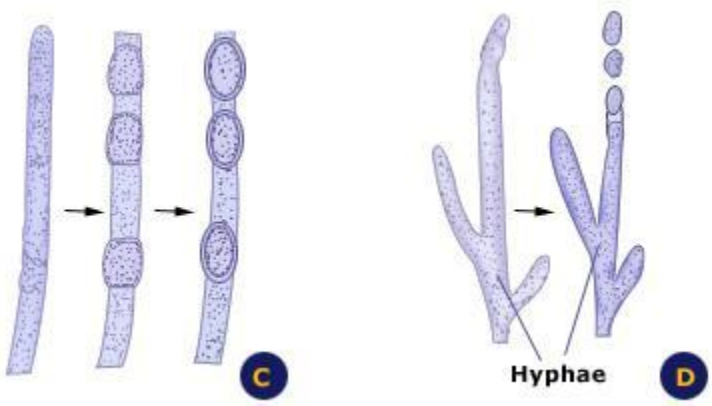
c. Chlamydospores

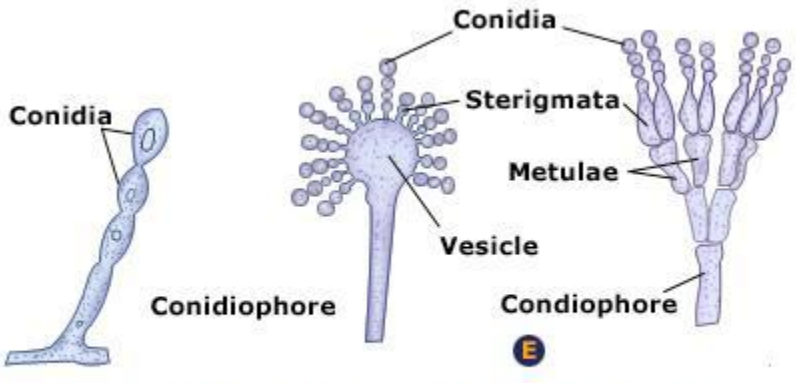
Chlamydospore (Gr. *Chlamys* = mantle + *spora* = seed, spore) is a thick-walled thallic conidium that generally function as a resting spore. Terminal or intercalary segments or mycelium may become packed with food reserves and develop thick walls. The walls may be colourless or pigmented with dark melanin pigment.



These structures are known as chlamydospores. e.g. *Fusarium*, *Mucor racemosus*, *Saprolegnia.* Generally there is no mechanism for detachment and dispersal of chlamydospores. They become separated from each other by the disintegration of intervening hyphae. They are the important organs or asexual survival in soil fungi. When chlamydospores are found in between fungal cells they are called 'intercalary chlamydospores'. Chlamydospores produced at the apex of the hypha are called 'apical or terminal chlamydospores'.







A. Zoospores; B. Sporangiospores; C. Chalmydospores; D. Oidia; E. Conidia

SEXUAL REPRODUCTION

Sexual reproduction in fungi involves union of two compatible nuclei. The nuclei may be carried in motile or non-motile gametes, in gametangia or in somatic cells of the thallus.

Phases of sexual reproduction

Three typical phases occur in sequence during the sexual reproduction.

1. Plasmogamy

In plasmogamy (Gr. *plasma*=a molded object, i.e. a being + *gamos* = marriage, union) anastomosis of two cells or gametes and fusion of their protoplasts take place. In the process the two haploid nuclei of opposite sexes (compatible nuclei) are brought together but eh nuclei will not fuse.

2. Karyogamy

The fusion of two haploid nuclei brought together as a result of plasmogamy is called karyogamy (Gr. *karyon* = nut, nucleus + *gamos* = marriage). This stage follows immediately after plasmogamy in many of the lower fungi or may be delayed in higher fungi. In higher fungi plasmogamy results in a binucleate cell containing one nucleus from each cell. Such a pair of nuclei is called dikaryon(NL. *Di* = two + Gr. *karyon* = nut). These two nuclei may not fuse until later in the life history of the fungus. Meanwhile, during growth and cell division of the binucleate cell, the dikaryotic condition may be perpetuated from cell to cell by conjugate division of the two closely associated nuclei and by the separation of the resulting sister nuclei with two daughter cells. Nuclear fusion, which eventually takes place in all sexually reproducing fungi, is followed by meiosis.

3. Meiosis

Karyogamy results in the formation of a diploid (2n) nucleus. Meiosis (Gr. *meiosis*=reduction) reduces the number of chromosomes to haploid and constitutes the third phase of the sexual reproduction. This nucleus undergoes a reduction division to form two haploid nuclei each with 'n'chromosomes. A mitotic division follows and four nuclei are formed. In ascomycetes another nuclear division takes place resulting in the formation eight nuclei. The nuclei get surrounded by a small amount of cytoplasm and secrete a wall to become spores.

In a true sexual cycle, the above three phases occur in a regular sequence and usually at specified points. If there is only one free living thallus, haploid or diploid in the life cycle of a fungus is called haplobiontic (Gr. *haplos* = single + *bios* = life). e.g. Oomycetes haploid gamete and diploid mycelium. If a haploid thallus alternates with a diploid, the life cycle is called diplobiontic (Gr. *diplos* = double + *bios* = life). e.g. *Allomyces* (water mold *Coelomomyces*, mosquito parasite) and in some yeasts.

Organs involved in sexual reproduction

Fungi, which produce morphologically distinguishable male and female sex organs in each thallus, are called hermaphroditic (Gr. *hermes* = the messenger of the Gods, symbol of the male sex + aphrodite = the Goddess of love, symbol of female sex) or monoecious or *unisexual* (Gr. *monos* = single, one + *oikos* = dwelling, home). A single thallus of a monoecious fungi can reproduce sexually by itself if it is self-compatible. In a fungus when the female and male organs are produced on two different thalli it is said to be dioecious or bisexual. (Gr. *dis* = twice, two + *oikos* = home; i.e.; the sexes separated into two different individuals). Normally a single thallus of a dioecious fungus cannot reproduce sexually by itself as the thallus is either male or female.

The sex organs of fungi are called gametangia (sing. gametangium; Gr. *gametes* = husband + *angeion* = vessel, container). Sex cells are called gametes and the mother cells (sex organs) are called gametangia. If the gametes and gametangia produced are morphologically identical or similar they are called as isogametes (Gr. *ison* = equal) and isogametangia respectively. When the gametes and gametangia produced differ in size and structure (morphologically different) they are called heterogametes (Gr. *heteros* = other, different) and heterogametangia respectively. In the latter case, the male gametangium is called antheridium (pl. antheridia; Gr. antheros = flowery + *idion*, dimin. suffix) and the female gametangium is

called oogonium (pl. oogonia; Gr. *oon* = egg + *gonos* = offspring). The male gamete is known as antherozoid or sperm and the female as an egg or oosphere.

Methods of sexual reproduction

The following are the five methods, which the fungi employ to bring the compatible nuclei together for fusion.

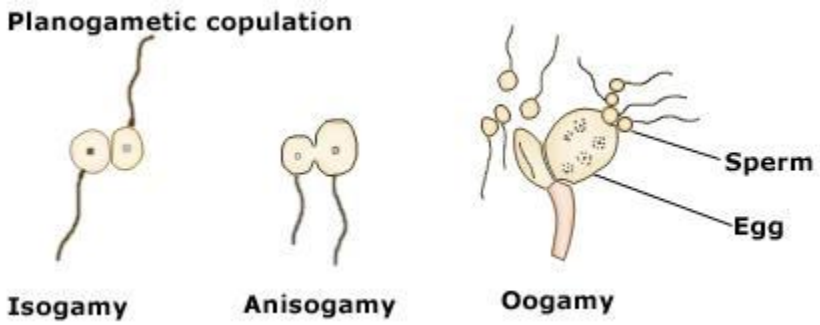
1. Planogametic copulation
2.Gametangial contact (Gametangy)
3. Gametangial copulation (Gametangiogamy)
4. Spermatization
5. Somatogamy

1. Planogametic copulation or conjugation

A planogamate is a motile gamete or sex cell. The fusion of two gametes, one or both of which are motile is called planogametic copulation. This type of sexual reproduction is common in aquatic fungi. There are three different types of planogametic copulation.

a. Copulation of isogamous motile gametes

In this type morphologically similar butcompatible type of mating type of gametes unite to form a motile zygote. e.g. *Synchytrium.*



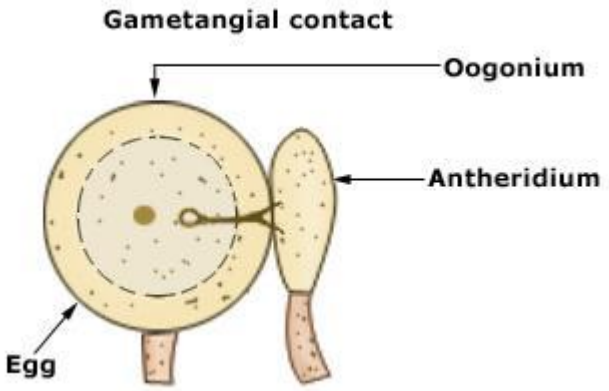
b. Copulation in anisogamous motile gametes

It involves union of one larger gamete with another smaller gamete. The resultant zygote is motile. The zygote resulting from isogamous or anisogamous planogametic copulation forms a 'resting sporangium'. On further development it functions as sporangium by differentiating zoospores internally.

c. Heterogamous planogametic copulation

In this type, a non-motile female gamete (oosphere) is fertilized by a motile male gamete. This results in the formation of oospores, a resistant structure and resting spore. Oospores germinate and produce mycelium directly.

2. Gametangial contact

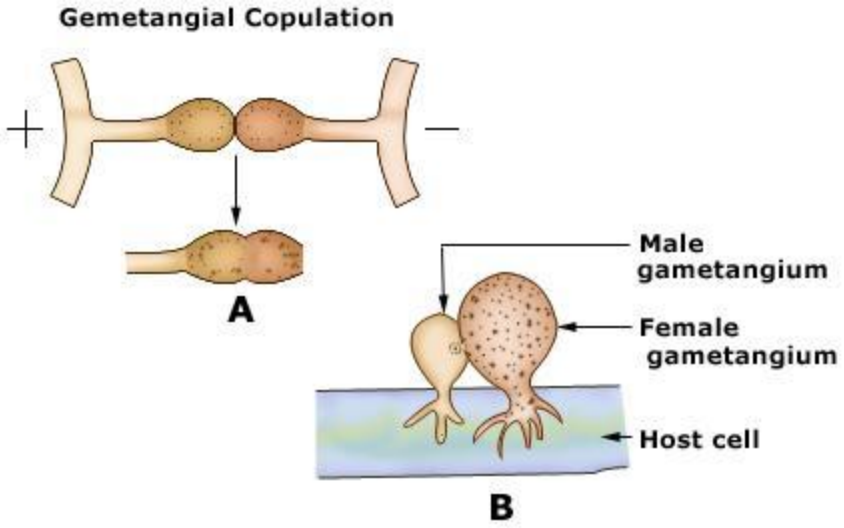


In this method the male gamete (antheridium) and the female gamete (oogonium) come in contact and one or more nuclei from the male gamete enter the female gamete, oogonium dissolved in the intervening wall through a pore or through a fertilization tube. In no case the gametangia actually fuse or lose their identify during the sexual act. e.g. Fungi in Peronosporales. Gametangial contact is also common in some Ascomycotina where antheridia and female organs (archigonia or ascogonia) may or may not be well defined.

3. Gametangial copulation: This is a process of fusion of entire contents of the two mating gametangia. There are two types.

a. Mixing of entire protoplasm of male and female gametangia

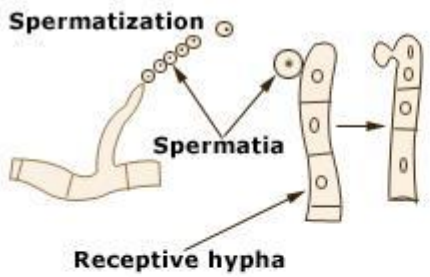
Two gametangia meet and their entire contents fuse in the female gametangium leading to formation of a zygote. The zygote forms a resting sporangium. e.g. Aquatic fungi (Chytridiomycetes).



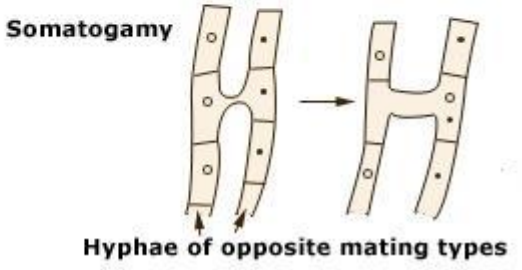
b. Isogamous copulation

Two morphologically similar gametangial hyphae come in contact, the wall at the point of contact dissolves and the contents mix in the cell thus formed. This results in the formation of zygospore. e.g. *Mucor, Rhizopus, Phycomyces*.

4. Spermatization



Some fungi like rusts bear numerous minute, non-motile uninucleate, male cells called spermatia. (sing. spermatium; Gr. *spermation*=little seed) Spermatia are produced in spiral receptacles called spermagonia (sing. spermagonium; Gr. Sperma =seed, sperm+ gennao=I give birth) or pycnia (sing. pycnium; Gr. *pycnos*=concentrated). Insects, wind or water to the female gametangium carries them, which is usually a special receptive hypha (or trichogyne) to which they become attached. A pore develops at the point of contact and the contents of spermatium pass into the particular respective hyphae. This results in plasmogamy and initiation of the dikaryotic stage of the cell.



5. Somatogamy

In somatogamy to sex organs are produced and somatic cells function as gametes somatogamy (Gr. *soma* = body + gamos = marriage, union) hyphae anastomose and the nuclei of opposite matting type are brought together in one cell. Somatogamy is common in Ascomycotina and Basidiomycotina fungi.

Heterokaryosis

The phenomenon of existence of different kinds of nuclei in the same individual is known as heterokaryosis. (Gr. *heteros* = other+ *karyon*=nut, nucleus). The individual which exhibit heterokaryosis is called heterokaryon or heterokaryotic. It has been demonstrated in numerous Ascomycetes, Basidiomycetes and Fungi Imperfecti (Davis, 1966). In a heterokaryotic individual, each nucleus is independent of all other nuclei, but the structure and behaviour of the

individual appear to be controlled by the kinds of genes it contains and the proportion of each kind. Heterokaryosis may arise in a fungal thallus in four ways:

1. By the germination of a heterokaryotic spore, which will give rise to a heterokaryotic soma.
2. By the introduction of genetically different nuclei into homokaryon (Gr. homo=same + karyon = nut, nucleus), a soma in which all nuclei are similar.
3. By mutation, in a multinucleate homokaryon.The mutant nuclei subsequently survive, multiply and spread among the wild-type nuclei.
4. By fusion of some nuclei in a haploid homokaryon to form diploid nuclei which subsequently survive, multiply and spread among the haploid nuclei. Thus in some fungi it is possible to have different kinds of haploid nuclei in the same soma and a mixture of haploid and diploid nuclei. In most fungal individuals, the haploid and diploid phases of the life cycle are clearly distinguishable.

Parasexuality or parasexual cycle

Some fungi (Deuteromycetes) do not go through a sexual cycle but derive many of the benefits of sexuality through parasexuality (Gr. *para* =beside+sex). This is a process in which plasmogamy, karyogamy and haploidization takes place, but not at specified points in the thallus or the life cycle of an organism. Parasexual cycle is very important in Deuteromycetes where sexual reproduction does not take place. Some fungi, which reproduce sexually, also exhibit parasexuality.

Pontecorvo and Roper from the University of Glasgow in Aspergillus nidulans, the imperfect stage of Emericella nidulans first discovered parasexuality in 1952. Since then it has been reported in number of fungi in Ascomycotina, *Cochliobolus sativus*, (imperfect state: *Bipolaris sorokiniana* (syn . *Helminthosporium sativum) Leptosphaeria maculans* etc.), *Basidiomycotina Puccinia graminis, Melampsora lini, Ustilago maydis, U. hordei, Schizophyllum commune, Coprinus lagopus* and *Deuteromycotina. Ascochyta imperfecta, Aspergillus amstelodami, A. fumigatus , A. rugulosus, A. oryzae, A. sojae, A. niger , Fusarium. oxysporum* f.sp. *cubense, F. oxysporum* f.sp. *callistephi, Phymatotrichum omnivorum, Pyricularia oryzae, Penicillium italicum, Penicillium chrysogenum Verticillium albo-atrum*.

The sequence of events in a complete parasexual cycle is as follows.

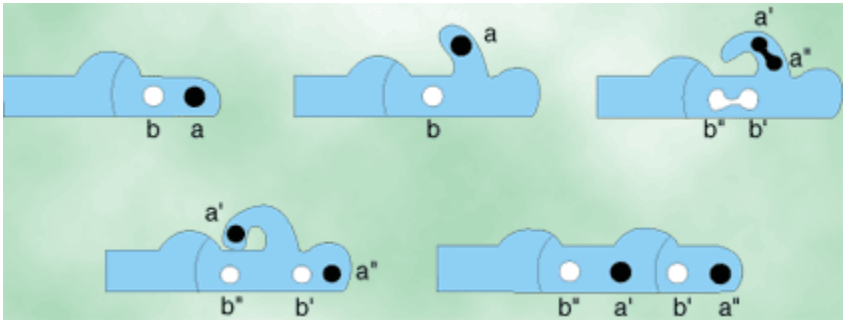
1. Formation of heterokaryotic mycelium
2. Fusion between two nuclei
    a. Fusion between like nuclei
    b. Fusion between unlike nuclei
3. Multiplication of diploid nuclei side by side with the haploid nuclei
4. Occasional mitotic crossing-over during the multiplication of the diploid nuclei
5. Sorting out of diploid nuclei
6. Occasional haploidization of the diploid nuclei
7. Sorting out of new haploid strains

Anastomosis

The important cause for heterokaryosis is anastomosis. Anastomosis involves fusion of hyphae of some species, movement of one or more nuclei into one or the other of the fused cells, and the establishment of a compatible heterokaryotic state. A similar nuclear displacement may occur in adjacent cells of the same hypha by formation of clamp connections through which nucleus or nuclei from one cell move into another.

Clamp connection

Clamp connection is a mechanism found in Basidiomycetes. It is a bridge-like hyphal connection characteristic of the secondary mycelium in many Basidiomycetes. In ensure that sister nuclei arising from conjugate division of the dikaryon become separated into two daughter cells. Clamp connections are found during nuclear division and supposed to help in dikaryotization of adjacent cells.



Sexual spores

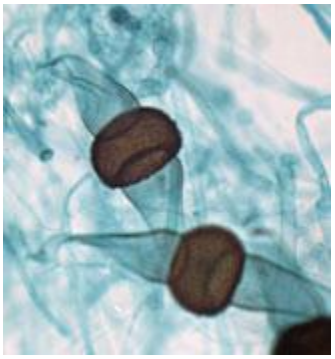
The sexual spores are formed as a result of fusion between two opposite sex gametes. They are resting spores, incapable of germination immediately after formation. Sexual spores are

oospores, zygospores, ascospores and basidiospores desiring their names from the class to which the fungi belong.

1. Oospores

An oospore (Gr.*oon* = egg + *spora* = seed, spore) is a sexually produced spore, which develops from unequal gametangial copulation or markedly unequal gametic fusion. It is the characteristic sexually produced spore of oomycetes. Oospores develop from fertilized oospheres (Gr. *oon* = egg + *sphaira* = sphere). One or more oospheres develop within 'oogonia', which are multinucleate, globose and female gametangia

2. Zygospores



Zygospores (Gr. *zygos* = yoke + *spora* = seed, spore) are sexually produced resting spores or structures formed as a result of plasmogamy between two gametangia, which are usually equal in size. They are resting structures. Zygospores are the typical sexually produced spores of Zygomycetes e.g. Mucorales and Entomophthorales. Zygospores are often large, thick-walled, warty structures with large food reserves and are unsuitable for long distance dispersal.

3. Ascospores

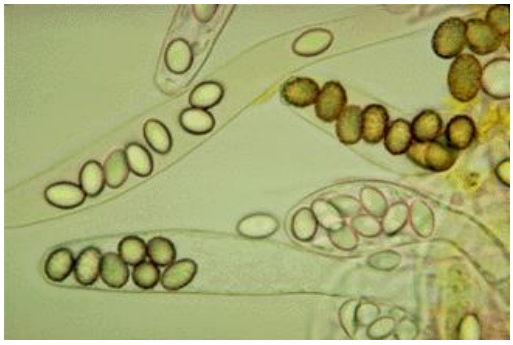
Ascospores (Gr. *askos* = sac + *spora* = seed, spore) are the characteristic spores of the large group of fungi known as Ascomycotina. They are formed as a result of nuclear fusion immediately followed by meiosis. The four haploid daughter nuclei then divide mitotically to give eight haploid nuclei around which the ascospores are cut out. In most ascomycetes, the eight ascospores are contained within a cylindrical sac or ascus from which they are forcible ejected by a squirting process in which the ascus contents, consisting of ascospores and ascus sap, are ejected by explosive breakdown of the tip of the turgid ascus whose elastic walls contract.

Ascospores vary greatly in size, shape, colour and wall ornamentation. In size, the range is from 4-5 x 1µm in small-spored forms such as minute cup fungus, Dasyscyphus to 130 x 45µm in lichen, Pertusaria pertusa, which is a symbiotic association between an ascomycetes and a green alga. Ascospore shape varies from globose, oval, elliptical, lemon shaped sausage-

shaped, cylindrical or needle-shaped. Ascospores may be uninucleate or multinucleate, unicellular or multicellular, divided up by transverse or by transverse and longitudinal septa.

The wall may be thin or thick, hyaline or coloured, smooth or rough, sometimes folded into reticulate folds and may have a mucilaginous outer layer which may be extended to form simple or branched appendages. In general, ascospores are resting structures, which survive adverse conditions. They may have extensive food reserves in the form of lipid and sugars such as trehalose.

Ascus



Ascus (pl. *asci;* Gr. *askos* = sac) is a sac-like cell generally containing a definite number of ascospores (typically eight) formed by free cell formation usually after karyogamy and meiosis. In the large majority of the Ascomycetes the asci are elongated, either club-shaped or cylindrical. But globose, ovoid or rectangular asci are also found. Ordinarily the ascus represents a single cell in which the ascospores are formed. Asci may be stalked or sessile, they may arise from a common fascicle and spread out like a fan or they may arise simply at various levels within the fruiting body.

Development of ascus

Ascus develops from a specialized hypha called, ascogenous hypha, which in turn develops from an ascogonium. The ascogenous hypha is multinucleate, and its tip is recurved to form a crozier (Shepherd's crook). Within the ascogenous hypha nuclear division occurs simultaneously. Two septa at the tip of the crozier cut off a penultimate cell destined to become an ascus. The terminal cell of the crozier curves round and fuses with the ascogenous hypha behind the penultimate cell, and this region of the ascogenous hypha may grow on to form a new crozier in which the same sequence of events is repeated. Repeated proliferation of the tip of the crozier can result in a cluster of asci. In the ascus initial the two nuclei fuse and the fusion nucleus undergoes meiosis to form four haploid daughter nuclei.

These nuclei then undergo a mitotic division so that eight haploid nuclei result. During these nuclear divisions the ascus is elongating and the plane of the division is parallel to the length of the ascus. Cytoplasm is cleared out around each nuclei to form an ascospore. In some

forms the eight nuclei divide further so that each ascospore is binucleate. Where the ascospores are multicellular there are repeated nuclear divisions. In some forms more than eight ascospores are formed or the eight ascospores may break up into part-spores. Double membranes form a cylindrical envelope lining the young ascus. The lining layer is termed as ascus vesicle or ascospore membrane. Between the two layers forming the membrane, the spore wall is secreted, and the inner membrane forms the plasma membrane of the ascospore.

The forms of asci vary. The ascus with non-explosive ascospore release is often a globose sac. But in the majority of the Ascomycetes, the ascus is cylindrical and the ascospores are expelled from the ascus explosively. It is thought that the explosive release follows increased turgour caused by water uptake. In many cases the asci are surrounded by packing tissue in the form of paraphyses, pseudoparaphyses and other asci, so that they can expand laterally but are forced to elongate. In the cup fungi or Discomycetes the elongation of asci raises their tips above the general level of the hymenium. The ascus tips are often phototropic and when the increased pressure causes the ascus tip to burst, the spores are shot out in a drop of liquid, the ascus sap. In this group, a large number of asci may be is charged simultaneously, so that a cloud of ascospores is visible. This phenomenon is known as puffing. In some Discomycetes (e.g. the Pezizales) the ascus tip is surrounded by a cap or operculum, which is blown aside or actually blown off the tip of the ascus by the force of explosion. However, in other Discomycetes (e.g. the Helotiales) the ascus tip is perforated by a pore and there is no operculum. These two types of asci are respectively termed *operculate* and *inoperculate* and the presence or absence of an operculum is an important feature of classification.

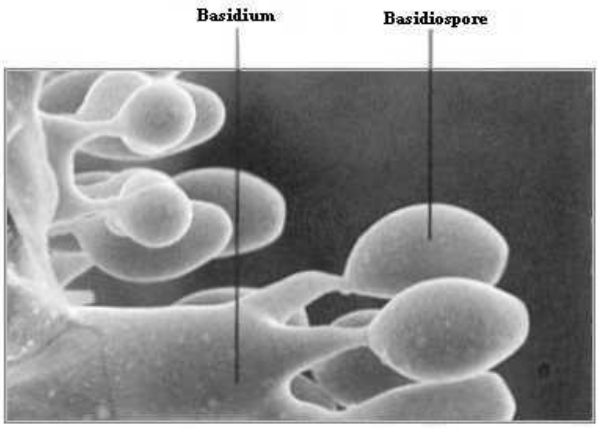
In a flask-fungi (Pyrenomycetes) the asci are enclosed in a cavity, which opens to the exterior through a narrow pore, the ostiole. As an ascus ripens, it elongates and takes up a position inside the ostiole, often gripped in position by a lining layer of hairs, periphyses. In this case the asci discharge their spores singly and puffing does not happen.

Asci of Pyrenomycetes are never operculate in many groups, the ascus tip has a distinctive apical apparatus. In many pyrenomycetes, there is an apical ring or annulus when the ascus explodes, the apical ring is everted and is believed to grip the ascospores as they are ejected. If the wall of the ascus is single it is called unitunicate and if the wall of the ascus is double it is called bitunicate. Loculoascomycetes have bitunicate asci. In bitunicate asci there are two wall layers, which physically separate from each other. The outer layer is termed or

ectoascus *or* ectotunica and the inner layer is called the endoascus or endotunica. Both the layers are made up of microfibrils embedded in an amorphous matrix. The two layers differ only in the arrangement of microfibrils.

Ascospores of *Venturia inaequalis* in asci.

4. Basidiospores



Basidiospore (Gr. *Basidion* = small base + *spora* = seed, spore) is a spore borne on the outside of a basidium, following karyogamy and meiosis. Basidiospores are more uniform compared to ascospores. Typically they are unicellular, but transversely septate spores are found in certain groups like Dacrymycetaceae (Reid, 1974) In shape, they vary from globose, sausage-shaped, fusoid, almond-shaped (i.e. flattened) and the wall may be smooth or ornamented with spores, ridges or folds. The colour of basidiospores is an important criterion of classification.

They may be colourless, white, cream, yellowish, brown, pink, purple or black. The spore colour may be due to coloured substances in the cytoplasm of the spore or in the spore wall. This explains the change of colour of a mushroom gill from pink when immature, due to cytoplasmic spore pigments to purple when mature due to wall pigments.

The spore is attached to the basidium at the tip of a 'sterigmata', a curve horn -like prong projecting from the apex of the basidium. The spore is projected for a short distance from a basidium. The point at which the spore is attached to the sterigma is 'hilum'. Hilum is usually found at the tip of a short conical projection, the 'hilar appendix' (Fig.31). The term ballistospores is used to describe basidiospores, which are violently projected from their sterigmata. Most basidiospores are ballistospores and in Gasteromycetes basidiospores are not projected violently.

Basidium (pl. basidia, Gr. *basidion* = a small base) is a spore bearing structure bearing on its surface a definite number of basidiospores (typically four) that are usually formed following karyogamy and meiosis. In contrast with the endogenous spores of the ascus, basidia bear spores exogenously, usually on projections called 'sterigmata'. The number of spores per basidium is typically four, but two spored basidia are quite common. There may be nine spores per basidium in *Phallus impudicus*.

Basidia vary in structure and the form of the basidium is an important criterion in classification. In the toadstools the basidium is a single cylindrical cell, undivided by septa, typically bearing four basidiospores at its apex. Such basidia are called 'holobasidia'

In the Uredinales and Ustilaginales the basidium develops from a thick-walled cell (teliospore or chlamydospore) and is usually divided into four cells by three transverse septa. Transversely segmented basidia are also found in the Auriculariaceae, but here the basidia do not arise from resting cells. In the Tremellaceae, the basidia are longitudinally divided into four cells, while in the Dacrymycetaceae the basidium is unsegmented but forked into two long arms, to form the tuning type of basidium. Segmented basidia are sometimes termed phragmobasidia (or heterobasidia).

Development of basidium

The development of basidium is well illustrated in *Oudemansiella radicata* (Syn. *Collybia radicata*) (Fig.30). The basidium arises as a terminal cell of a hypha making up the gill tissue on the underside of the cap of the fruit body. The basidia are packed together to form a fertile layer or hymenium. A basidium is at first densely packed with cytoplasm, but soon several small vacuoles appear. Later, a single large vacuole develops at the base of the basidium and, by the enlargement of this vacuole, cytoplasm is pushed towards the end of the basidium. A clear

cap is visible at the tip and it is here that the sterigmata develop. In the fully developed basidium the spores are full of cytoplasm while the body of the basidium contains only a thin lining of cytoplasm, surrounding an enlarged vacuole. Young basidia are binucleate, and nuclear fusion occurs here. The resulting fusion nucleus undergoes meiosis immediately, so that four haploid daughter nuclei result, and one is distributed to each basidiospore. In some basidia a mitotic division follows meiosis, so that some basidiospores are binucleate.

Reproductive structures

Fungi reproduce by means of their propagules. In most fungi the propagules are differentiated as spores. But in some fungi the stromatic aggregations of hyphae like the sclerotia also perform the function of propagation. The simple or branched spore-bearing hyphae are known as sporophores, but in some fungi the spores may be formed directly by the hyphal cell e.g. chlamydospores. In general spore formation starts when the vegetative growth has reached a certain development.

Types of sporophores

Spore bearing or sporogenous organs (sporophores) develop as special branches from the vegetative hyphae. There are two types of sporophores viz., simple and compound. The spore bearing branches usually arise vertically and may be distinctly branched. When these branches bear sporangia they are called sporangiophores (as in Oomycetes of Mastigomycotina and Zygomycotina When the spore bearing branches bear conidia they are called conidiophores (as in Ascomycotina and Deuteromycotina). These sporangiophores and conidiophores are called simple or filamentous sporophores. Aggregation of hyphae from stromatic or semistromatic structures and grows into compound sporophores. They contain or bear layers of sporogenous cells and spores and form the fructifications and fruit bodies. e.g. stipes formed by germination of sclerotia in Ascomycotina and by higher basidiomycotina.

Fructifications and fruit bodies

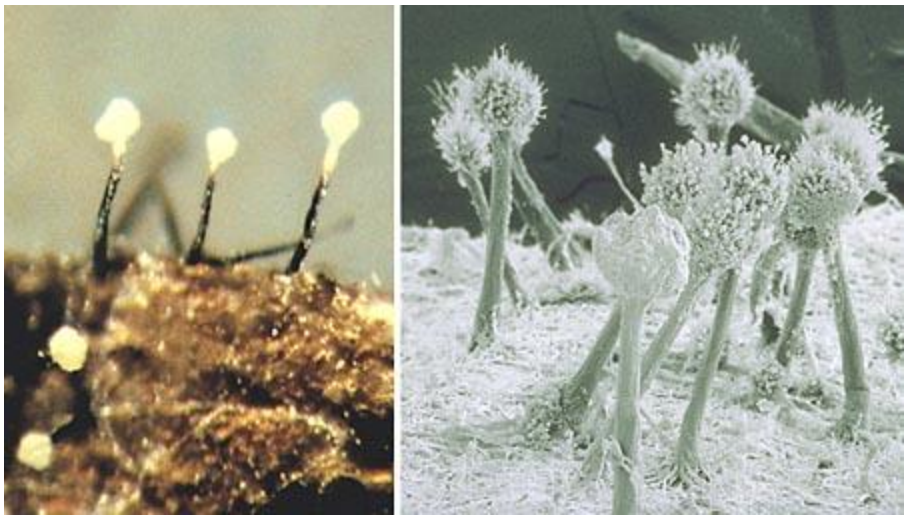
The sporophores bear fruiting bodies or form fructifications, which may be asexual or sexual in nature. In lower fungi Plasmodiophoromycetes, Chytridiomycetes, Oomycetes and Zygomycotina) asexual spores are usually enclosed in simple sacs called sporangia or zoosporangia. In higher fungi (Ascomycetes and Basidiomycetes) complex aggregates of spore bearing hyphae are formed and supporting and protective tissues surround it. These complex structures are called as spore fruits or fructifications (L.*fructus* = fruit).

Asexual fructifications

In fungi conidiophores are grouped together to form specialized structures such as synnemata (sing. synnema) and sporodochia (sing. sporodochium) or produced in fructifications known as pycnidia (sing. pycnidium) and acervuli (sing. acervulus).

a. Synnema or coremium

Synnema or Coremium (pl. coremia) Consists of a group of conidiophores often united at the base and part way up the top. Conidia may be formed along the length of the synnema or only at its apex. The conidiophores comprising a synnema are often branched at the top with the conidia arising from the conidiogenous cells at the tips of the numerous branches. e.g. Deuteromycotina *(Arthrobotryum* sp (Fig), *Penicillium claviforme, Doratomyces stemonitis, Ceratocystis ulmi.*



synnema: (pl. synnemata; syn. coremium) compact or fused, generally upright conidiophores, with branches and spores forming a headlike cluster

[synnemata of *Ophiostoma (Graphium) ulmi]*

b. Sporodochium

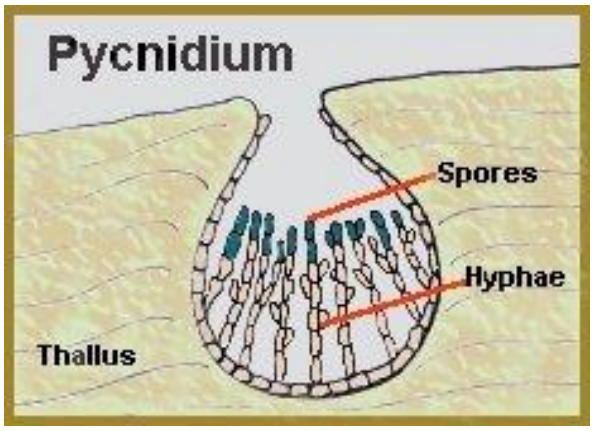
Sporodochium is a fruiting body in which conidiophores arise from a central cushion-like aggregation of hyphae. The conidiophores are packed tightly together and are generally shorter than those composing a synnema. e.g. *Epicoccum, Nectria.*

sporodochium: (pl. sporodochia)

Superficial, cushion-shaped asexual fruiting body consisting of a cluster of conidiophores

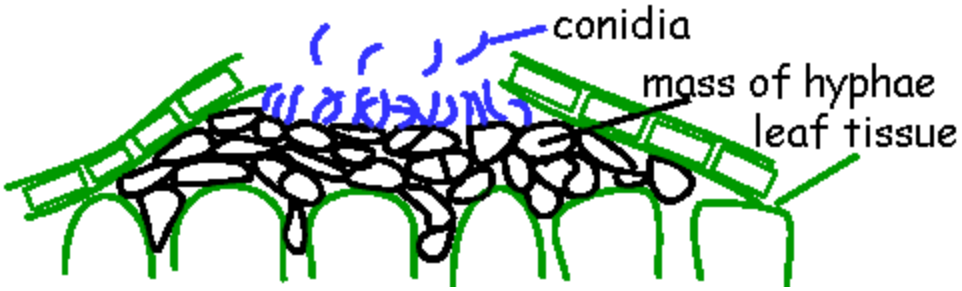
c. Pycnidium

Pycnidium is a globose or flask-shaped body, which is lined on the inside with conidiophores. e.g. *Septoria ,Phoma, Ascochyta, Leptosphaeria.* Pycnidia may be completely closed or may have an opening. The opening or mouth of pycnidium is called ostiole (L. *ostiolum* = little door). They may be provided with a small papilla or with a long neck leading to the opening. Pycnidia vary greatly in size, shape, colour and consistency of the pseudoparenchymous wall. The wall of pycnidium is called peridium (pl. *peridia*; G. peridion=small leather pouch) and it is composed of multicellular layer, as fungal tissues. Pycnidia may formed superficially or sunken in the substratum. They may be formed directly by the loose mycelium or may be definitely stromatic.



d. Acervulus

Acervulus (pl. acervuli) is a fruiting structure commonly found in the order Melanconiales (Deuteromycotina). It is typically a flat or saucer-shaped mass of aggregated hyphae bearing short conidiophores in a compact layer. Intermingled with the conidiophores, setae (sing. seta; L. *seta* = bristle) are found. Setae are long, pointed, dark coloured, sterile structures. In nature acervuli are produced on plant tissues subepidermally or subcuticularly and becomes erumpent on maturity. e.g. *Colletotrichum*.



Sorus

Sorus (pl. sori; Gr. *Soros* = heap) is a little heap of sporangia or spores. It may be naked or covered by a thin false membrane, as in smuts, or protected by the epidermis as in rust diseases or white blister or white rust (*Albugo* spp.). The structures break open at maturity and release the spores within, in the form of rust, which is characteristic of these diseases.

Sexual fruiting bodies

a. Pycnium

Pycnium or spermagonium (pl. pycnia; Gr.*pycnos* = concentrated) is a fruit body, which is similar to pycnidium and is formed in sexual cycle of rust fungi. Pycnia are produced from primary uninucleate mycelium growing in the tissues of the host. They may be determinate or indeterminate in growth and may form in a subcuticular, subepidermal or subcortical fashion. Pycnia may be flask-shaped,conical, flat and sprawling. The flask-shaped type is more typical, The mouth of the flask (called ostiole) is lined by a bunch of unbranched, tapering, pointed, orange coloured hairs called 'periphyses' (sing. periphysis; Gr. *peri* = around + *physis* = a being, a growth). Periphyses develop from the upper edge of spermagonial wall, converge toward a central point and curved upward.

The tips of the periphyses, pushing against the host epidermis from below, rupture it and protrude above it through the opening they have created. Among the periphyses thinner-walled and branched hyphae called flexuous hyphae or receptive hyphae are found. The pycnial wall cells send many closely -packed, elongated, tapering, unbranched uninucleate sporogenous cells or spermatiophores (Gr. spermation = little seed+ phoreus=bearer) in the cavity. These spermatiophores give rise to a series of uninucleate spermatia (sing. spermatium Gr. spermation=little seed) or pycnospores in a basipetal fashion.

Pycnospore is a non-motile, uninucleate, unicellular spore-like male structure that empties its contents into a receptive female structure during plasmogamy. Pycnospores are variously regarded as gametes or gametangia. The pycnospores produced in large numbers are exuded up, out of the pycnial cavity through the ostiole in a droplet of nectar (a thick, sticky, fragrant, sweet liquid). e.g. pycnium is produced by *Puccinia graminis tritici* in the alternate host, barberry *(Berberis vulgaris)*.

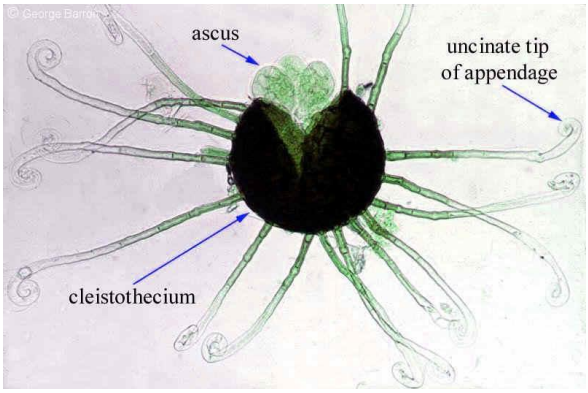
b. Aecium

Aecium (pl. Aecia: Gr. aikia = injury) is also formed during sexual cycle. Aecium is a shallow or deep cup-shaped structure produced in a leaf and located in the lower portion and break through the lower epidermis. Aecia may be with or without peridium (Fig.38). It is a group of typically dikaryotic hyphal cells within the parasitized host that give rise to chains of dikaryotic aeciospores. Larger aeciospores are alternated with small, sterile intercalary cells or disjunctor.

In most rust fungi the peripheral cells of the aecial base successively divide and gives rise to a wall that surrounds the spore chain in the form of a cup. The wall is known as 'peridium'. In a young aecium that has not broken the host epidermis, the peridium surrounds the spore chain on all sides, forming a complete dome over them. When the aecium matures, the spore chains push through the roof of the peridium and the aeciospore are released. The torn peridium forms a lip-like structure around the aecial cup.

c. Ascocarps

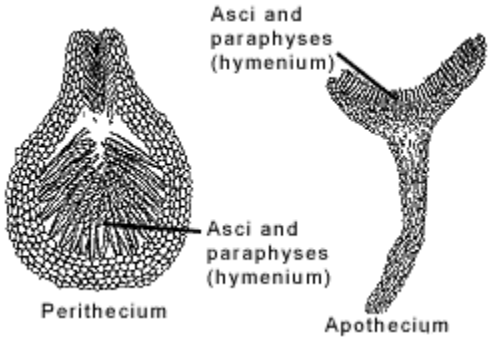
Ascocarp (Gr. askos = sac+ *karpos* =fruit) is a fruiting body that contains asci and ascospores. Ascomycetes fungi with few exceptions produce ascocarps. They are in various forms like spherical, flask-shaped, cup-and saucer shaped and pod-shaped. They may be closed in some, and provided with a narrow wide opening in others. Ascocarps may formed singly or in groups. They may be superficial, erumpent or deeply embedded in the substratum. The substratum may be composed entirely of hose tissue, or it may be a hyphal stroma or in which the ascocarps form. There are four categories ascocarps.



i. Cleistothecium: Asci are produced in completely closed ascocarp.

ii. Perithecium: It is more or less closed ascocarp; but at maturity it is provided with ostiole through which the ascospores escape.

iii. Apothecium: Ascocarp produce asci in open.



iv. Ascostroma or Pseudothecium: Stromatic ascocarp, which bears asci directly in locules within the stroma.

i. Cleistothecium: (pl. cleistothecia; Gr. *kleistos* = closed + *theke* = case).

Cleistothecium or cleistocarp is a closed ascocarp and has no ostiole. It is deep brown to black in colour, more or less spherical and often provided with appendages on its body, which serve as organs of anchorage and help in dissemination. They may contain one to several asci, which discharge their spores violently. Each cleistothecium of *Sphaerotheca* and *Podosphaera* contains a single ascus whereas each cleistothecium in *Erysiphe*, *Microsphaera*, *Uncinula*, *Leveillula* and *Phyllactinia* contain several asci. Cleistothecia crack open at maturity by swelling of the contents. They are found in Eurotiales and Erysiphales (powdery mildews or white mildews or true mildews. The matured cleistothecia of most Erysiphaceae are provided with characteristic appendages that vary considerably in length and character, and which together with the number of asci developed in the cleistothecium, form the basis for differentiation of genera. Cleistothecial appendages are of four types viz.

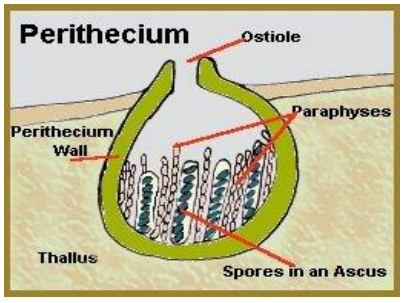
Myceloid appendages: Appendages resemble somatic hyphae in flaccidity and indefinite growth. e.g. *Erysiphe, Sphaerotheca* and *Leveillula*.

Appendages are rigid, spear-like with a bulbous base and pointed tip. e.g.*Phyllactinia.*

Appendages are rigid with curved tips e.g. *Uncinula, Pleochaeta.*

Appendages are rigid with dichotomously branched tips. e.g. *Microsphaera, Podosphaera.*

ii. Perithecium



Perithecium (pl. perithecia, Gr. *peri* = around + *theke* = a case) is a flask -shaped ascocarp with a wall of its own. It is provided with a narrow ostiole and may possess a short or a long neck through which the asci are released at maturity. The asci are arranged in a regular manner and are lined the inside wall. The asci are intermingled with sterile filaments called *paraphyses,* which help the asci in with sterile filaments called *paraphyses,* which help the asci in nutrition and dispersal. The *paraphyses, which* are rigid and appear in the ostiole are called periphyses. The perithecia may be borne singly or in groups.

In Sphaeriales and Hypocreales, the perithecia are borne on or embedded in a mass of fungal tissue termed the 'perithecial stroma' and these are found in Xylariaceae and by *Cordyceps* and *Claviceps*. In some cases, in addition to the perithecial stroma, a fungus may develop a stromatic tissue on which or within which asexual spores or conidia develop. e.g. *Nectria cinnabarina* (Coral -spot fungus) forms pink conidial stromata. In perithecia, the ascus wall is

single and is called 'unitunicate'(L. *unus*=one+*tunica* =coat, mantle). Perithecia are produced by fungi in Hypocreales *(Hypocrea , Nectria, eratocystis, Podospora, Chaetomium, Xylaria, Ustulina, Rosellinia, Claviceps* and *Cordyceps)* in Sphaeriales.

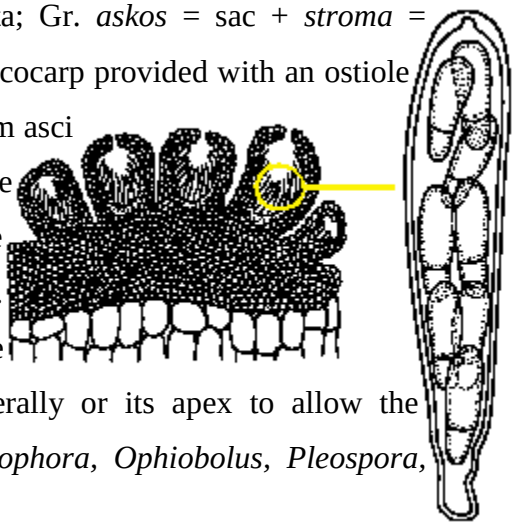
iii. Apothecium

Apothecium (pl. Apothecia; Gr. *apotheke*=store house) is an open ascocarp. It has a broad opening and is either cup or saucer shaped with asci arranged in a palisade layer within. It is usually fleshy or leathery in nature. An apothecium consists of three parts viz. hymenium, hypothecium and excipulum. The hymenium is the layer of asci that lines the surface of hollow part of the disc, cup or saddle. It is made up of club-shaped or cylindrical asci, usually with many or few paraphyses among them. These paraphyses may be as long as the asci, longer or somewhat shorter.

In some apothecia, the tips of paraphyses may be branched and the tips of branches may unite above the asci and form a layer called the epithecium (pl. epithecia; Gr. *epi* =upon+ *theke* =a case). The 'hypothecium'(pl. hypothecia; Gr. *Hypo*=under+ *theke* =a case) is a thin layer of interwoven hyphae, which is found immediately below the hymenium. The apothecium proper (i.e., the fleshy part of the ascocarp that supports the hypothecium and hymenium) is called excipulum (pl. excipula ; N.L. *excipulum*=receptacle), Excipulum consists of two parts viz., ectal excipulum and medullary excipulum. Ectal excipulum is the outer layer of the apothecium and the medullary excipulum is the inner portion. e.g. cup fungi *(Pyronema, Ascobolus, Peziza, Morchella* etc) in Pezizales and *Sclerotinia, Trichoscyphella* etc.) in elotiales.

iv. Pseudothecium

Pseudothecium or ascostroma (pl. ascostromata; Gr. *askos* = sac + *stroma* = mattress, cushion) like perithecium is a flask-shaped ascocarp provided with an ostiole through which the asci are discharged. In pseudothecium asci are directly formed in a cavity (locule) within the stroma. The stroma itself thus forms the wall of the ascocarp. In pseudothecium the ascus wall is double i.e. the ascus is bitunicate. The walls are separable. The outer wall does not stretch readily but ruptures laterally or its apex to allow the stretching of a inner layer. e.g. *Cochliobolus, Pyrenophora, Ophiobolus, Pleospora, Leptosphaeria* of the class Loculoascomycetes.



d. Basidiocarps

Basidiocarp (Gr. *basidion*=small base + *karps* = fruit) is a fruiting body, which bears basidia and basidiospores. Basidia are borne on the under surface of fruit body. Basidia bear basidiospores exogenously usually on projections called sterigmata. Basidia are typically formed in definite layers called hymenium (pl. hymenia; Gr. *hymen*=membrane). Hymenium is composed of basidia and large sterile structures called *cystidia* (sing. cystidium; Gr. *kystis* =bladder + *-idion* = dimin. Suffix). They are highly developed and have compound structure. Basidiocarps may be thin and crust-like, gelatinous, cartilaginous, papery, fleshy, spongy, corky or woody. They may vary in size from microscopic to a metre or more in dia. Most fungi in basidiomycotina except smuts (Ustilaginales) and rusts (Uredinales) form basidiocarps. They include mushrooms, (*Agaricus, Pleurotus, Volvariella),* shelf fungi, coral fungi (Clavariaceae) puff balls (Lycoperdaceae-*Lycoperdon* sp.) earth stars, (Geastraceae-*Geastrum* stinkhorns sp. (Phallales -*phallus*) and birds-nest fungi. (Nidulariales-*Nidula* sp.). The main body of the fungus in each case is the extensive mycelium, which usually goes unnoticed. Basidiocarp may be open from the beginning, exposing their basidia, or they may open at a later stage, or even remain closed. In closed basidiocarps the spores are liberated only on the disintegration of the basidiocarp or with its accidental fracture by external forces (e.g. *Lycoperdon).*

Lecture 04

Nomenclature-Binomial system of nomenclature, rules of nomenclature, classification of fungi. Key to divisions and sub-divisions

Taxonomy and Nomenclature

Nomenclature is the naming of organisms. Both classification and nomenclature are governed by International code of Botanical Nomenclature, in order to devise stable methods of naming various taxa, As per binomial nomenclature, genus and species represent the name of an organism. Binomials when written should be underlined or italicized when printed. First letter of the genus should be capital and is commonly a noun, while species is often an adjective. An example for binomial can be cited as:

Kingdom = Fungi

Division = Eumycota

Subdivision = Basidiomycotina

Class = Teliomycetes

Order = Uredinales

Family = Pucciniaceae

Genus = *Puccinia*

Species = *graminis*

Classification of Fungi

An outline of classification (G.C. Ainsworth, F.K. Sparrow and A.S. Sussman, The Fungi Vol. IV-B, 1973)

Key to divisions of Mycota

Plasmodium or pseudoplasmodium present. MYXOMYCOTA

Plasmodium or pseudoplasmodium absent, Assimilative phase filamentous.

EUMYCOTA

MYXOMYCOTA

Class: Plasmodiophoromycetes

1. Plasmodiophorales Plasmodiophoraceae *Plasmodiophora*, *Spongospora*, *Polymyxa*

Key to sub divisions of Eumycota

Motile cells (zoospores) present, … MASTIGOMYCOTINA Sexual spores typically oospores Motile cells absent

Perfect (sexual) state present as

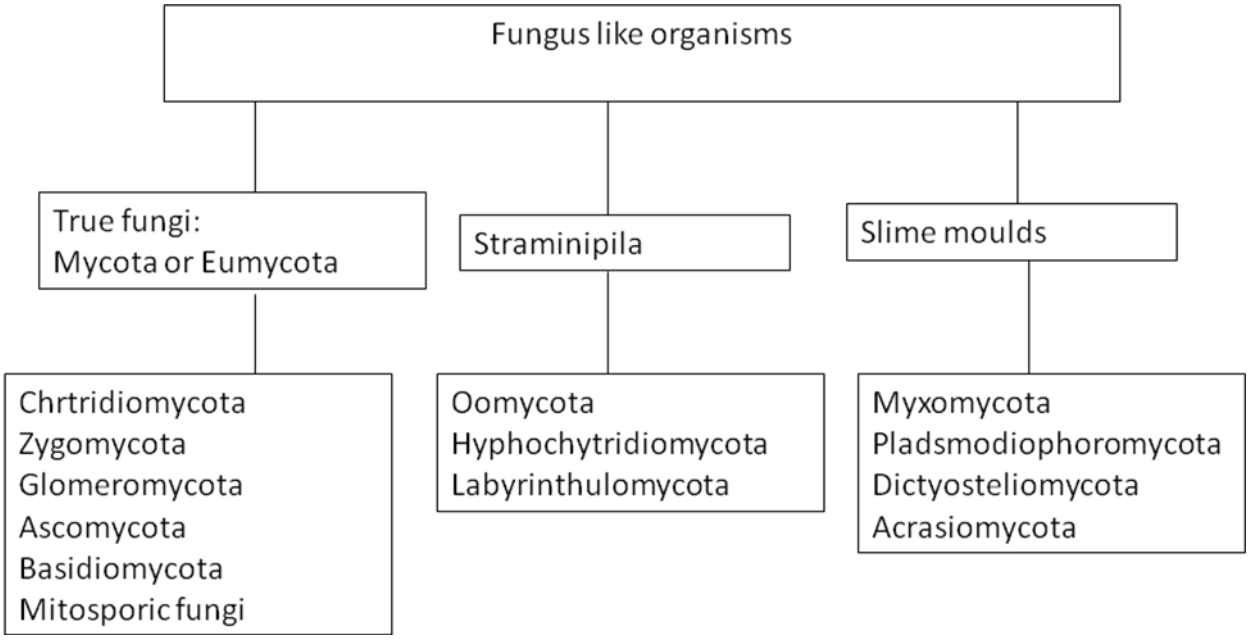
Zygospores… ZYGOMYCOTINA

Ascospores… ASCOMYCOTINA

Basidiospores… BASIDIOMYCOTINA

Perfect (sexual) state not seen … DEUTEROMYCOTINA

Classification of Fungi



Lecture 05

Division I: Myxomycota, Class: Plasmodiophoromycetes, Order: Plasmodiophorales

Key to divisions of Mycota

Plasmodium or pseudoplasmodium present - **Myxomycota**

Plasmodium or pseudoplasmodium absent,

Assimilative phase filamentous - **Eumycota**

Myxomycota

Class: Plasmodiophoromycetes

1. Plasmodiophorales

Plasmodiophoraceae *Plasmodiophora, Spongospora, Polymyxa*

Club root of cabbage caused by *Plasmodiophora brassicae*

Systematic position

Kingdom : Protista (Eukaryote)

Sub-kingdom : Mycota

Division : Myxomycota

Class : Plasmodiophoromycetes

Order : Plasmodiophorales

Family : Plasmodiophoraceae

Genus : *Plasmodiophora*

Species : *P. brassicae*

Symptoms

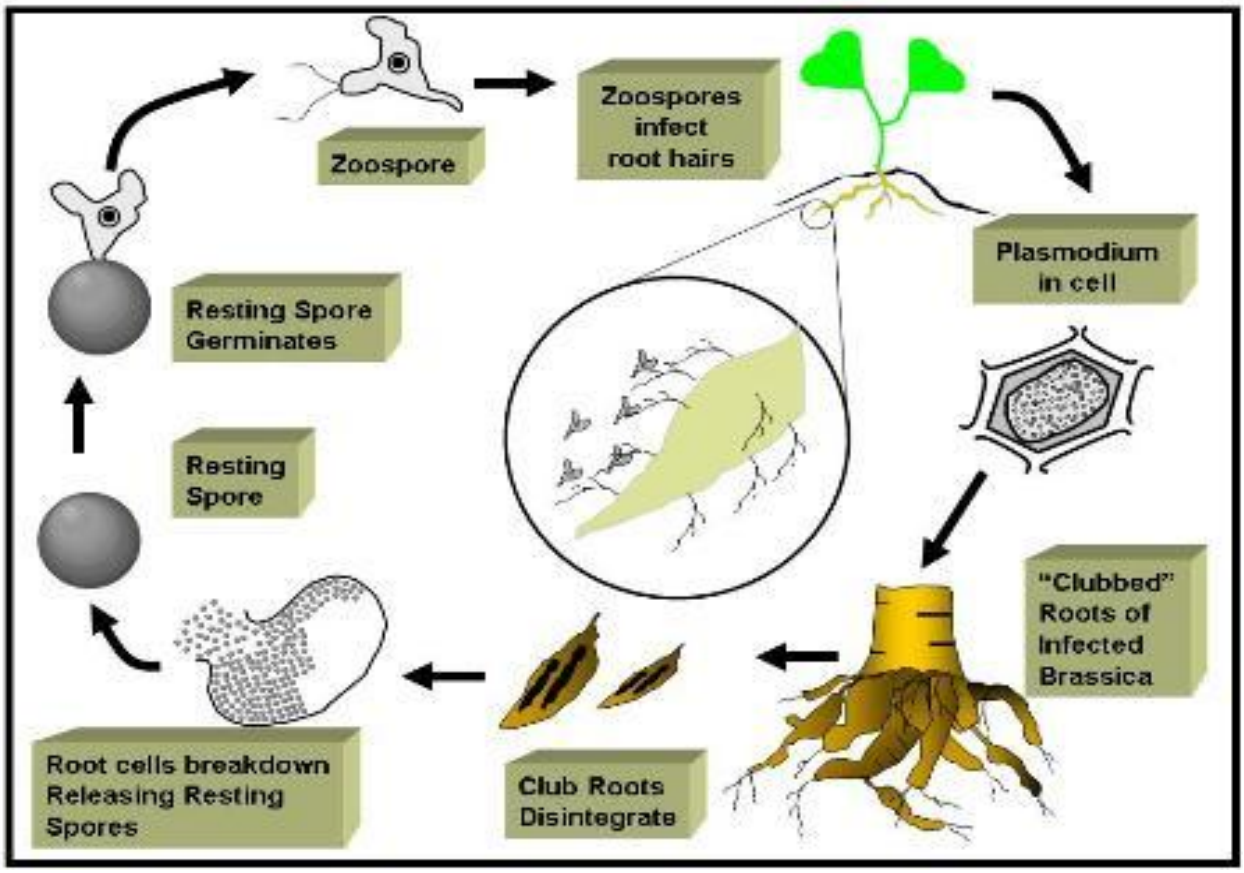
Enlargement of roots, club-shaped roots due to hyperplasia and hypertrophy, gradual and inconspicuous stunting, yellowing and wilting of plant.

Pathogen

The thallus is a plasmodium (a naked mass of nucleated cytoplasm with amoeboid movement), which gives to zoosporangia or resting spore, which on germination produce zoospores. Resting spores are spherical with spiny walls. Zoospores are anteriorly biflagellate, heterokont (unequal in length) and uninucleate, both the flagella are of whiplash type.

Life cycle

Infection of the root hairs occurs during the seedling stage. Resting spores, which lie dormant in the soil upto several years. Germinate and a circular pore is formed on its wall. Al apically biflagellate zoospore comes out. Each resting spore produces single zoospore. The zoospore penetrates the root hair and develops into uninucleate primary plasmodium. The plasmodium cleaves into multinucleate portions. Each portion develops into a zoosporangium containing 4-8 zoospores. The zoospores are discharged outside the host through pores dissolved in the host cell wall. The zoospores fuse in pairs to produce zygotes. These zygotes with four flagella case new infection and produce new plasmodium. This plasmodium penetrates the young root tissues directly or the older roots and underground stems through wounds. Thus the plasmodium spreads to cortical cells in cambium by direct penetration. When the plasmodia establishes in the host cells, they are stimulated to enlarge (hypertrophy) and divide abnormally (hyperplasia). The cells become larger (5 or more times). The plasmodium develops into large



number of resting spores inside the plant tissues, which are released into soil by disintegration of clubbed roots.

Lecture 06

Division II: Eumycota Subdivision: Mastigomycotina, class: Chytridiomycetes (Chytridiales), Oomycetes (Peronosporales)

General characters

Members of the class Oomycetes are mostly aquatic but some are facultative or obligate parasites of vascular plants. Majority of them are with filamentous hyaline coenocytic mycelium. Cell wall contains cellulose. They produce asexual spores called zoospores. Oospore is the sexual spores.

Class: Oomycetes

Zoospores biflagellate (posterior flagellum whiplash-type; anterior tinsel-type); cell wall cellulosic.

1. Members of the class comycetes are mostly aquatic but some are facultative or obligate parasites of vascular plants.
2. They are distinguished by the presence of well-developed holocarpic or eucarpic mycelium or rhizomycelium and zoospores bearing two flagella, one whiplash type and the other tinsel type. In some members, Zoospores are not formed and the zoosporangia function as conidia. The cell wall does not contain chitin, small amounts of cellulose are detected but the principal components are glucans.
3. In sexual reproduction the union of antheridia and oogonia produces oospores.

Order: Peronosporales

This order includes highly economically important plant pathogens. The members cause downy mildew and white rust diseases. Hyphae are well developed and aseptate. Cell wall is composed of glucan-cellulose complex and hydroxyproline. Parasites produce haustoria, which may be knob-like, elongated or branched and are found within the host cells. Asexual reproduction is by well-defined sporangia. Sexual reproduction is by means of well-differentiated sex organs, antheridia (male) and oogonia (female). Oospores germinate directly or by producing a sporangium.

Families

Pythiacea*e*

Sporangiophores similar to the vegetative hyphae or if different then of indeterminate growth. Pythiaceae contains genera like *Pythium* and P*hytophthora*

Albuginaceae

Sporangiophores strikingly different from vegetative hyphae, slender or thick, variously club-shaped, arranged in a layer, and bear sporangia in chain at the tip. These are obligate parasites. It contains a single genus, Albugo.

Peronosporaceae

Sporangiophores strikingly different from vegetative hyphae, slender or thick, variously shaped, and with determine growth; sporangia produced singly or in cluster at the tip of sporangiophores or their branches; obligate parasites.

Classification of Peronosporaceae

A. Sporophores determinate, hyphae-like short, unbranched or obpyriform, not maturing synchronously, germinating by zoospores; antheridia always paragynous; oogonial wall thick and confluent with that of the oospores; oospore germinates by germ tube or a sporophore terminated by a sporangium. **-** ***Sclerophthora***

AA. Sporophores determinate, macronemous, stout, 10 or more microns broad, branched or unbranched, oogonial wall thick and rough or ornamented:

B. Sporophores unbranched, apex swollen and with short sterigmata bearing papillate sporangia germinating by zoospores; oospores aplerotic**.-** ***Basidiophora***

BB. Sporophores repeatedly branched in the upper portion, dichotomous; spores mature synchronously; oogonial wall thick; oospore plerotic; sporangia germinate by zoospores or germ tube; oospores germinate by a germ tube**.-** ***Sclerospora***

AAA. Sporophores determinate, narrow, not more than 15 microns broad, usually 8- 10 microns; oogonial wall unornamented except in *Bremiella:*

B. Spore wall uniformly thick (non-poroid), germination typically by germ tube. **-** ***Peronospora***

BB. Spore wall poroid, emerging through an apical pore with or without papilla:

C. Branching of sporophore at right angles, tips or branches blunt.**-** ***Plasmopara***

CC. Branching at acute angles:

D. Tips of branches acute **-** ***Pseudoperonospora***

DD. Tips much enlarged and bearing 3-4 peripheral sterigmata; oogonial wall and oospore wall thin and unornamented.. *Bremia* DDD. Tips of branches blunt and slightly enlarged; oogonial wall thick and ornamented.**-** ***Bremiella***.

Club root of cabbage, damping off and life cycles of *Plasmodiophora, Pythium* and *Phytophthora*

Club root of cabbage caused by *Plasmodiophora brassicae*

Enlarged roots appearing like spindles or clubs due to stimulation of root cells to abnormal enlargement (hypertrophy) and abnormal division (hyperplasia) is called **club root.**

Systematic position

Scientific categorization of the organisms in a hierarchal series of groups. Based on characteristics of the spores, spore bearing structures and mycelium. Many fungi were classified earlier based on the asexual spore and same were reclassified once they produced sexual spore.

Kingdom: Protista (Eukaryote)

Sub-kingdom: Mycota

Division: Myxomycota

Class: Plasmodiophoromycetes

Order: Plasmodiophorales

Family: Plasmodiophoraceae

Genus: *Plasmodiophora*

Species: *P. brassicae*

Symptoms

Enlargement of roots, club-shaped roots due to hyperplasia and hypertrophy, gradual and inconspicuous stunting, yellowing and wilting of plant.

Pathogen

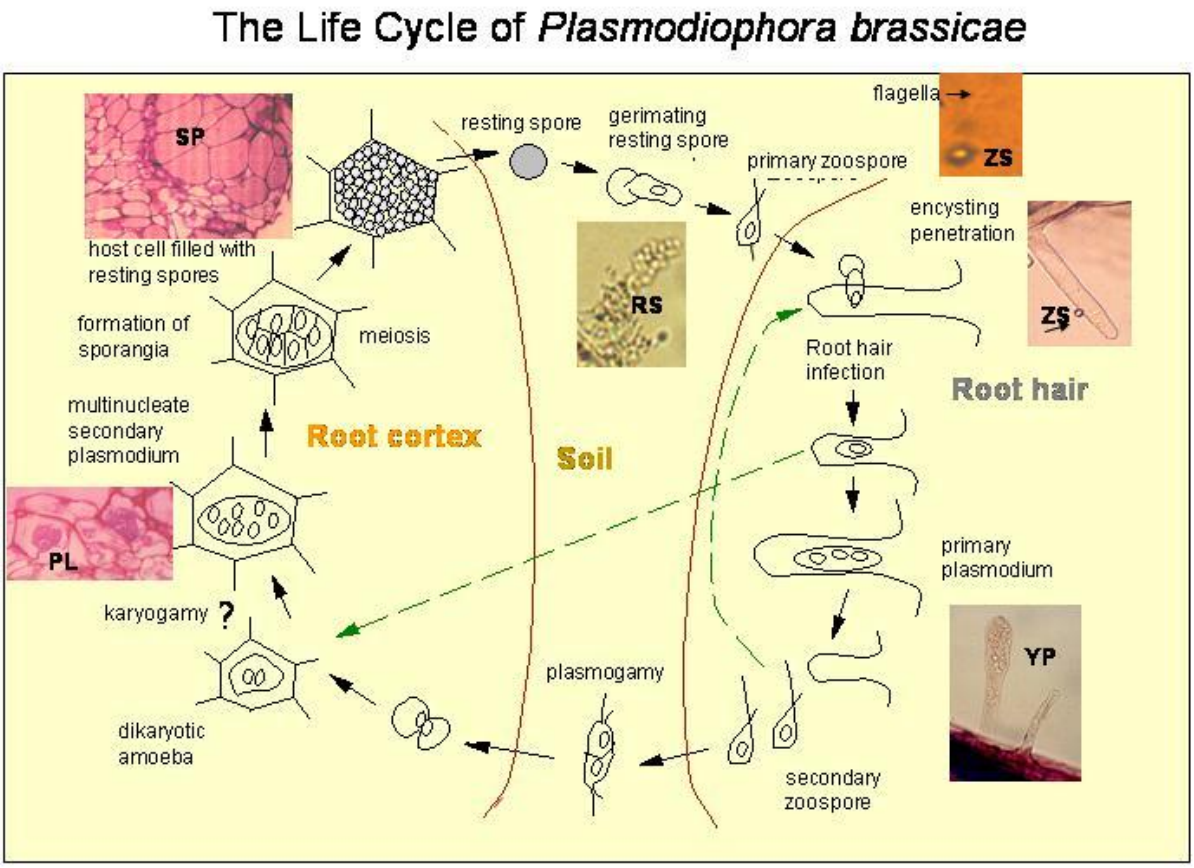
The thallus is a plasmodium (a naked mass of nucleated cytoplasm with amoeboid movement) which gives to zoosporangia or resting spore, which on germination produce zoospores. Resting spores are spherical with spiny walls. Zoospores are anteriorly biflagellate, heterokont (unequal in length) and uninucleate, both the flagella are of whiplash type.

Disease cycle

Infection of the root hairs occurs during the seedling stage. Resting spores, which lie dormant in the soil upto several years, germinate and a circular pore is formed on its wall. An apically biflagellate zoospore comes out. Each resting spore produces single zoospore.

The zoospore penetrates the root hair and develops into uninucleate primary plasmodium. The plasmodium cleaves into multinucleate portions. Each portion develops into a zoosporangium containing 4-8 zoospores. The zoospores are discharged outside the host through pores dissolved in the host cell wall. The zoospores fuse in pairs to produce zygotes.

These zygotes with four flagella cause new infection and produce new plasmodium. This plasmodium penetrates the young root tissues directly or the older roots and underground stems through wounds. Thus the plasmodium spreads to cortical cells in cambium by direct penetration. When the plasmodia establishes in the host cells, they are stimulated to enlarge (hypertrophy) and divide abnormality (hyperplasia). The cells become larger (5 or more times). The plasmodium develops into large number of resting spores inside the. Plant tissues, which are released into soil by disintegration of, clubbed roots.



Damping off of vegetables (tomato, brinjal, chillies, etc.) and tobacco – *Pythium aphanidermatum*

Damping off is a special name given to denote wilting of young seedlings in nursery. The rapid death and collapse of very young seedlings in the seedbed is called **damping off**.

Systematic position

Sub-kingdom: Mycota

Division: Eumycota

Sub-division: Mastigomycotira

Class: Oomycetes

Family: Pythiaceae

Genus: *Pythium*

Species: *P. aphanidermatum*

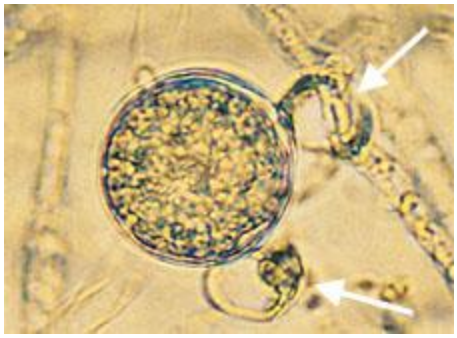
Symptoms

It is generally observed two weeks after sowing. Water-soaked lesions appear on the collar region of seedlings; browning and shriveling of stem tissues at soil level in the collar region; toppling down of seedlings in the nursery; ultimate death of sick seedling.

Pathogen

It is a facultative parasite and homothallic (both male and female gametes are produced in the same mycelium. Mycelium is hyaline, coenocytic (von-septate), branched, inter and intra cellular giving the appearance of a white fluffy cellular mass, does not have haustoria. Cell wall of this fungus contains cellulose. Sporangium is lobed or irregular; it forms vesicle. Sporangiophores are undifferentiated and similar to somatic hyphae.

Zoospores are produced in spherical vesicle and liberated after bursting of vesicle. They are reniform and biflagellate with flagella attached to lateral side, one pointing upward is tinsel type and the other pointing downward is whiplash type. Antheridium (male gametangium) is paragynous, club shaped, terminal or intercalary and it is applied to the side of the oogonium; the hyphal branch bearing antheridium may arise either from oogonial stalk (monoclinous) or from a separate -hypha (diclinous). Oogonium (female gametangium) is globose, generally develops at the tip of hyphal branch and consists of central denser zone called ooplasm or oosphere and peripheral lighter zone called periplasm. Oospores are the sexual spore, which helps to tide over adverse conditions (resting spore). They are spherical, thick walled with yellowish brown wall and does not fill oogonial cavity called aplerotic oospore.

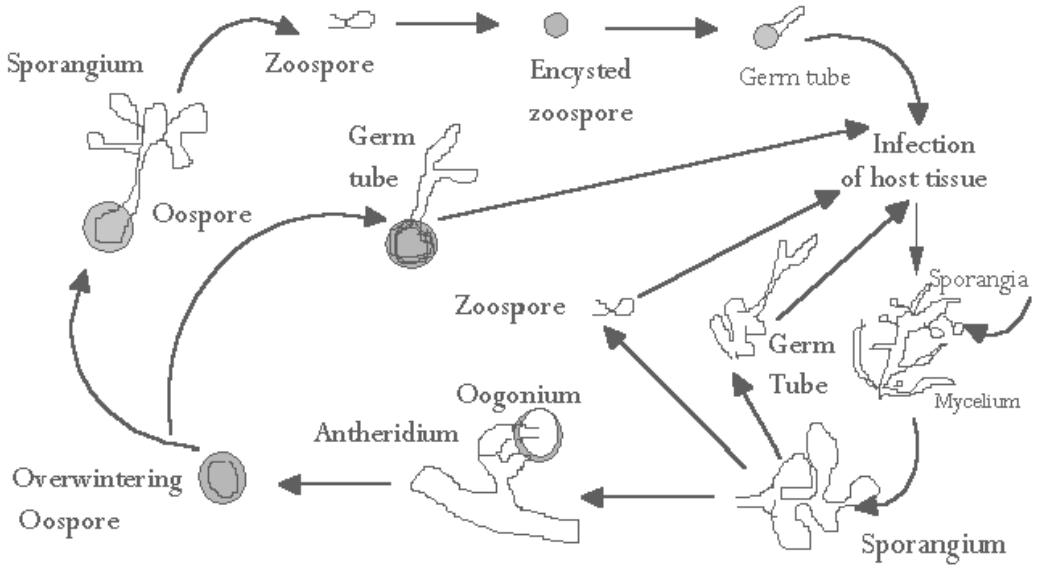


Paragynous arrangement of oogonium and antheridia in *Pythium*. (Courtesy P.B. Hamm) (arrows indicate antheridia)

Disease cycle

In the asexual stage, sporangia are borne terminally on sporangiophore. At the time of zoospore formation, a bubble-like protoplast moves into the vesicle and the zoospores are formed in this vesicle. When the crowded zoospores start rocking motion and bounce on the wall, the delicate vesicle bursts like a soap bubble. In the sexual reproduction oogonia and antheridia are produced. Antheridia get attached to the side of oogonium. On gametangial contact the walls between the sex organs are dissolved and a short tubular projections called fertilization tube is produced by the antheridium.

The fertilization tube passes through periplasm and penetrates oosphere. The contents of the antheridium moves through fertilization tube and evacuated into the oogonial cavity. The protoplasmic content of oogonium and antheridium mixes (plasmogamy). Plasmogamy is soon followed by nuclear fusion (karyogamy). The osphere after fertilization develops a thick mass and it is called oospore.



Life cycle of *Pythium aphanidermatum*

Disease cycle

Oospore or encysted zoospore germinates and produce germ tubes or saprophytic mycelium which come in contact with seed or seedling tissues of host plant and enter by direct penetration. Pectinolytic enzymes of the fungus dissolve the pectins (holding cells together) resulting in maceration of tissues. The mycelium grows between and through the cells. Proteolytic and or cellulolytic enzymes causing complete collapse and disintegration of cell walls break down the protoplasts of invaded cells. As a result, the infected seeds / young seedlings are killed and turned into a rotten mass.

Late blight of potato and tomato caused by *Phytophthora infestans*

Systematic position

Sub-kingdom : Mycota

Division : Eumycota

Sub-division : Mastigomycotina

Class : Oomycetes

Order : Peronosporales

Family : Pythiaceae

Genus : *Phytophthora*

Species : *P. infestans*

Symptoms

Brown to purplish black water-soaked lesions; enlarge rapidly; lower surface shows whitish mildew growth, severe defoliation; potato tubers show purplish, slightly sunken lesions leading to dry rot.

Late blight of potato on tuber

Late blight of tomato

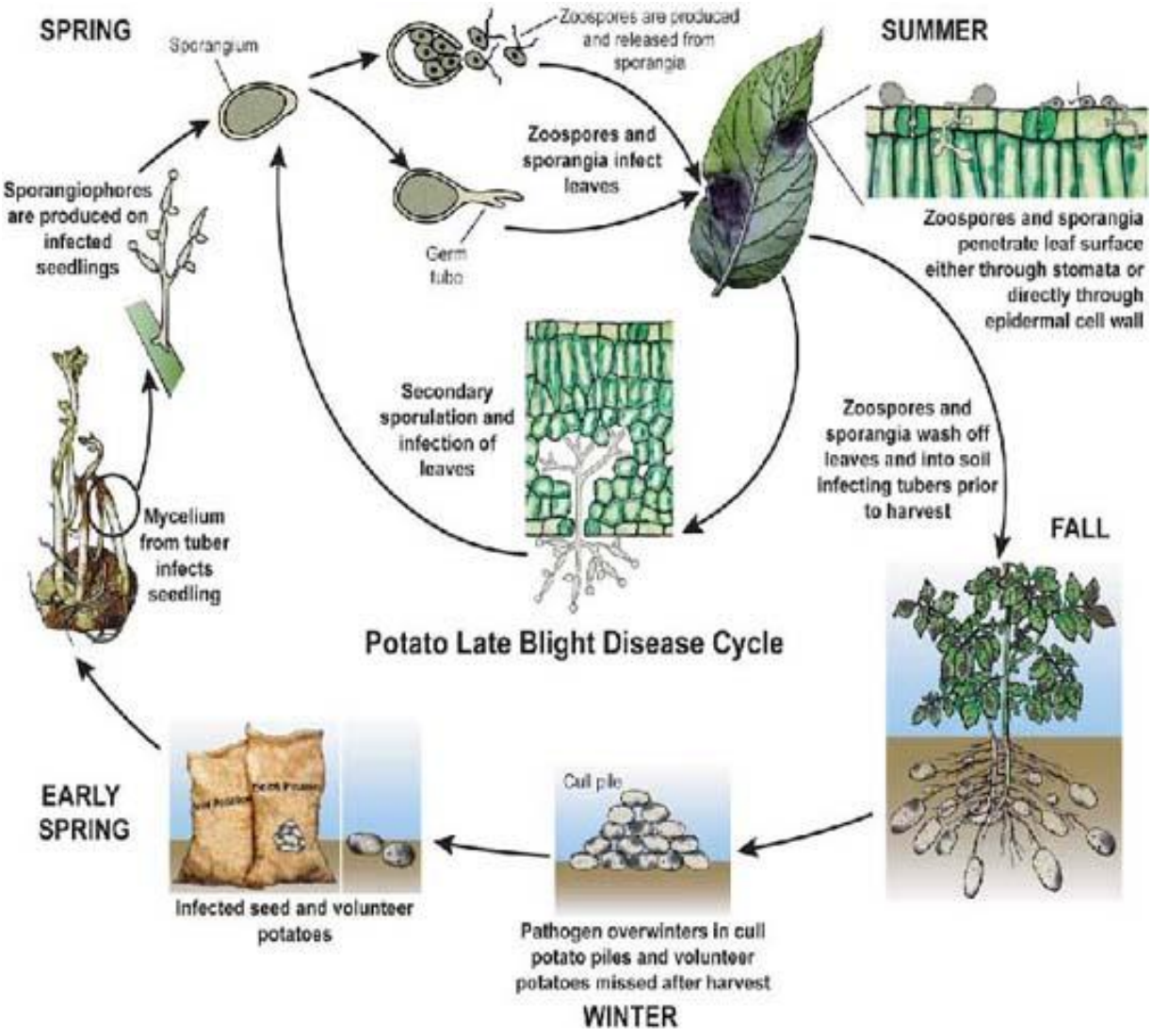
Late blight of potato on leaf

Pathogen

Mycelium is endophytic, coenocytic, hyaline, branched, and inter-cellular. Haustoria club shaped. Sporangiophores are hyaline, branched, indeterminate, thickwalled, arise through stomata on leaves or lenticels on tubers. Sporangia are multinucleate, thin-walled, hyaline, and oval or per shaped with a definite papilla at the apex. Zoospores are reniform, biflagellate (anterior tinsel and posterior whiplash). Oospores are thick-walled and smooth.

Life cycle

Primary infection is through use of infected tubers. Mycelium spreads into shoots produced from infected tubers and reaches the aerial parts of the plant. Sporangiophore emerges through stomata on stem and leaves and produce sporangia, which are spread by rain to wet potato, leaves or stem and cause disease. Large number of asexual generation in a growing season kills the foliage rapidly. The zoospores found in the soil germinate, penetrate through lentils or wounds into the tubers and send intercellular mycelium and haustoria into the cells and cause infection.



Life cycles of *Sclerospora* and *Albugo*

Downy mildew

Appearance of white downy growth in patches on the lower surface of the leaves and yellow discolouration correspondingly on the upper surface. Downy mildew fungi are obligate parasites belonging to the family peronosporaceae of the sub division Mastigomycotina cause downy mildew disease. They produce sporangia during asexual reproduction and oospores during sexual reproduction. Sporangiophore branching characters of genera, which cause downy mildew diseases are given below.

i. Sporangiophore is club-shaped with a swollen head, over which the sporangia are borne on minute sterigmata. e.g., *Basidiophora.*

ii. Sporangiophore is short, stout with many upright branches near the end, bearing the sporangia at tips. e.g., *Sclerospora.*

iii. Sporangiophore is branched at right angles and are irregularly spaced. e.g., *Plasmopara.*

iv. Sporangiophore is dichotomously branched at acute angles and taper to gracefully curved pointed tips on which sporangia are borne. e.g., *Peronospora* and *Pseudoperonospora.*

v. Sporangiophore is dichotomously branched at acute angles and the tips of the branches are expanded into cup-shaped apophyses with four sterigmata. e.g., *Bremia.*

Downy mildew of pearlmillet caused by *Sclerospora graminicola*

Systematic position

Sub-kingdom : Mycota

Division : Eumycota

Sub-division : Mastigomycotina

Class . Oomycetes

Order : Peronosporales

Family : Peronosporaceae

Genus : *Sclerospora*

Species : S. *graminicola*

Symptoms

Pale yellow discolouration of leaves; whitish fungal growth on the lower surface of leaves; twisting and crinkling of leaves; drying of leaves; infected seedlings when planted die within 30 days; green ear symptom i.e., transformation of floral parts into green leaf-like structures.

Symptoms often vary as a result of systemic infection. Leaf symptoms begin as chlorosis at the base and successively higher leaves show progressively greater chlorosis. Infected chlorotic leaf areas can support abundant white asexual sporulation on the lower leaf surface. Severely infected plants are generally stunted and do not produce panicles. Green ear symptoms result from transformation of floral parts into leafy structures

Pathogen

It is an obligate parasite. Mycelium is hyaline, coenocytic, intercellular and become systemic. Haustoria are finger- or button - like. Sporangiophores emerge through stomata, short, stout, non-septate with upright branches, crowded with sporangia bearing stalks (sterigmata) with pointed ends at the apex. Sporangia are hyaline, broadly elliptical, thin, smooth walled and papillate. Each sporangium contains 3 to 23 zoospores, which are irregularly reniform and biflagellate. Oospores are spherical, thick walled and yellowish brown.

Disease cycle

Soil borne oospores germinate by put forth germ tube and infect the root hairs / coleoptile of the host seedlings. Inside host tissue, fungus becomes systemic and produces hyaline, coenocytic, highly branched, strictly intercellular mycelium with **finger shaper haustoria**. During dewly nights, hyphae emerge through the stomata and form sporangiophores either singly or in groups. During such period, downy growth is noticed on the diseased area. A single sporangium is formed at the tip of the sterigma. The sporangia are deciduous and are carried by wind. The sporangia germinate by releasing zoospores. Zoospores swim for sometimes, come to rest, encyst and then germinate by germ tube to form new mycelium. Infected plant parts produces sporangia over a considerable period of time under humid condition and then necrosis begins.

In the sexual stage, the sex organs (antheridia and oogonia) develop in the intercellular spaces of the host tissues (leaves and malformed floral organs). It is typically oogamous. The fertilization tube formed by the antheridium carries the male nucleus into the oosphere where the two nuclei fuse to form a diploid zygote nucleus. The oosphere develops a warty wall and becomes the oospore. Oospores have a long period of rest lie in the soil (soil - borne) or on the seed surface. Oospores are liberated by the disintegration of the host tissue .They germinate and infect roots of young seedlings, from where the mycelium spreads systemically in the entire plant.

White rusts or white blisters

White rusts or white blisters are the characteristic pustules fructifications of *Albugo* in Albuginaceae on plant surfaces, especially on leaves.e.g.,white rust of Amaranthus caused by *Albugo bliti*, white rust of crucifers caused by *A. candida* and white rust of sweetpotato caused by *A. ipomeae panduranae.*

White rust of crucifers - *A. candida*

Systematic position

Sub-kingdom : Mycota

Division : Eumycota

Subdivision : Mastigomycotina

Class : Oomycetes

Order : Peronosporales

Family : Albuginaceae

Genus : *Albugo*

Species : *A. candida*

Symptoms

The fungus attacks cabbage, cauliflower, mustard, radish and turnip. The disease name is a misnomer. The pustules formed by white rust resembles the aecial stage of true rust belonging to the subdivision Basidiomycotina and hence the name. All aerial plant parts viz., leaf, stem and inflorescence are affected. On the lower surface of leaves it causes white or creamy yellow pustules of various sizes and shape. They are shiny and 1 to 2 mm in dia. Rarely the infection is seen on the upper leaf surface. Very often several of them coalesce to form patches.

They are formed below the epidermis and are unbroken. But with the pressure of sporangia from below, they rupture the epidermis and appear as powdery masses on the surface of leaves. The leaves are not distorted. In severe cases, the infection spreads to the stem, which is uniformly swollen for a length of several centimetres. Lateral buds, which are normally latent, may proliferate resulting in a bushy growth. Flowers and peduncles are also attacked. Peduncles become enormously swol1en. Affected flowers show various discolouration and malformation. The petals become green and stamens turned into leaf-like structures.Some times they may be changed into thickened club-shaped sterile bodies.

The pistil is hypertrophied into a large conical, thick walled sac or transformed into a sterile carpillary leaf. The fungal parasite stimulates cell activity leading to an abnormal increase in cell size (hypertrophy) and abnormal increase in cell division (hyperplasia) and formation of chlorophyll and starch at place where none is usually seen. Sepals become enlarged to several times than the normal sepals. Normally seed development is arrested. Pustules may occur on hypertrophied organ also.

White rust on leaf

White rust stag head symptom

Pathogen

It is an obligate parasite. The thallus is eucarpic and mycelial. Mycelium is well developed, strictly intercellular, hyaline, non-septate (coenocytic) and branched. Haustoria are knob-like or globular. Sporangiophore is club-shaped, short, erect, non-septate, closely arranged, unbranched and thick walled. Sporangia are globose or hexagonal (flattened at the sides), hyaline, smooth, thin walled and produced in basipetal chains (oldest at the top and youngest at bottom) with isthmus.Sporangia are formed at the tip of the sporangiophores. Antheridia are clavate or club shaped, multinucleate and paragynous. Oogonia are globose, terminal or

intercalary. Oospores are reticulate and round. Zoospores are biflagellate and reniform and 4 to 8 per sporangium.

Disease cycle

In the asexual stage, hyphae aggregate at several places under the epidermis. Sporangiospores are formed as a palisade-like layer. These cut multinucleate sporangia, which remain, attached to form a chain at the apex. The oldest sporangia lie at the top and youngest at the base of the chain (called basipetal). The sporangia are separated from each other by a gelatinuous disc-like structure called disjunctor or isthmus. The disjunctors are dissolved by water and the sporangia are set free. The numerous sporangia that are produced at the apical end of sporangiophores push against the epidermis, which bulges out and ultimately breaks.

The areas with broken epidermis and creamy mass of sporangia appear as pustules or blisters on the leaves. Sporangia germinate by means of germ tube (direct germination) or by formation of zoospores (indirect germination). Direct germination is not common. Sexual reproduction occurs when the crop season comes to an end and it is typically oogamous.

The antheridia and oogonia borne terminally on somatic hyphae. Plasmogamy takes place by gametangial contact, where the male nucleus from antheridium is transferred to oogonium through the fertilization tube. Karyogamy occurs and a thin membrane develops around the diploid zygote and a thick warty, tuberculate or roughened epispore. After a resting period, the oospore germinates and forms a vesicle, which contains 40-60 zoospores. The rupture of the vesicle wall releases the zoospores. The zoospore germinates by forming a germ tube, which infects the host plant.

Lecture 07

Subdivision: Zygomycotina (Mucorales)

General characters of Zygomycotina

Majority of them are saprobic some are coprophilous some are weak parasites attacking plants. It produces well-developed, branched coenocytic mycelium. Cell wall is composed of chitin –chitosan. Asexual spores are non-motile and are called sporangiospores. Sexual spores are zygospores.

Key to the classes of Zygomycotina

Class: Zygomycetes

Saprobic or, if parasitic or predaceous, mycelium immersed in hot tissues

Order: Mucorales

Asexual reproduction is by means of non -motile, but sometimes appendaged, spores or by sporangioles or conidia. The sporangiospores are formed in sporangia or merosporangia.

Order: Mucorales

Family	**Genera**
1. Mucoraceae	*Mucor, Rhizopus, Phycomyces, Absidia, Zygorhynchus, Syzgites, Rhizomucor*
2. Choanephoraceae	*Choanephora, Blakeslea*
3. Endogonaceae	*Endogone*

Fruit rot of jack caused by *Rhizopus artocarpii, R. nigricans*

It is a soft rot; rotting and decaying of fruits or tubers.

Systematic position

Subkingdom: Mycota

Division: Eumycota

Sub-division: Zygomycotina

Class: Zygomycetes

Order: Mucorales

Family: Mucoraceae

Genus: *Rhizopus*

Species: *R. artocarpi*

Symptoms

It causes soft rot of young fruits and male inflorescens. A large number of the infected fruits fall off early. In the first stage of attack the fungus appears as a greyish growth with abundant mycelia, which gradually becomes denser forming a black growth.

Pathogen

Mycelium is non-septate, brown coloured, profusely branched; aerial hyphae bends at certain points and produce repeatedly branched root - like structure called rhizoids (holdfast) for anchorage on substratum. The hypha in between two groups or rhizoids is called stolon. Sporangiophores are short, stiff, brown, unbranched, erect, arise in groups from stolons, almost opposite to rhizoids, which bear a terminal sporangium; Sporangia are spherical, dark brown or black and contains sporangiospores; Sporangiospores are round, single celled, non-motile, brown individually but black in mass; Zygospore are thick walled black and warty; two layered (outer warty exine and inner intine).

Disease cycle

In the asexual stage, the sporangiospores are produced within the sporangia. The spherical sporangia are separated from the sporangiop40re by a septum which later bulges and projects into the former as a dome-shaped structure called columella. The spherical structure including the columella is called the sporangium. The protoplasm cleaves into numerous multinucleate segments; each of which secretes a wall and becomes a spore called the sporangiospore. When the sporangial wall dissolves on maturity, the spores are released. The aplanospore germinate by forming germ tube and develops into a fluffy well branched white aerial mycelium.

Sexual reproduction occurs through fusion of morphologically similar gametangia designated as plus (+) and minus (-) (gametangial copulation) and subsequent production of a thick walled zygospore. It is heterothallic species and sexual reproduction is effected only when physiologically different strains are brought together. Two hyphal branches lie parallel to each other producing a lateral tubular outgrowth called as progametangium. The tips of the pro gametangia swell and meet each other. A septum is formed in each pro gametangium dividing it into two, the terminal portion becoming the gametangium and the other portion becoming the suspensor.

At the point of contact the walls between the gametangia are dissolved and a single fusion cell results. Plasmogamy occurs in the fusion cell which develops as a zygospore. Zygospore after a resting period of about nine months germinate, produce germ tube which functions as sporangiophore and develops a germ sporangium at its tip. The sporangium is of usual columella type. The germ sporangia contain all plus (+) or all minus (-) spore or mixture of both. These spores called germ spores or microspores. They germinates and form fresh mycelium.

Lecture 08

Subdivision: Ascomycotina, class: Hemiascomycetes (Taphrinales), class: Plectomycetes (Eurotiales), class: Pyrenomycetes (Erysiphales, Clavicepitales), class: Loculoascomycetes (Pleosporales)

General characters

Mycelium is well developed branched and septate. Yeast is single celled organism. Septum has a central pore. Cell wall is made up of chitin. Asexual spores are non-motile conidia. Sexual spores are ascospores. Ascospores are usually 8 in an ascus. They are produced endogenously inside the ascus.

Key to the classes of Ascomycotina

Ascocarps and ascogenous hyphae absent, thallus mycelial or yeast-like - **Hemiascomycetes**

Ascocarps and ascogenous hyphae present, Thallus mycelial: Asci bitunicate, ascocarp an ascostroma **- Loculoascomycetes**

Asci typically unitunicate, if bitunicate, ascocarp as apothecium: Ascocarp a cleistothecium, asci evanescent and scattered **- Plectomycetes**

Asci regularly arranged as basal or peripheral layer in the ascocarp

Insect parasites **- Laboulbeniomycetes**

Not insect parasites, Ascocarp perithecium **- Pyrenomycetes**

Ascocarp apothecium **– Discomycetes**

Class: Hemiascomycetes

The class is characterized by the lack of ascocarp, vegetative phase comprising of unicellular thallus or poorly developed mycelium. It is divided into three orders:

1. Asci developing parthenogenetically from a single cell or directly from a zygote formed by population of 2 cells **- *Endomycetales***
2. Asci developing from ascogenous cells, forming a palisade like layer **- Taphrinales**
3. Asci developing in a compound spore sac (synascus), produced singly from thick walled chlamydospores **- Protomycetales**

Order: Endomycetales

Family	Genus
Saccharomycetaceae	*Sacchromyces, Schizosaccharomyces, Saccharomycodes*

Order: Taphrinales

Family: Taphrinaceae **Genus*:*** *Taphrina*

Taphrina deformans - Leaf curl or leaf blister of peach

T. maculans -Leaf spot of turmeric and ginger

Order: Protomycetales

Family: Protomycetaceae **Genus:** *Protomyces Protomyces macrosporus*-

Stem gall of coriander

Class: Loculoascomycetes

It comprises the following 5 orders

Myriangiales, Dothideales, Pleosporales (Pseudosphaeriales), Hemisphaeriales (Microthyriales) and Hysteriales

Order: Myriangiales

Family: Myriangiaceae (Genera: *Elsinoe, Myriangium*)

Order: Dothideales

Family: 1. Capnodiaceae (Genera: *Capnodium, Limacinia*)

2. Dothideaceae (Genera: *Mycosphaerella, Guignardia*)

Order: Pleosporales

Family: Venturiaceae

Superficial mycelium lacking. Pseudothecial immersed or erumpent or developing superficially on immersed hypostroma or mycelium arising from it.Pseudothecial wall composed of distinct dark brown cells, ascospores smooth, and bicelled.

e.g., *Venturia inaequalis* -apple scab;

V. pirina -pear scab

Class: Pyrenomycetes

Order: Meliolales

Family: Meliolaceae (Genus*: Meliola*)

Order: Erysiphales

The fungal species in this order cause plant diseases commonly called as powdery mildews. The mycelium is usually ectophytic to partially endophytic. Asexual reproduction is by conidia borne on conidiophores either singly or in basipetal chains. Conidia of powdery mildews germinate at 0 to 100% RH. Their germination at very low RH has been explained due to their very high osmotic pressure, which makes them able to draw sufficient moisture for germination from dry air. The ascocarps are provided with characteristic appendages, which in addition to the number of asci are used in differentiating genera. Many of the powdery mildews are not known to produce ascocarps or these are produced rarely. In the absence of ascocarps, conidia have been utilized for classifying these fungi. It has only one family, Erysiphaceae and it has the following genera.

1. Ascocarps present

A. Mycelium superficial

1. Ascocarp containing one ascus only

a. Perithecial appendages simple, myceloid -*Sphaerotheca*

b. Perithecial appendages dichotomously branched -*Podosphaera*

2. Ascocarp containing many asci

a. Perithecial appendages simples, myceloid -*Erysiphe*

b. Perithecial appendages dichotomously branched -*Microsphaera*

c. Perithecial appendages coiled at the top -*Uncinula*

B. Mycelium partially endophytic

Perithecial appendages simple, imperfect state -Oidiopsis, *Leveillula*

Perithecial appendages coiled at the tip, imperfect state -Oidiopsis –*Pleochaeta* 1 Perithecial appendages with basal swellings, imperfect state -*Ovulariopsis*

II. Ascocarp absent

A. Mycelium superficial

Basal cell of the conidiophore swollen

2. Basal cell of the conidiophore not swollen

a. Conidia borne in chains -*Euoidium*

b. Conidia borne singly -*Pseudoidium*

B. Mycelium partly endophytic

Conidia ovoid, obclavate -*Oidiopsis*

Conidia pyriform -*Ovulariopsis*

Order: Clavicipitales

Family: *Clavicipitaceae* Genus C*laviceps*

Claviceps

The stromatic structures are quite prominent. The perithecia are deeply immersed in stroma which develops as an apical head on an erect stalk (stipe) arising from a dark coloured sclerotium, Perithecia are produced towards the periphery of the stroma. Ascospores are thread like.

Claviceps microcephala (C. fusiformis) -ergot of pearl millet

C. oryzae -sativae -false smut of rice/

Claviceps purpurea -ergot of rye

C. sorghi (Sphacelia sorghi) -ergot of sorghum

Classification, symptoms and life cycle of powdery mildew – *Erysiphe* and *claviceps*

I. Powdery Mildews

Powdery mildew is the appearance of white powdery growth mostly on upper leaf surfaces on stems, floral parts and fruits leading to premature defoliation. Powdery mildews arc caused by members in the order Erysiphales in the subdivision Ascomycotina. There are three types of powdery mildew pathogens have been recognized based on the mycelium and type of conidia the differences are given below.

S. No.	**Description**	***Oidium***	***Oidiopsis***	***Ovulariopsis***
1.	Symptoms	Mostly on upper surface of leaves	Mostly on lower surface of leaves	Lower or upper surface of leaves
2.	Mycelium	Hyaline, septate ectophytic	Hyaline, septate, endophytic	Hyaline, septate, ecto and endophytic
3.	Haustoria	Present in epidermis only	Present in Epidermis	Epidermal haustoria

			and spongy cells	absent, haustoria in inner cells
4.	Conidiophores	Short, single, club shaped, non septate,	Long, branched, Septate	Long, single, septate
5.	Conidia	Cylindrical or barrel shaped, in chains	Club shaped single celled,	Club shaped, single celled
6.	Examples	Grapes - *Uncinula Necator* Blackgram- *Erysiphe po/ygoni* Bhendi - *Erysiphe cichoracearum* Apple - *Podosphaera Eucotricha* Rose - *Sphae rotheca pannosa var.rosae* Oak - *Microsphaera alphitoides*	Chillies and Pigeonpea - *Leveillula taurica* (syn. *Oidiopsis taurica)*	Muberry *Phyllactillia guttata* (syn. *P. corylea)*

The powdery mildew fungi produces closed ascocarp called cleistothecium. The genera are differentiated based on the number of asci in the cleistothecium and type of appendages on it. They are classified as follows.

I. One ascus in a cleistothecium

i. Myceloid appendages - e.g., *Sphaerotheca*

ii. Dichotomously branched appendages - e.g., *Podosphaera*

II. Many asci in a cleistothecium

i. Myceloid appendages - e.g., *Erysiphe Leveillula.*

ii. Appendage coiled at the tip (circinoid type) - e.g., *Uncinu/a.*

iii. Dichotomously branched appendages - e.g., *Microsphaera*

iv. Appendage with bulbouse base and spear like tip - e.g., *Phyllactinia.*

Powdery mildew of grapevine - *Uncinula necator.*

Systematic position

Sub-kingdom : Mycota

Division : Eumycota

Subdivision Class : Ascomycotina

Order : Pyrenomycetes

Family : Erysiphales

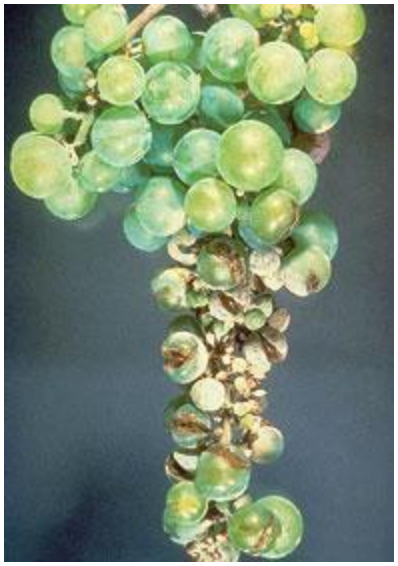
Genus : Erysiphaceae

Species : *Uncinula*

Mycota : *U .necator*

Symptoms

Whitish powdery growth on the upper surface of the leaves and in several cases leaves dry and fall off. On berries also it produce white coloured fungal growth which leads to deformation and cracking of berries.



Powdery mildew symptoms on grape berries (L) and Rachis (cluster stem) (R)

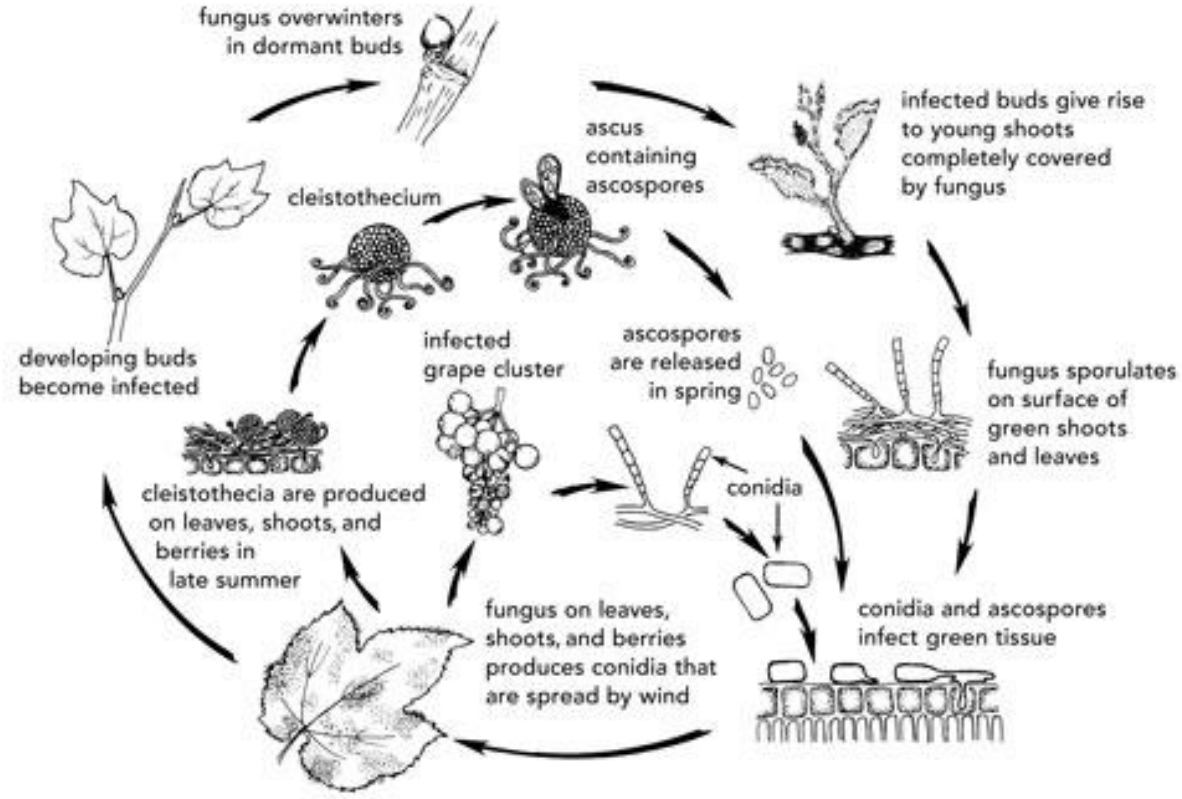
Primary infections of powdery mildew on grape leaf (Left) and powdery mildew covering grape leaf surface (Right)

Pathogen

Mycelium is hyaline, septate, branched and ectophytic. Haustoeia are saclike. Conidiophore is erect, long, hyaline, single celled, simples, club-shaped are barrel shaped, hyaline, thin walled and are produced in chain. 'Cleistothecium is of circinate type, globose and brown or black in colour. Asci are ovate and 4 to 8 asci per cleistothecium .Ascospores are 4 to 6 per ascus, single celled, hyaline and oval.

Disease cycle

The fungus survives through hyphae inside the dormant vegetative buds and through c1eistothecia. The ascospores or the hibernating mycelium in the host buds cause infection and produce enormous conidia. They spread through wind, germinate on the leaf surface and produce germ tubes and appresorium and cause infection. Cleistothecia are formed late in the season on leaves and stem. They are also formed on the fallen leaves. The ascospores in the cleistothecium are released in the spring by the swelling and rupturing of perithecial wall. Ascospores which fall on any green surface of the developing vine cause primary infection.



Powdery mildew of pulses - *Erysiphe polygoni*

Symptoms

Greyish white powdery growth appears on the upper surface of the leaves, stems, petioles and pods. Later the growth becomes brown and the leaves turn yellow and drop.

Pathogen

Mycelium is ectophytic, hyaline, septate and branched. Haustoria are bulbous and sac-like. Conidiophore is simple, erect, hyaline and bear chain of conidia. Conidia are hyaline, thin walled, single celled and ovate or barrel or cylindrical in shape. Cleistothecia are black, round with myceloid appendages and each cleistothecium bears 2 to 8 asci. Asci are ovate and contain 3 to 8 ascospores. Ascospores are hyaline, elliptical and single celled.

Powdery mildew of chillies and pigeonpea - *Leveillula taurica*

Symptoms

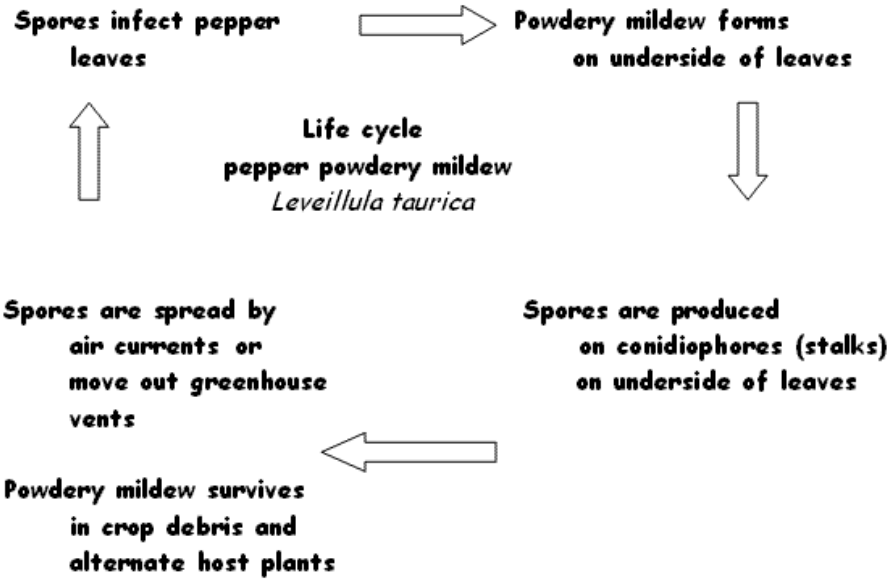
Whitish fungal growth on the under surface of the leaf and the corresponding upper surface show yellow discolouration. Later the disease spreads to entire leaf surface cause yellowing and defoliation of leaves.

Pathogen

Mycelium is endophytic, hyaline, septate and branched. Conidiophores emerge through stomata, single or in groups, branched, septate and bear single conidium at its tip. Conidia are hyaline, single celled and clavate. Cleistothecia are with myceloid appendages. Asci are cylindrical and 9 – 20 / cleistothecium. Each ascus contains two ascospores.

Disease cycle

Ascospores from the perennating cleistothecia infect the lower most leaves near the soil level. The fungus penetrates through stomata. Mycelium sends globular haustoria in to the mesophyll cells and epidermis. C**onidiophores** with a conidium at the tip arise vertically from the plane of mycelial growth. Conidia are wind borne and helps in secondary spread.Later in the season, black, globose **cleistothecia** are produced. Asci are cylindrical and 9 – 20 / ascocarp. **Ascospores** are hyaline, 8 / ascus and are elliptical.



iv. Powdery mildew of mulberry - *Phyllactinia guttata (*syn*. P.corylea).*

Symptoms

White fungal growth on lower surface of leaves and corresponding upper surface shows yellow discolouration; leaves dry and defoliate.

Pathogen

Mycelium is hyaline, septate and branched. Conidiophores are erect,septate, hyaline and simple. Conidia are hyaline, single celled, clavate or flame shaped and borne singly on

conidiophore. Cleistothecia are flat, spherical, black and with bulbous base and pointed spear-like tip appendages. Asci are clavate. Asci are 10-30 in each cleistothecium. Ascospores are two per ascus and oval in shape.

Disease cycle

Ascospores from the perennating cleistothecia infect leaves and penetrate through stomata.mycelium is endophytic and produces conidia which are spread through air. Cleistothecia help in the survival.

II. Sugary disease / Ergot

Exudation of honey-like sticky fluid from spikelets (conidial stage) and later with formation of black scletoria, (ergot) is known as **sugar disease or ergot.**

Sugary disease / ergot of pearlmillet- *Claviceps fusiformis* (syn**. *Claviceps microcephala)***

Systematic position

Sub-kingdom : Mycota

Division : Eumycota

Sub-division : Ascomycotina

Class : Pyrenomycetes

Order : Clavicepitales

Family : Clavicepitaceae

Genus : *Claviceps*

Species : C. *fusiformis*

Symptoms

Exudation of small droplets of light pinkish or brownish sticky fluid from the spikelets, trickling down of honey dew secretion; at later stage, black, dark sticky patch may be seen; transformation of ovary to a hard structure consisting of mycelial mat of fungus called **sclerotia**.

Pathogen

Mycelium is septate, hyaline and branched. It produces two types of conidia *viz.*, macroconidia and microconidia. Macroconidia are hyaline, fusiform, and unicellular and germinate by producing one to three germ tubes. Microconidia are hyaline, globular, unicellular and germinate by producing only one germ tube. Sclerotia are dark grey, long and club shaped. Perithecia are pyriform. The asci are long and hyaline. The ascospores are thread-like, hyaline and non-septate.

Disease cycle

The fungus spreads from plant to plant in the conidial stage. The honeydew mixed with the inoculum (conidia) attracts insects, which help in the dissemination of conidia and spread the disease in the field. The sclerotia form at the later stage in the diseased earheads. After harvest when the earheads are thrashed sclerotia are found mixed with seed and reach soil when they (seed and sclerotia) are sown help the fungus to perpetuate from season to season. They may fall and remain in the soil or plant debris and germinate during the next season and produce perithecia containing asci and ascospores. The ascospores, which spread through air, cause infection of the spike, producing the conidial stage.

Sugary disease / ergot of sorghum - ***Claviceps sorghi*** (syn.: ***Sphacelia sorghi)***

Sugary disease / ergot of rye-*Claviceps purpurea*

Symptoms

Droplets of light pinkish / brownish sticky fluid exudes from the spikelets and honeydew secretion trickling down from the earhead. Infected spikelets turn black and finally several sticky patches are seen on the ear. This stage is known as **honeydew / sphacelia stage**. It may continue for 20-25 days.Later, infected ovary is transformed into a hard, black structure called sclerotia, which are projecting out of the spikelet. This stage is called **ergot / sclerotial stage.**

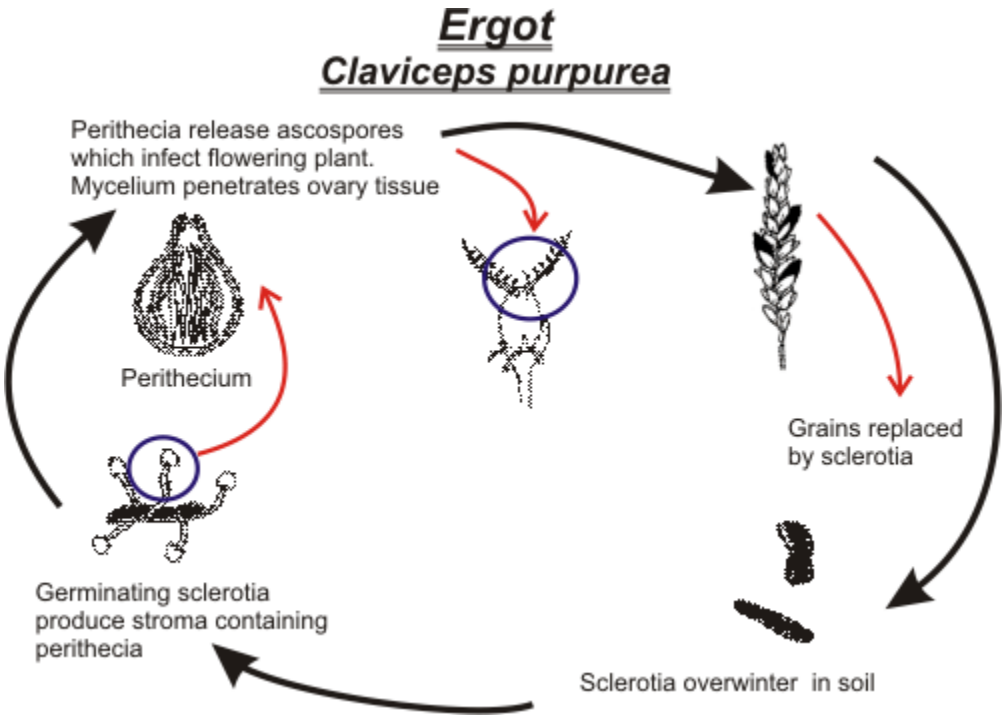
Pathogen

Conidia are hyaline, single celled, oblong with a constriction in the middle. Sclerotia are hard, compact, black, cylindrical, straight or curved.

Disease cycle

Sclerotia germinate under favourable condition and produce vertical column of mass of hyphae called as stromatic stalk or stipe. Pyriform perithecia are arranged in the periphery of the head of the stipe. Perithecia contain hyaline asci. Ascospores are hyaline, aseptate and filiform. Ascospores are ejected with force, spread by wind and reach healthy flowers. These spores germinate on stigma and infection thread reaches the ovary through style. Honeydew stage / sphacelia stage develops as result of infection. Fungus produces dull brown, septate and branched mycelium on the ovary. Generative hyphae comprise of conidiophores and conidia are produced on the surface of the ovary.

Conidiophores are hyaline, short and simple. Conidia are are mixed with honeydew and ooze out. Insects attracted by honeydew carry conidia to healthy flowers and results in secondary infection of new ovaries. Later, ovary has been replaced by sclerotia, which forms horny structures between the glumes. Sclerotia spread along the seed as a contaminant or it falls on the ground and survives in the soil.



Lecture 09

Subdivition: Basidiomycotina, class: Teliomycetes (Uredinales, Ustilaginales) class: Hymenomycetes (Aphyllophorales)

General character of Basidiomycotina

Basidiomycotina fungi are highly evolved group. Mycelium is septate. Dolipore septum is present except rusts and smuts. Clamp connections present. Cell wall consists of chitin and glucans. Sexual spores are basidiospores. They are exogenously produced on basidium.

Key to the classes of Basidiomycotina

Basidiocarp lacking and replaced byTeliospores grouped in sori or scatteredwithin the host tissues **- Teliomycetes**

Basidiocarp usually well-developed,Basidia typically organized as a hymenium;Saprobes or rarely parasites **- Hymenomycetes and Gasteromycetes**

Class: Teliomycetes

This class includes many economically important plant pathogens commonly known as rusts and smuts. Mycelial hyphae septate and the septa are of simple type. Asexual reproduction is uncommon, through dikaryotic spores of conidial nature produced in rusts. In smut fungi, haploid sporidia may bud off into daughter cells. Basidiocarps absent. The class is characterized by thick walled, dikaryotic resting spores commonly called as teliospores in rusts and chlamydospores in smuts, Karyogamy takes place in this part and therefore, is actually a probasidium. The resting spores on germination produce promycelium (metabasidium) into which diploid nucleus moves and after meiosis four haploid nuclei are produced. These nuclei later, result in the formation of haploid basidiospores. The class is divided into 2 orders:

This class is divided into 2 orders:

Basidia arising from a thick-walled probasidium

1. Basidia becoming septate, bearing 2 to 4 (mostly 4) basidiospores, one at each septum and one nearly terminal - **Uredinales**
2. Basidia aseptate or septate, number of basidiospores indefinite **– Ustilaginales**

Characters	Smuts	Rusts
Perfect spore	Intercalary	Terminal
Number of basidiospores per promycelium	Many	Definite and four
Basidiospores	Globular	Sickle-shaped, elliptical or hypha like.
Basidiospores are borne on	Short sterigmata	Sessile spores
Basidiospores discharge	Discharged violently	Not discharged violently
Teleutospores	They are formed from terminal cells of binucleate mycelium	They are formed from intercalary cells of the binucleate mycelium.
Basidiocarps	Rare	Absent
Parasitic mycelium	Intercellular with haustoria	Intercellular with haustoria
Clamp connection	Present	Rare
Parasitism	Facultative saprobes	Biotrophs
Sex organs	Absent	Specialized
Heteroecism	Absent	Common
Polymorphism	Absent	Distinct

Order Uredinales (The rust fungi)

The members of this order are commonly called as 'rust fungi' due to the characteristic reddish brown colour of some of their spores. These are obligate parasites and cause great losses to many cultivated crops. The mycelium is septate without clamp connections. It grows intercellularly, frequently producing haustoria. In general, these fungi cause local infections in above ground parts of plants but sometimes these are systemic and may overwinter in roots or other parts. In recent years, rusts have been grown in tissues and axenic cultures e.g., Puccinia malvacearum, *M. lini*.

The rust in which life cycle is short and completed by only two types of spores (teleutospores and basidiospores) called microcyclic rust. The rust which has all the five spore stages (teleutospore, basidiospore, spermatia, pycniospore, aeciospore and uredospore) in its life cycle called macrocyclic rust. A macrocyclic rust in which uredospores are not formed has been named as demicyclic rust. The rust fungi that complete their life cycle in one host are termed as autoecious and those requiring two hosts for the completion of their life cycle are called as heteroecious. The rust fungi produce upto five types of spores in their life cycle, as given below:

Stage 0: Spermagonia with spermatia and receptive hyphae .

Stage I : Aecia with aeciospores

Stage II: Uredia with uredospores

Stage III: Telia with teleutospores

Stage IV: Basidia with basidiospores

(a) Pycniospores Stage(0)

These are the spores produced in a flask-shaped structure called as pycnium, containing a palisade of sporogenous cells which produce spores in nectar exuded from the ostiole. Periphyses and flexuous hyphae (receptive hyphae) are commonly present in pycnia. Pycnia are formed in the host after it is infected by the basidiospores. Pycniospores are single celled and behave as spermatia.

(b) Aeciospores Stage (I)

These are single celled dikaryotic spores produced in chains in cup-like structures known as aecia. The spores are yellow to orange in colour with a hyaline characteristically verrucose wall.

(c) Uredospores Stage (II)

These are single celled binucleate, pedicellate deciduous spores borne in naked or paraphysate sori breaking through the host epidermis, commonly called as uredia or uredinia. Uredospores are brown, echinulate having almost conspicuous germ pores. They behave as conidia and repeat several cycles in a season and are also called as summer spores.

(d)Teliospores Stage(III)

These are binucleate; pedicellate or sessile; erumpent or embedded in host tissue. They may be single celled, bicelled or more than 2-celled, with dark brown walls, having one or more germ pores. They produce basidium and basidiospores upon germination.

(e) Basidiospores Stage(IV)

They are haploid, unicellular spores borne on sterigma. These arise from cylindrical to club-shaped 2 to 4 celled basidia. Depending on the reproductive stages present in the life cycle of rusts, rusts can be termed as 'macrocyclic'(all 5 stages present), 'demicyclic'(uredial stage absent) or 'microcyclic'(teliospore only as the binucleate spore). Rusts are either homothallic or heterothallic.

In the former case pycnia, are not necessary and frequently absent. Dikaryotic phase starts from two cell nuclei at some point in the life cycle. In the case of heterothallic macrocyclic rusts, basidium bears four basidiospores; two of +type or

two of -type. These basidiospores produce pycnia of + or-type respectively. The pycniospores behave as spermatia and fuse with the receptive hyphae of the opposite sex. The dikaryotic phase thus resulted, leads to the development of aecia.

Classification

There are four families in Uredinales

A. Teliospores sessile

1. Teliospores in single, palisade-like layers or solitary, germinating to produce a septate promycelium; mostly the spores are unicellular **- Melampsoraceae**

2. Teliospores in waxy crusts of one or two layers, becoming septate during germination without forming an external promycelium **- Coleosporiaceae**

3. Teliospores in chains **- Cronartianceae**

B. Teliospores pedicellate, germinating to form a promycelium, which become septate; spores uni -or multicellular, free **- Pucciniaceae**

Family: Pucciniaceae

This is one of the largest family of Uredinales and contains members , which attack a wide variety of angiosperms, often causing destructive diseases of cereals and legumes. The teliospores are pedicellate. Teliospores are never present in the form of layers of crusts. They may be simple (1-celled) or compound (2-or more celled). The uredinia may or may not have paraphyses. The aecia may be cupulate (cup-like) or hyphoid (naked). The peridium may be revolute (curved back). Spermagonia may be subcuticular and flattened or subepidermal and spherical with an ostiole. Both heteroecious and autoecious species are present. The family

contains more than 85 genera and about 3,000 species of which genera *Puccinia* and *Uromyces* account for 1800 and 600 species, respectively. Other genera in Pucciniaceae are *Gymnosporangium, Phragmidium, Hemileia* and *Ravenelia.*

Classification

Important genera in Pucciniaceae are

I. Teliospores single celled.

1. Telia non-gelatinous.

A. Teliospores walls colourless; uredospores reniform, basidia slender, symmetrical - ***Hemileia***

B. Teliospore walls coloured, thickened, ornamented or with visible pores. Telia subepidermal, each pedicel bearing single teliospore

a. Telial pedicel septate - *Trachyspora*

b. Telial pedicel aseptate; uredia and telia non-peridiate

i. Pycnia subepidermal, globose; teliospore wall thicker above than sides or coloured or smooth - ***Uromyces***

ii. Pycnia subcuticular, conical; teliospore usually ornamented, globose to ellipsoid.

On Anacardiacea **- *Pileolaria***

2. Telia gelatinous, telial pedicel aseptate; teliospore cells arranged serially, with pedicel attached to the lower one only. On Cupressaceae **- *Gymnosporangium***

II. Teliospores bicelled, subepidermal, non-gelatinous; uredia and telia non-peridiate; teliospore with one germ pore/cell.

1 .Teliospores in fascicles **- *Tranzschelia***

2. Teliospores not in fascicles. Pycnia globose, subepidermal; teliospores truly pedicellate, sometimes >2 celled **- *Puccinia***

III. Teliospores 3 or >3 celled.

A. Teliospore cells arranged as in phragmospores; teliospore wall coloured with 2 or more germ pores in each cell; pedicel usually long, teliospore without conspicuous outer hygroscopic layer **- *Phragmidium***

B. Teliospore cells arranged as inverted triangle; teliospore wall with 2 or >2 germ pore/cell **- *Nyssopsora***

C. Teliospore cells arranged in a radially discoid head; teliospore pedicels several per head, fused together, telial head with hygroscopic cysts – ***Ravenelia***

Genus 1

***Puccinia*:** In Puccinia the teliospores are brown and are with mostly 2 cells. They are borne on a simple pedicel. Telia are at first embedded in the host tissue but sooner or later the epidermis is ruptured and the spores become free. Spermagonia are subepidermal and spherical with ostiole. Aecia are cupulate with recurved peridium or maturity. Urediniospores (uredospores) are single and stalked, with long pedicel. They are often present in the same sori in which later the teliospores (teleutospores) are formed species are heteroecious.

They mostly parasitize and cause rust diseases in Gramineae and Cyperaceae. It is the largest genus with about 3000 to 4000 species parasitic on angiospermic plants. The important plant pathogenic species are as follows:

Uromyces

Uromyces is the second largest rust genus with about 600 species. It is characterized by the stalked, one celled teliospores on a simple pedicel with a papillum. Uredial, aecial and spermagonial characters are similar to *Puccinia*. The species may be heteroecious or autoecious. The members mostly cause rust disease in leguminous plants. The important species causing pant diseases are given below.

Fungus	**Disease**
P. arachidis	Groundnut rust
P.asparagi	Rust of Asparagus
P. chrysanthemi	Chrysanthemum rust
P. coronata	Crown rust of wheat
P. helianthi	Sunflower rust
P. hordei (P. anomala)	Barley rust
P. kuehnii & P. erianthi)	Sugarcane rust

P.substriata var. penicillariae (*P. penniseti*)	Pearlmillet rust
P. sorghi (P. zeae, P. maydis)	Sorghum rust
P. recondita (P. triticina)	Brown or leaf rust of wheat
P. striiformis (P. glumarum)	Yellow or stripe rust of wheat
P. graminis tritici	Wheat stem or black rust
P. graminis hordei	Barley rust
P. graminis avenae	Oat rust
P. graminis secalis	Rye rust
P. graminis phleipratensis	Timothy rust
P. graminis poae	*Poa pratensis* rust
P. graminis agrostidis	Rust on red top and other *Agrostis* spp.
P. antirrhini	Anirrhinum rust
P. sorghi & P. polyspora, *P . carthami*	Corn rust Safflower rust
P. cacabata P. allii Onion rust	Cotton rust
P. malvacearum	Holly hock rust
P. menthae	Mint (*Piper mentha*) rust
P. psidii	Guava rust

Fungus Diseases

Uromyces ciceris-arietini -Gram rust

U. *dianthi* -Carnation rust

U. *fabae* -Pea rust, *Vicia* rust, lentil rust

U. *phaseoli typica*=(*U. appendiculatus*) -Bean rust, blackgram rust, *Dolichos* and *Vigna* rust.

U. *pisi* -Pea rust

Family: Melampsoraceae

Melampsora lini – Linseed rust

M. ricini -Castor rust

Order: Ustilaginales

There are two families in this order.

Family: Ustilaginaceae

The general characters of the family are same as for the order. The family includes all the smut fungi in which the promycelium is transversely septate into several, usually four, cells with lateral and terminal sporidia, one or more from each cell. Sometimes there may be only one sporidium on the septate promycelium. Occasionally, the basidium (promycelium) develops directly into a mycelium without forming sporidia, as in *Ustilago nuda tritici*, or both conditions may be present (*Sphacelotheca sorghi*). Sometimes two ore more promycelia are produced by the same spore. Important genera are *Ustilago Sphacelotheca*, *Tolyposporium* and *Melanopsichium*.

Ustilago

Sori contain 1-celled teliospores, dusty at maturity and are covered by membrane of host origin. Germination is by means of septate promycelium, which may become infection hyphae or may produce sporidia laterally near the septa. The sporidia germinate easily in water by infection. Hyphae or may multiply by budding.

U*stilago nuda tritici* -Loose smut of wheat

U. zeae -Common smut of corn (syn. *U. maydis)*

U. hordei -Covered smut of barley

U. nuda -Loose smut of barley

U. kolleri -Covered smut of oats

U. avenae -Loose smut of oats

U. scitaminea -Whip smut of sugarcane

Family: Tilletiaceae

The general characters of this family also are same as for the order. However, the family includes only those smuts in which the promycelium is aseptate with terminal whorl of sporidia. The teliospores are single or combined into more or less permanent balls usually including sterile cells. Promycelium is simple, usually nonseptate up to the time of formation of sporidia. Sporidia are longer than in Ustilaginaceae, produced in clusters at the apex of the promycelium, fusing or not fusing in pairs, producing similar or dissimilar sporidia or germinating directly into infection threads. Important genera are *Tilletia, Neovossia, Urocystis, Entyloma* and *Turbicina*.

Class Hymenomycetes

This class is characterized by usually well-developed basidiocarp or fruiting bodies. Basidiocarps are typically gymnocarpic (primordium and mature sporocarp have exposed hymenium) or semiangiocarpic (partially closed till spores are matured). Basidiospores are ejected forcibly i.e. these are ballistospores.

Classification

a. Basidia aseptate -Sub-class Holobasidiomycetidae.

b. Basidia septate -Sub-class Phragmobasidiomycetidae

Holobasidiomycetidae

Holobasidiomycetidae is characterized by an undivided, cylindrical to clavate basidium (i.e. holobasidum), which usually extends into four sterigmata each bearing a basidiospores. The basidiospores produced in this group are non-repetitive. It contains mushrooms, pore fungi, tooth fungi, coral fungi, chantarelles, boletes and bracket fungi.

Phragmobasidiomycetidae

The metabasidium of these is completely or incompletely divided into 4 cells by transverse or longitudinal septa. The basidiocarp is usually gelatinous, waxy or dry. The probasidia may or may not be persistent. The basidiospores are often repetitive and sterigmata swollen.

Sub-class Holobasidiomycetidae

Order: Exobasidales

It is a small order consisting of the gall-forming plant parasites, especially of Ericaceae, Commelinaceae and Theaceae. The order is characterized by the 4-spored basidia, which form a layer (hymenium) on the leaf surface and lack the well-define basidiocarps. This order has a

single family, Exobasidiaceae with five genera. The genus, *Exobasidium* is important. *Exobasidium*: The characteristic feature of the genus is that the basidia, which arise between the epidermal cells of the host, form a more or less continuous hymenium at maturity. The dikaryotic mycelium is devoid of clamp connections, grows intercellularly and produces haustoria. This genus has about 50 species. They are parasitic on leaf, short stem and flowers of Dicotyledonous plants causing hypertrophy and deformation. *E. vexans* is responsible for blister blight of tea. *E. japonica* is responsible for galls of *Azalea.*

Order: Tulasnellales

Family: Ceratobasidiaceae

Ceratobasidium

Metabasidia much wider than pedicels, basidia abruptly narrowed at pedicels, hyphal cells binucleate; sclerotia present or absent.

Thanatephorus

Metabasidia little wider than the pedicels, spores ellipsoid with one side flattened, rarely obpyriform to obovate, hyphal cells multinucleate, sclerotial or sterile mycelia state (Rhizoctonia) present.

Order: Aphyllophorales/ Polyporales

Family: Corticiaceae: (Genera: *Chondrostereum, Peniophora, Athelia, Corticium*):

Family: Ganodermataceae (Genus: *Ganoderma*)

Genus: *Ganoderma*

The fruit bodies of this genus are either sessile or stipitate, the upper surface of the pileus being shiny as if varnished due to the presence of an amorphous waxy substance secreted by the hyphae. The basidiospores are coloured, elliptical, with a wall consisting of two layers, the apex at first rounded but later truncated.

Order: Agaricales

The order Agaricales is commonly called 'gill fungi', which include mushrooms, (edible), toadstools (poisonous) and boletes. Mushrooms are mainly terrestrial or lignicolous mostly growing saprophytically and some enter into mycorrhizal relationship with higher plants. The chracteristic macroscopic basidiocarp or fruit body is fleshy, generally having a stalk i.e. stipulate, and has a pileus bearing hymenium-covering lamellae on the underside. The young basidiocarp may be covered by a universal veil, which becomes broken down by the growth of

the stipe and pileus but part may remain as volva at the base of the stipe and as fragments on the upper surface of the mature pileus.

The developing hymenium may be covered by a partial veil, which later becomes a cortina or an annuals around the mature stipe. The hymenium may consist of cystidia of various kinds, setae, or hyphidia among the basidia the latter producing unicellular, hyaline or coloured ballistospores, typically in fours. Mycelium of Agaricales is typically basidiomycetous with primary, secondary and tertiary mycelia. In few of the Agaricales asexual reproduction takes place by oidia (*Coprinus* spp.) and chlamydospores (*Volvariella volvacea*). Majority of the members are heterothallic and show either unifactorial or bifactorial heterothallism. The compatible thalli are brought together either by hyphal fusion or by means of oidia. The dikaryotic mycelium thus formed ultimately leads to the formation of basidiocarps. The fusion of the dikaryotic nuclei takes place in the basidium (produced in the gills), which is followed by reduction division resulting in the formation of generally uninucleate but sometimes-binucleate basidiospores, which are haploid.

The order Agaricales contains 16 families (Smith, 1973). They are Boletaceae, Hygrophoraceae, Tricholomataceae, Entolomataceae, Amanitaceae, Pluteaceae, Lepiotaceae, Agaricaceae Bolbitiaceae, Strophariaceae, Coprinaceae, Cortinariaceae, Paxillaceae, Gomphidiaceae, Russulaceae and Cantharellaceae.

Family: Tricholomataceae *Armillariella*, *Pleurotus, Marasmius*, *Clitocybe, Tricholoma, Panus, Mycena* and *Omphalotus* are the important genera in this family.

***Pleurotus*:** Stripe is generally eccentric and pileus resupinate in some species. They have white or pigmented range fruiting bodies. They grow on wood, on dead or living hosts. This genus contains most valuable edible mushroom.

P. sajor -caju Oyster mushroom

P. ostreatus - Oyster mushroom.

Family : *Amanitaceae*

The characteristic feature of the family is the presence of free gills with bilateral trama and the presence of both outer and inner veil. The basidiospores are white to creamish in colour. The members are found on the ground in woods, on termite nests or on wood. *Amanita, Limacella* and *Termitomyces* are the important general in this family. *Amanita:* The genus is characterized by free gills and the presence of the annulus and volva on the stripe. Remnant of

the volva may persist as volva scales on the cap. More than 5 species are known to be mycorrhizal in habit. Some are more attractive and used in decoration. Some are poisonous and produce toxins called phallotoxin and amatoxins.

A. virosa - called as 'Destroying angel'; or death angel. Decorative by its pure white basidiocarp; poisonous

A. caesarea - Called 'caesar's mushroom', yellow and orange capped and used in decoration

A. muscaria - Called 'fly agaric'; yellow or orange or brilliant red capped and used in decoration; poisonous to flies

A. phalloides - Called 'Depth cap fungus'and it is poisonous.

Family: Pluteaceae

It is characterized by the free gills having bilateral hymenophoral trama, which are convergent toward the center of the trama, and by the production of dull pink basidiospores. The genera *Volvariella, Pluteus* and *Chamaeota* are included in this family.

Volvariella

The genus *Volvariella* contains approximately 25 species reported from tropical, subtropical and temperate regions found growing in shady places on soil and on decaying organic matter. They appear during the rainy season and are recognized by pink spores, free gills forming a ring around the stipe or a stipe which bears no annulus but is enclosed at the base by a cup-shaped persistent 'volva'; The pileus is fleshy, white or pigmented and circular with a central stipe and is responsible for its name *Volvariella.* A few of the species such as *V. volvacea* and *V. diplasia* (commonly called the straw, or paddy straw or Chinese mushrooms) are edible.

Family: Agaricaceae

The family Agaricaceae is characterized by the blackish or brown colour of the basidiospores and the presence of pallid to pink or rosaceous coloured free gills on the pileus.

An annulus is typically present on the stipe. *Agaricus, Cystoagaricus* and *Melanophyllium* are important genera. *Agaricu*s: The characteristic features of the genus are the presence of deep purplishbrown free gills, and an annulus but no volva, and stalk that readily separates from the pileus. They are commonly found growing on ground in pastures. These mushrooms are edible for their delicacy.

A. campestris -Common or Field mushroom; or white button mushroom; edible

A. brunnescens - edible and cultivated mushroom *(=A. bisporus*)

A. placomyces – poisonous

A. silvaticus – poisonous

Edible mushrooms

Mushroom is a fleshy to tough, edible umberella like sporophores (basidiocarp)of certain basidiomycetes fungi. The mushroom consists of **stipe or stalk**, a membranous annular ring called **annulus**, cap or **pileus** arid **gills** or lamellae (plates). Each gill on cross section shows closely packed elongated fungal cells called trauma. On both sides of the trauma a **sub-hymenium** with spherical cells is formed. Over the sub-hymenial layer a fertile layer with palisade like cells called **hymenium** is found. It consists of club shaped **basidia**, sterigmata bearing single-celled basidiospores. In the hymenial layer stout sterile structure called **cystidia** are also found.

Morphology of Mushroom

Morphology of the edible and cultivated mushroom *Agaricus campestris* is given below: *Agaricus campestris* is a field mushroom growing on all organic matter in the fields. The mycelium is highly organized and the hyphae are often found to form rhizomorphs, which are thick strands or rope-like structures. Clamp connections are also formed by the hyphae and chlamydospores may be produced to resist the adverse conditions. The fruiting body or the basidiocarp commonly called as mushroom comes out of the soil and it consists of thick stalk called **stipe** on which an umbrellashaped **pileus**(cap) rest.

The stipe is cylindrical in shape, fleshy and usually swollen at the base. Just above the middle the stipe has a membranous ring known as **annulus**. This represents the remnants of the inner veil, which enclosed the lower surface of the pileus in the initial stages of development. The stipe is constituted by well packed hyphae at the basal portions being loosely placed towards the center permitting the formation of large air space. The pileus on the under surface exhibits numerous structures radiating from the stipe. They are called **lamellae** or **gills**, which are slender, pink when young becoming brown later. The lamellae are suspended from the pileus as thin strips of tissues converging towards the centre with their ends bend towards. The cross-section of a lamella or gills show the central loosely packed elongated fungal cells known as **trama**. On both sides of the trama are found **subhymenial** layers the cells of which will be spherical in shape. Over the sub-hymenial layer a layer of palisade-like cells known as **hymenial layer** is formed.

The hymenial layer consist of club shaped **basidia** which have two to four minute **sterigmata** at their tip. The sterigmata bear the haploid single celled, ink basidiospores. In the hymenial layer there are some stout sterile structures known as **cystidia** (sing. cystidium). The **basidiospores** are released forcibly and fall near the base of the stipe and form a pink mass.

Agaricus* and *Pleurotus

Agaricus

Agaricus spp. are called **white button mushroom** or European mushroom or button mushroom. It has two important commercia1Jy cultivated species viz., temperate mushroom or white button mushroom, *Agaricus bisporus* and hot weather mushrooms, *A. bitorquis*

A .bisporus

It has stout, cylindrical, fleshy umberella-like pileus and possess annulus. Good crop of mushroom comes at low temperature of 15 to 25º C. Well decomposed wheat / paddy straw compost incorporated with nutrients is used as substrate. In a period of 85-100 days, 300-350 kg of mushroom can be harvested from one ton of compost. It ranks first in the world mushroom production.

Pleurotus

Pleurotus spp. are called oyster mushroom as it resembles shell of an oyster. The stipe is eccentric. In India it is called Dhingri. It is a tropical mushroom coming up well between 25-30°C. The colour may be white or grey or pink depending upon the species. Commonly cultivated species in India are *Pleurotus sajor-caju, P. eous, P.citrinopileatus, P.ostreatus, P.eryingii* etc., It is grown on paddy straw (substrate) in polybags. In a period of 30-45 days, it yield 1.0 to 1.4 kg per kg of paddy straw.

Symptoms of rust – Life cycle of *Puccinia*

Rust appears as brown or reddish brown pustules scattered on upper or lower or on both the surfaces of leaves sometimes on the stem also. The rust diseases are in the order Uredinales of the subdivision Basidiomycotina. The rust genera viz., *Puccinia, Uromyces, Hemileia, Phragmidium, Gymnosporangium* in the family *Pucciniaceae* and *Melampsora, Phakopsora, Coleosporium* and *Cronatium* in the family *Melampsoraceae* cause rust disease in crop plants.

There are three types of rusts based on the life cycle. They are,

1. Macrocyclic rust

a. Autoecious rust

b. Heteroecions rust

2. Demicyclic rust

3. Microcyclic rust.

1. Macrocyclic rust: Five spore stages are produced in their life cycle.

a. Autoecious rust: Five spore stages are formed on a single host. e.g., Sunflower rust - *Puccinia helianthi* , Pea rust - *Uromyces fabae* , Linseed rust - *Melampsora lini* and Castor rust – *M. ricini.*

b. Heteroecious rust: Two different hosts (viz., primary host and alternate hosts) are required for completion of its life cycle. **Primary host** is the plant where the teliospores are produced. Alternate host is a plant which is required to complete life cycle without which the pathogen cannot survive. Uredia and uredospores and telia and teliospores are formed on the primary host. Pycnia and pycniospores and aecia and aeciospores are formed on the alternate hosts. e.g., Wheat stem rust – *Puccinia graminis* var. *tritici.* For this rust wheat is the primary host and the barberry is the **alternate host.**

2. Demicyclic rust: Uredial stage absent and spermagonia may be present or absent. e.g., Cedar apple rust - *Gymnosporangium juniperi-virginianae*

3. Microcyclic rust: Teliospore is the only binucleate spore produced in this rust. It may be with or without spermagonia e.g., Holly-cock *rust-Puccinia malvacearum.*

i. Black or stem rust of wheat - *Puccinia graminis* var**. *tritici***

Systematic position

Sub-kingdom : Mycota

Division : Eumycota

Subdivision : Basidiomycotina

Class : Teliomycetes

Order : Uredinales

Family : Pucciniaceae

Genus : *Puccinia*

Species : *P.graminis*

Variety : *P.g. var.tritici*

Symptoms

Oblong, reddish brown pustules (raised blisters) are produced mostly on the stem and also on leaves in the initial stage. Later they become conspicuous, linear or oblong, dark brown to black and often merge with one another. Late in the season linear, black telia are formed in the same uredosori or on a separate place; severe infection causes drying of leaves.

Pathogen

It is a heteroecious rust. Primary host is wheat and the alternate host is barberry. The pathogen produces five kinds of spores viz., uredospore and teliospores on wheat, basidiospores from the teliospores found on the infected fallen leaves in the soil, pycniospores and aeciospores on barberry. The characters of different rust spores are described below.

Uredospores

(urediniospore, repeating spores or summer spores) are brown, binucleate, single celled, oval, thick walled with echinulations (thin short spines), borne singly on stalks and with four equatorial germ pores. **Teleutospores** (Teleutospore, resting spores or winter spores) are two celled, pedicellate, dark brown or cheshnut brown, thick and smooth walled. They are at the top rounded and somewhat pointed and thickened apex each cell has a germ pore.

Basidiospores

(Sporidia) are hyaline, haploid; thin walled, single celled and oval. Pycniospores (spermatia) are hyaline, thin walled, small and spherical. Teliospore has a constricted at the septum. Aeciospores are yellow, unicellular, thin walled, hexagonal and produced in chains.

Disease cycle

The fungus overwinters as teliospores on infected wheat debris. They germinate and produce basidia and basidiospores. The basidiospores are ejected forcibly into the air. They are spread through wind and fall on the upper surface barberry leaf, where they germinate and penetrate the epidermal cells. It grows intercellularly and in 3-4 days, the mycelium develops into spermagonia (pycnia), which ruptures the epidermis. The opening of the spermagonia emerges on the upper surface of the leaf. The spermatia are exuded through the opening called **ostiole** and are found embedded in a honey like sticky liquid. Long, flexuous and branched structures called receptive hyphae from the spermagonium extend beyond the opening. Visiting insects spread the spermatia to the receptive hypha of other spermagonia. Rain water or dew running on the plant surface also helps in spreading the spermatia. Spermatization between a

spermagonium of a (+) type when comes in contact with receptive hypha of a (-) type (compatible) or *vice-versa.* It leads to aecial primordial (dikaryote) and formation of aecia on the lower side of the leaf.

The aecia are formed in groups or clusters and called cluster cups and protrude beyond the surface of the barberry leaf. The aecisopores are produced in chains inside the aecium and are released. They are carried by wind to wheat plant on which they germinate and infect stem or leaf sheath or leaf through stomata. The mycelium grows intercellularly and collects below the epidermis as a mat of mycelium. Many short sporophores and uredospores are produced and they exert pressure on the epidermis and pushed out as uredosori. Later, the epidermis breaks irregularly and release 100 thousands of rust coloured uredospores giving a powdery appearance. Uredospores are carried by wind to several kilometres from the point of their origin and infect the wheat plant in the presence of dew or film of water.

They germinate and produce germ tubes, enters through stomata, forms mycelium and leads to formation of uredia in 8-10 days. The uredospores infect wheat plant and produce uredospores till the plant reaches maturity. When the wheat plant approaches maturity telia develop on the wheat leaves or stems separately or from the ured33ia. Teliospores from the telia do not germinate immediately, they overwinter for sometime and do not infect wheat again. In the teliospores fusion of two nuclei takes place. Teliospore germinate and produce promycelium and basidiospores and infects only barberry, the alternate host and not wheat.

ii. Rust of pearlmillet - *Puccinia substriata* var**. *penicillariae***

Systematic position

Sub-kingdom : Mycota

Division : Eumycota

Sub-division : Basidiomycotina

Class : Teliomycetes

Order : Uredinales

Family : Pucciniaceae

Genus : *Puccinia*

Species : *P.substriata*

Variety : *P.s. penicillariae*

Symptoms

The uredosori are round, reddish brown and occur in groups on both the surfaces of leaves. The teliosori are black and elliptical. Finally the leaves dry.

Pathogen

It is also heteroecious rust. Primary host is pearlmillet and the alternate post is **brinjal**. Uredospores are oval, yellowish brown, single celled, sparsely echinulated with four equatorial germ pores and pedicellate. Teleutospores are pedicellate thick walled, two celled cylindrical or club-shaped, broad at top and taper towards the base, with single germ pore. Basidiospores are single celled. Pycniospores are hyaline and elliptical. Aeciospores are yellowish orange coloured, polygonal, thin walled, smooth and are formed in chains. Other examples are, rust of groundnut caused by *Puccinia arachidis,* rust of sunflower caused by *P. helianthi,* rust of sorghum caused by *P.purpurea,* rust of maize caused by *P. sorghi*

Rust of black gram / greengram / cowpea / beans /horsegram – *Uromyces* *phaseoli-typica* (syn. *U. appendiculatus).*

Symptoms

It is an autoecious and macrocylic (long cycle) rust. The uredosori are small, roundish, open, powdery, brown coloured and are formed in groups. Each sorus is surround by a yellow halo. Several sori on a leaf cause premature defoliation. The teliosori are fewer in number, dark brown and linear.

Pathogen

Uredospores are globose, **single celled**, echinulated, Pedicellate, golden brown with two equatorial germ pores. Teliospores are single celled, smooth walled, globose, chestnut brown, pedicellate and with hyaline papilla at the top. Other examples are chickpea rust caused by *U. ciceris-arietini,* Pea rust caused by *U. fabae* and U. *pisi,* coffee rust caused by *Hemileia vastatrix* and cotton tropical rust caused by *Phakopsora gossypii.*

Symptoms of smuts and life cycle of *Ustilago* and *Neovassia* Smut

Smut is a disease caused by the fungi in Ustilaginales of the subdivision Basidiomycotina that is characterized by the transformation of ovary into black dusty or powdery dark spore mass. Smut spores are called teleutospores, chlamydospores or ustilospores. Smut fungi are more dangerous than rust fungi. They are facultative saprophytes. Smut fungi belong to the order Ustilaginales in the subdivision Basidiomycotina.

The order ustilaginales is divided into two families *viz.*, Ustilaginaceae and Tilletiaceae, on the basis of the mode of teliospore germination. The family Ustilaginaceae produces a septate promycelium bearing terminal and lateral basidiospores. *Ustilago, Sporisorium, melanopsichium, Sphacelotheca and Tolyposporium.* In Tilletiaceae, the promycelium is a hollow tube, which bears only terminal basidiospores, are, included in this family *Tilletia, Neovossia, Urocystis and Entyloma are included in Tilletiaceae.*

Covered / kernel / short / grain smut of sorghum- *Sporisorium sorghi.*

(Syn. Sphacelotheca sorghi)

Systematic position

Sub-kingdom : Mycota

Division : Eumycota

Sub-division : Basidiomycotina

Class : Teliomycetes

Order : Ustilaginales

Family : Ustilaginaceae

Genus : *Sporisorium*

Species : S *sorghi*

Symptoms

The smut sori are oval, long and dully-grey in colour. Most of the grains of an infected earhead are replaced by the smut sori.

Pathogen

The sorus has a tough wall and a long, hard, central tissue called **columellum**. The columellum is made up of host tissues, including, parenchyma and vascular elements. A dense mass of black to dark-brown, smooth, thick walled, single-celled spores and fills the space between the columellum and sorus wall.

Disease cycle

The smut spores germinate in water by producing four celled promycelium and a single sporidium from each cell. They infect the seedling by penetrating through the radicle or mesocotyl to establish systemic infection that develops along the meristematic tissues. At the

time of flowering the fungal hyphae get converted into spores, replacing the ovary with the soil. If the diseased earheads are harvested with the healthy ones threshed together, the healthy grains become contaminated with the smut spores released from bursted sori. The spores remain dormant on the seed until next season. It is externally seed-borne.

Loose smut of sorghum - *Sporisorium cruentum* (syn. ***Sphacelotheca cruenta)***

Symptoms

The infected plants are shorter than the healthy plants, produce thinner stalks, more tillers and earlier flowering (2 weeks earlier) than the healthy plants. All the spikelets of an infected earhead are malformed and hypertrophied. The sorus replaces the pistil and stamens and is borne on glumes and pedicel. The infected earhead become loose and appears like a leafy or leathery structure.

Pathogen

The smut spores are in the form of masses of spores enclosed by thin sorus membrane. Columellum is longer, bigger and more curved than the columellum of grain smut. The smut spores are spherical to elliptical, dark brown with a minutely pitted spore wall. It is primarily spread by infected seeds (externally seed-borne). Disease cycle is as in grain smut.

Long smut of sorghum -*Tolyposporium ehrenbergii*

Symptoms

Only a few grains are converted into smut sori and are scattered. The sorus is covered by a whitish membrane and is cylindrical and much longer than those of the other two smuts.

Pathogen

The spores are firmly united into **spore balls**, which is characteristic of this genus. They are globose, or angular, brownish green.

Head smut of sorghum -*Sporisorium reilianum* (syn**. *Sphacelotheca reiliana)***

Symptoms

In the place of a normal inflorescence, a sorus fully covered with a greyish-white membrane emerges from the boot leaf when it has fully emerged. The fungal wall ruptures, exposing large mass of black, powdery smut spores. The spores are blown away exposing dark filaments or fibres. Complete destruction of the earhead is common unlike in other smuts.

Pathogen

The smut spores or chlamydospores are angular to spherical, brown. It is both soil-borne and seed-borne.

Smut of pearl millet smut- *Tolyposporium penicillariae*

Symptoms

Florets are transformed into larger green smut sorus. Later sori become dark brown, break and release black smut spore balls. Only few florets in an earhead in affected.

Pathogen

Smut spores are in compact mass of spore balls. The spores are round and light brown.

Loose smut of wheat - *Ustilago nuda tritici*

Symptoms

Infected plants are shorter than the healthy plants. Usually infected ears emerge from the boot leaf, a few days earlier than healthy. All spikelets of an earhead are transfonned into a mass of black powdery spores. Before emergence the smutted spikelet in covered by a thin silvery membrane, which breaks while the ear. Emerges

Pathogen

The smut spores or chlamydospores are pale olive-brown, spherical or oval and are with minute echinulations. It is **internally seed-borne** and viable in stored seeds for more than 15 years.

Whip smut of sugarcane - *Ustilago scitaminea*

Symptoms

Production of a long (up to several feet) whip-like structure (modified inflorescences / stem) from the apex of the infected stalk. In early stage, a thin silvery white membrane covers the whip and it ruptures exposing dense black dust of smut spores.

Pathogen

The smut spores are light brown, spherical and echinulated.

Lecture 10

Subdivition: Deuteromycotina: class: Coelomycetes (Sphaeropsidales), class: Hyphomycetes (Hyphomycetales, Agonomycetales)

General characters

Fungi possess branched, septate and multinucleate mycelium. They reproduce through asexual methods. the most common method of reproduction is by conidia. No sexual spores are produced. They are called as Fungi Imperfecti.

Classification

Key to Classes of Deuteromycotina

A. True mycelium lacking or not well-developed, soma is made up of yeast (budding) cells with or without pseudomycelium .. Blastomycetes. AA. Mycelium well-developed, assimilative budding cells absent ... B, BB

B. Reproduction by conidia borne in pycnidia or acervuli ... Coelomycetes BB. Reproduction absent i.e. sterile forms or takes place by conidia produced on separate hyphae or aggregations of hyphae (as synnemata or sporodochia) but not within pycnidia or acervuli ... Hyphomycetes

Class: Coelomycetes

The members are found both in tropical and temperate regions. They are commonly found in cultivated and uncultivated soils, leaf litter organic debris, fresh water and saline water. They may found on other fungi and lichens. They are also pathogens of plants, insects and vertebrates. Coelomycetes is divided into two orders, Melanconiales and Sphaeropsidales. In this class conidia are produced either in acervuli or pycnidia and accordingly the members have been grouped into two orders:

1 Conidia produced in acervuli -Melanconiales

2 Conidia produced in pycnidia –Sphaeropsidales

Order: Melanconiales

In Melanconiales the fructifications are acervuli. It contains a single family, 'Melanconiaceae'which is characterized by the production of acervuli. Acervuli may develop subepidermally or subcuticularly. Conidia may be hyaline to cream, pink, orange or black. Acervuli develop by simple meristogenous, compound meristogenous or sympogenous methods. More than 120 genera are included in this family and they cause plant disease known as anthracnose. The important genera are

1. *Colletotrichum*

2. Coryneum

3. Cylindrosporium

4. Entomosporium

5. Marssoninia

6. Melanconium

7. Monochaetia

8. Pestalotia

9. Pestalotiopsis

10. Gloeosporium

11. Sphaceloma

12. Didymosporium

13. Septogloeum

Colletotrichum

Acervuli may be subcuticular, epidermal or subepidermal. They may be either separate or confluent. Conidiophores are hyaline to brown, septate, smooth, branched at the base. Conidia are hyaline, unicellular, falcate or lunate (sickleshaped) or cylindrical.. Perfect state of the fungus belongs to *Glomerella.* The important plant pathogenic species of *Colletotrichum* are given below:

C. capsici-Fruit rot and dieback ofchillies, anthracnoseand boll rot of cotton.

C. circinans -Smudge of onion

C. coffeanum -Coffee berry disease

C. falcatum -Red rot of sugarcane

*C. gloeosporioides*Anthracnose of citrus andbanana.

C. graminicola Anthracnose of corn and sorghum .

C. lindemuthianum-Anthracnose of cowpea and*Phaseolus* spp.

C. musae -Anthracnose of banana*(Gloeosporium musarum)*

C. truncatum -Anthracnose of legumes.

Pestalotia (Pestalozzia)

The genus is characterized by the conidia which are fusiform, straight or slightly curved and five septate, with four median cells brown and end cells hyaline lacking cytoplasm. There

may be 3-9 apical, cellular, simple or dichotomously branched appendages and one basal endogenous cellular, simple or branched appendage. The conidiophores are long, branched and septate. The fructifications are dark brown.

Pestalotiopsis

Pestalotiopsis differ from *Pestalotia* in the production of 4 septate conidia (5 celled) with two or more apical appendages and conidiogenous cell with several proliferations. The fructifications eustromatic and cupulate. Acervuli are subepidermal and are irregularly erumpent through the epidermis or longitudinal cracks may appear. They are either found on decaying leaves. Many are important plant pathogens.

P. palmarum -Grey blight of coconut (*Pestilential palmarum)* and other palms.

P. theae -Grey blight of tea and blight of *(Pestalotia theae)* mango, palms and cotton.

P. mangiferae -Grey blight of mango *(Pestalotia mangiferae)*

Order: Sphaeropsidales

In this order the conidia and conidiogenous cells or conidiophores are produced in pycnidia. Mycelium may be immersed in the substrate or superficial. Conidia are produced in several ways from phialides, annellides etc. Conidia are solitary, sympodial catenate etc. Sphaeropsidales is divided into four families based on the colour, shape and texture of the pycnidia. They are Sphaeropsidaceae ,Nectrioidaceae (Zythiaceae), Leptostromataceae and Excipulaceae (Discellaceae).

Family : Sphaeropsidaceae

This is a large family consisting of both saprobes and a stroma. These are tough, leathery to brittle, globose, ostiolate and dark coloured. The spores are hyaline spherical or oval and often exude from the ostiole in damp weather in a worm like mass or citrus.

Macrophomina

Mycelium superficial or immersed, hyaline to brown, branched, septate, often tree like in form (dendroid). Pycnidia separate, globose, dark brown, immersed, with one cavity, thick-walled; wall consisting of an outer layer of darkbrown; thick walled, closely packed polyhedral cells, becoming hyaline towards the inside. Ostiole central, circular, papillate. Conidiophores absent. Conidiogenous cells enteroblastic, phialidic, determinate, lageniform to doliform, hyaline, smooth with aperture and minute collarette, formed from cells lining the pycnidial cavity.

Conidia (Pycnospores) hyaline, aseptate, obtuse at each end straight cylindrical to fusiform, thin-walled, smooth with aperture and minute collarette, formed from cells lining the pycnidial cavity. Conidia (Pycnospores) hyaline, aseptate, obtuse at each end, straight cylindrical to fusiform, thin-walled, smooth, may be guttulate. Forming mainly sclerotia in cultures, which are black, smooth, hard, formed of dark-brown thickwalled cells. The genus *Macrophomina* is monotypic and contains the only species, *M. phaseolina*, *Macrophomina phaseolina* (syn .*Rhizoctonia bataticola).* This fungus causes charcoal rot, ashy stem blight, Dry root rot, canker, damping off and leaf lesions on hosts like sorghum, pearl millet, soybean, groundnut, cotton, *Phaseolus* spp., tomato, potato etc.,

Ascochyta

It is a very large and widely distributed genus containing about 350 species. Most of them are plant pathogens. Mycelium immersed, branched, septate, hyaline to pale brown. Pycnidia are amphigenous, separate, globose, brown, immersed, unilocular and thin-walled. Ostiole central, circular, slightly papillate. Conidiophores are absent. Conidiogenous cells enteroblastic, phialidic, determinate , discrete, doliform to lageniform, hyaline, smooth, formed from the inner cells of pycnidial cavity. Conidia hyaline, thin-walled, cylindrical, ovoid, oblong to irregular, medianly one-septate, continuous or constricted at the septum. Conidia may be guttulate.

The important plant pathogens are as follows:

A. abelmoschi -Leaf, fruit and stem spot of lady's finger.

A. caricae-papayae -Fruit rot of papaya

A. fabae -Leaf and pod spot of broad beans

A. melongenae -Leaf spot of lady's finger

A. phaseolorum -Leaf and pod spot of common bean and other legumes.

A. pisi -Leaf and pod spot of pea.

A. pinodes -Foot rot or blight of pea

A. rabiei -Blight of chickpea

A. sorghi -Leaf spot of sorghum

Septoria

It is a large and cosmopolitan genus with 1000 species, which are parasitic causing leaf spot diseases in plants. The pycnidia are immersed in the substratum and are either separate or

aggregated and not confluent. They are globose, ostiolate, thin walled and brown. . Conidia are hyaline, smooth, filiform (scolecospore), continuous or constricted at septa. The perfect states in Ascomycotina genera are *Mycosphaerella* and *Leptosphaeria*.

Septoria apii -Celery leaf blight

S. chrysanthemella -Black leaf spot of sweet potato

S. bataticola -Leaf spot of sweetpotato

S. glycinea -Brown spot of soybean

S. lycopersici -Leaf spot of tomato

S. nodorum -Speckled leaf blotch of wheat

S. thespesiae -Leaf spot of Portia tree

S. tritici -Leaf spot of wheat

Family: Excipulaceae (Discellaceae) (Genera: *Excipula, Discula, Dinemosporium, Sporonema*)

Class: Hyphomycetes

Hawksworth *et al.* (1983) classified Hyphomycetes into four orders, Agonomycetales, Hyphomycetales, Stilbellales and Tuberculariales. The orders have been separated on the basis of presence of absence of conidia and the degree of aggregation of the conidiophores into specialized structures such as synnemata or sporodochia.

Classification of Hyphomycetes

Conidia absent except for chlamydospores - Agonomycetales or Mycelial sterilia Conidia present Conidiophores are not organized as synnemata or sporodochia- Hyphomycetales (Moniliales) Conidiophores are organized as synnemata or sporodochia.

a. Synnemata formed - **Stilbellales**

b. Sporodochia formed – **Tuberculariales**

Order: Agonomycetales or Mycelia sterilia

1. Leaf parasites and forming sclerotia that are immersed in leaf tissue - *Dactuliphora*

2. Sclerotia not immersed in leaf tissue, if leaf parasites:

(a) Sclerotia formed of loosely woven hyphae; irregular in shape - *Rhizoctonia*

(b) Sclerotia formed of compact hyphae; large - *Sclerotium*

(c) Compact cells arranged in cluster like forms; true sclerotia absent – *Populaspora*

The fungi included in this order are referred as Mycelia sterilia as they lack even the imperfect state (spores) and reproduce only by fragmentation of mycelium. They do form sclerotia or chlamydospores, which help in perpetuation and dissemination of the pathogen. Agonomycetales may be states of Basidiomycetes, Ascomycetes or other Deuteromycetes. It has a single family Agonomycetaceae containing 42 genera. *Aegerita, Arbuscula, Dactuliophora, Papulaspora, Rhizoctonia* and *Sclerotium* are important genera.

Rhizoctonia

The form-genus *Rhizoctonia* has about 15 species. They are facultative necrotrophs i.e. they are capable of prolonged existence as saprophyte in the soil. Under suitable conditions they cause diseases like damping off and root rots. Important characters of this are the formation of sclerotia of irregular size and shape but of uniform texture brown or black, more or less loosely packed. The cells of the hyphae are barrel shaped, anastomosing frequently, branching more or less at right angles, and pale brown to brown in colour. Perfect states of *Rhizoctonia* are *Ceratobasidium* and *Thanatephorus* (of Basidiomycotina) and *Macrophomina* (Pycnidial state).

R. bataticola - Dry root rot of pulses, cotton etc. (Pycnidial state: *Macrophomina phaseolina)*

R. solani - Root rot of cotton. (Perfect state: *Thanatephorus cucumeris)*

Sclerotium

It is a large genus with about 100 species. They cause important plant diseases. It is characterized by hard, brown to black, fairly large sclerotia with pseudoparenchymatous rind. These are produced on sterile, cotton, white mycelium provided with clamp connections. The perfect states of *Sclerotium* are *Pellicularia* (Hymenomycetes of Basidiomycotina) and *Sclerotinia* (of Ascomycotina)

Sclerotium cepivorum -White rot of onion

S. oryzae-Stem rot of rice (Perfect state: *Magnaporthe salvinii* Conidial state: *Nakataea sigmoidea*)

S. rolfsii - Root rot of soybean, black pepper groundnut, cotton, cabbage tomato etc. (Perfect State: *Corticium rolfsii*(syn.*Pellicularia rolfsii)*

Order: Hyphomycetales (Moniliales)

This order has important saprobes used in decomposition of organic matters. It has pathogens on plant, animal and human beings. In this order the conidiogenous cells are produced on the conidiophores, which may be either micronematous. i.e morphologically similar to

vegetative hyphae or macronematous. i.e. which are morphologically very different from purely vegetative hyphae but are always mononematous i.e. they are sporodochia. The order is divided into two families, Moniliaceae and Dematiaceae.

The order is divided into 2 families:

1 Conidia and conidiophores hyaline or brightly coloured -*Moniliaceae*

2 Conidia or conidiophores or both with distinct dark pigment –*Dematiaceae*

Form-family 1: Moniliaceae

Most of the members in this family are saprobes in soil, dead organic matter and foodstuffs. Some are plant, human and animal pathogens whereas some others are predaceous fungi on nematodes. The members of this form-family are characterized by the production of free conidiophores or conidiogenous cells from the somatic hyphae and all the structures i.e. hyphae, conidiophores and conidia are hyaline. A key to important plant pathogenic genera is given here:

I. Conidia unicellular, globose to cylindrical, conidiophore distinct:

(a) Conidia almost similar to apical cells of conidiophores *Monilia*

(b) Conidia not as above; borne in chains; dry:

(i) Phialides in heads on simple conidiophores -*Aspergillus*

(ii) Phialides bush like; upright -*Penicillium*

(c) Conidia not borne in chains; conidiophores verticillate, phialospores in mucilaginous mass -*Verticillium*

(d) Conidiophore branching irregularly or dichotomously; conidia dry, borne on inflated **apical cells -*Botrytis***

II. Conidia bicelled, ovoid to cylindrical:

(a) Conidiophores reduced to stromal cells - *Rhyncosporium*

(b) Conidiophoredistinct, rarely branched, in clusters; conidia cylindrical, in short chains -*Ramularia*

III. Conidia 3 or more celled:

(a) Conidia usually of 2 types, multiseptate macroconidia canoe shaped; unicellular microconidia often present -*Fusarium*

(b) Conidiophores rarely branched, conidia simple, attenuated at the apex - *Cercosporella*

(c) Conidiophores usually simple; conidia on denticles –*Pyricularia Aspergillus* and *Penicillium* belong here, Imperfect stages of the Erysiphales (powdery mildews) viz. *Acrosporium* (formerly known as oidium) is also placed here.

Imperfect stage of Ascomycetes -*Neurospora* and *Monilinia* and *Botryotinia* also belong here and placed in the form genera *Monilia* and *Botrytis* respectively. The genera *Verticillium* and *Trichoderma* are known to have Trichoderma as imperfect states. Pathogens of man and animals viz., *Microsporium* (Imperfect state: *Arthroderma*), *Trichophyton* (Imperfect state: *Nannizzia*), *Histoplasma* (Imperfect state: Ajellomyces), *Geotrichum, Sporothrix, Coccidioides, Paracoccidioides* and *Epidermophyton* belong to his family. *Arthroderma (Microsporium), Phymatotrichum,* Predaceous fungi like *Dactylaria, Arthrobotrys* and *Monacrosporium* are also included in the family Moniliaceae.

Verticillium

The genus is characterized by the production of balls of amerospores on verticillately arranged phialides. The conidiophores are erect, hyaline or slightly pigmented and simple or branched. Chlamydospores, aleuriospores and microsclerotia are also produced by some species. *V. albo-atrum* -Wilt of cotton, tobacco, cowpea, tomato, brinjal, potato, lucerne. *V. dahliae* -Wilt of tobacco and brinjal Form-family 2: Dematiaceae.

This family is characterized by the production of dark-conidia and/or conidiophores. Conidiophores are simple and not produced in any type of fruiting body. Many members are saprobic found in soil and on dead organic matters. Others are pathogens of plants. *Alternaria , Bipolaris, Cladosporium, Cercospora, Curvularia, Drechslera, Helminthosporium* and *Pyricularia* are important genera in this family.

A key to important genera is given below:

I. Conidia single celled, globose to cylindrical in shape.

(a) Conidia hyaline to sub-hyaline, *phialosporous*, endogenous; phialides often single; aleuriospores dark, borne singly or in short chains - ***Thielaviopsis***

(b) Conidia blastospores, dark, borne acropetally in long chains; ovoid to oblong, sometimes >2 celled - ***Cladosporium***

(c) Conidia dark, in short chains:

(i) Mycelium subcuticular, conidia annelospores, acute at apex, sometimes 2-celled - ***Spilocaea***

(ii) Conidia blastospores, dry, borne in apical clusters - ***Periconia***

(d) Conidiophore simple, intertwined; conidia holoblastic, spherical; in ovaries of individual grains of Gramineae - ***Ustilaginoidea***

II. Conidia usually bicelled, borne singly on conidiophores. Mycelium subepidermal, without forming stroma, apical cell of conidia narrower than basal cell - ***Passalora***

III. Conidia more than 3 celled, not borne in chains, only transversely septate.

A. Conidiophores in clusters, simple or rarely branched, conidia long cylindrical to filamentous:

(i) Stroma well developed -***Cercosporidium***

(ii) Stroma not developed -***Cercospora***

B. Conidiophores packed together, arising from a well-developed stroma. Conidia annellospores, ellipsoid ovoid -***Strigmina***

C. Conidiophores single; stroma absent:

1. Conidia porosporous.

(i) Conidia borne apically -**Corynespora**

(ii) Conidia borne laterally and apically -***Helminthosporium***

2. Conidia sympodulospores.

(i) Conidia typically bent, middle cell enlarged -***Curvularia***

(ii) Conidia straight, sometimes curved slightly

(a) Conidial germination by any of its cells -***Drechslera***

(b) Conidial germination by end cells only -***Bipolaris***

IV. Conidia several celled, longitudinal as well transverse septa present.

(a) Conidia borne in acropetal chains -***Alternaria***

(b) Conidia borne singly, apical, sub-globose, obovate or broadly ellipsoid - *Stemphylium*

Alternaria

It is a polyphagous fungus and occurs most frequently as a saprobe on dead and decaying organic materials, on or in seeds and is responsible for causing leaf spots of economically important crop plants. Conidiophores are dark, septate, sometimes inconspicuous, simple or branched, bearing conidia at the apex. Conidia (Porospores) solitary or more often produced in acropetal succession to form simple or branched chains, muriform, darkly pigmented, ovate to obclavate, tapering abruptly or gradually towards the apex, smooth or roughened.

Important plant diseases caused by *Alternaria* spp. are

Alternaria alternata - Black point disease of wheat grains

A. brassicae - Leaf spot of crucifers

A. brassicola - Leaf and pod spot of Crucifers

A. carthami - Leaf spot of safflower

A. cucumerina - Leaf spot of cucurbit

A. citri - Black rot of oranges, fruit rot of lemons and tangerines, leaf spot of rough lemon and mandarin.

A. longipes - Brown spot of tobacco

A. macrospora - Leaf spot of cotton

A. padwickii - Stackburn, seedling blight or leaf spot (=*Trichoconis padwickii*) of rice

A. porri - Purple blotch of onion

A. solani - Early blight of potato and leaf spot of tomato, chillies and tobacco

A. triticina - Leaf blight of wheat

Cercospora: They are weak parasites on dead or drying plant tissues or pathogens of plants or human beings. This genus is characterized by long, hyaline or pigmented conidia borne in acropetal succession from a usually simple, sympodially extending, cicatrized (i.e. with conspicuous scars), pigmented conidiophores which are frequently aggregated in fascicles . The conidia are filiform and several celled.

Cercospora apii - Leaf spot of celery

C. arachidicola - Early leaf spot of groundnut

C. beticola - Leaf spot of sugar beet

C. coffeicola - Leaf spot of coffee and spinach

C. nicotianae - Frog -eye spot of tobacco

C. kikuchii - Purple stain of soybean

Cercospora musae - Sigatoka leaf spot

C. personata - Late leaf spot of groundnut

Helminthosporium

Colonies effuse, dark and hairy. Mycelium immersed stromata usually present. Conidiophores often in fascicles, erect, brown to dark brown. Conidia develop laterally, often in verticils, through pores beneath the septa of the conidiophore while the tip of the conidiophores continues to grow but growth cases with the formation of terminal conidia. Conidia sub-hyaline to brown, usually obclavate, pseudoseptate and frequently with a dark brown to black protruding

scar at the base. This genus contains approximately 20 species. *Helminthosporium* imperfect state is produced in *Pseudocochliobolus* belonging to the Dothideales.

List of *Helminthosporium* transferred to *Drechslera*

***Helminthosporium* sp.**	***Drechslera* sp.**	**Ascigerous state**
H. carbonum	*D. zeicola*	*Cochliobolus carbonum*
H. gramineum	*D. graminea* (Leaf stripe of Barely)	*Pyrenophora graminea*
H. heveae	*D. heveae* *(Birds eye spot of rubber)*	
H. maydis	*D. maydis* (Leaf blight of corn)	*Cochliobolus heterosporus*
H. nodulosum	*D. nodulosus*	*C. nodulosus*
H. oryzae	*D. oryzae* (brown leaf spot of rice)	*C. miyabeanus*
H. sacchari	*D. sacchari* (seedling blight of sugarcane)	
H. sativum	*Bipolaris*	*C. sativum*
H. sigmoideum	*Nakataea sigmoidea*	*Leptosphaeria salvinii*

Drechslera

It is characterized by the sympodially extending conidiophore, which produces an acropetal succession of multiseptate porospores, which are cylindric in shape and germinate from any or all cells. Conidiophores are indeterminate, extending by sympodial growth. The cells of conidium are capable of germination. Conidiophores are brown and produce the conidia singly at the apices. Conidia are cylindrical, multiseptate and dark. *Cochliobolus, Pyrenophora, Pleospora* and *Trichometasphaeria* are imperfect states of *Drechslera.*

Bipolaris

Bipolaris is characterized by germination of conidia from the end cells only. Conidiophores brown, producing conidia through an apical pore and forming a new apex by growth of the sub-terminal region. Conidia fusoid, straight or curved, germinating by one germ tube from each end cell. Exosporium smooth, rigid and brown. Endosporium hyaline, amorphous, separating cells of the mature phragmospores. They are pathogenic on members in grass family. The perfect state is *Cochliobolus*.

Pyricularia

There are only few species, which are causing important plant diseases. Conidiophores are more or less erect, simple or rarely branched, septate, hyaline to lightly pigmented, ultimate cells sympodulae. Conidia borne singly and terminally at the apex of conidiophore with successive conidia being produced in acropetal succession by sympodial extension of the sporogenous cell. Abscission of conidia leaves pronounced denticles on the spore-bearing apex. Conidia ellipsoid or more often pyriform, broader and truncated at the attachment point, tapering towards the distal end, mostly one septate or two septate, hyaline to lightly pigmented.

Pyricularia oryzae -Blast of rice

P. setariae -Blast of fox-tail millet

P. grisea -Blast of ragi / finger millet

Order: Tuberculariales

The characteristic features of this order is the production of sporodochia (sing. sporodochium; Gr. spora = seed + dochien = container) in which the spore mass is supported by a superficial, cushion -like (pulvinate) mass of conidiogenous cells or short conidiophores. The order contains a single family, Tuberculariaceae that has more than 160 form-genera. Following genera are important:

I. Conidia unicellular, hyaline to bright coloured.

(a) Sporodochia stromatic, parasitic on grains -*Sphacelia*

(b) Sporodochia pulvinate, sometimes with prominent, hyaline setae, Conidia in chains, usually greenish in mass –*Myrothecium*

II. Conidia multicellular, long slender, setae absent in sporodochia.

(a) Macroconidia canoe shaped -*Fusarium*

(b)Conidia curved with short side branches –*Ramulispora*

III. Conidia dictyospores, dark, globose to subglobse.

(a) Sporodochia pulvinate -*Epicoccum*

(b)Sporodochia convoluted -*Cerebella*

Fusarium, Tubercularia, Volutella, Epicoccum and *Exosporium* are important genera.

Fusarium

The macroconidia (phialospores) are produced on conidiophores, which may be solitary and simple or aggregated (sporodochia) and with complex branching and the ultimate branched terminating in sporogenous cells. The sporogenous cells. The sporogenous cells are phialides, sometimes with an apical collarette. In addition to macroconidia in some fusaria another type of conidia, i.e. microconidia are produced.

Microconidia are non-septate or one-septate, ovoid to short cylindric, gathering in short chains or more commonly in spore balls. Thick walled chlamydospores are also produced either terminally or intercalarily on the somatic hyphae. The mycelium, microconidia, macroconidia and sporodochia are bright in colour. Perfect state of *Fusarium* is found in Ascomycetes in the family Hypocreaceae in which the genera, *Nectria, Calonectria, Gibberella* and *Micronectriella* are found. The genus *Fusarium* contains about 50 species, which are widely distributed in soil and organic substrates. Some of the species, which are serious plant pathogens are listed below.

F. avenaceum(syn.*F. roseum*) -Damping off of seedlings, seedling blight, foot and root rot, ear blight of wheat, barley, oats, corn etc.

F. coeruleum -Dry rot of potato

F. moniliforme -Foot rot of rice

F. oxysporum f.sp. *batatae* -Wilt of sweet potato

F. oxysporum f.sp. *betae* -Wilt of beetroot

F. oxysporum f.sp. *carthami* -Wilt of safflower

F. oxysporum f.sp. *cepae* -Wilt of onion

F. oxysporum f.sp. *ciceris* -Wilt of chickpea

F. oxysporum f.sp. *conglutinans* -Cabbage yellows

F. oxysporum f.sp. *coriandri* -Wilt of coriander

F. oxysporum f.sp. *cubense* -Panama disease of banana

F. oxysporum f.sp. *cucumerinum*-Wilt / foot rot of cucumber

F. oxysporum f.sp. *cumini* -Wilt of cumin

F. oxysporum f.sp. *fabae* -Wilt of broad bean

F. oxysporum f.sp. *glycines* -Wilt of soybean

F. oxysporum f.sp. *lagenariae*-Wilt of bottlegourd

F. oxysporum f.sp. *lathyri* -Wilt of *Lathyrus sativus*

F. oxysporum f.sp. *lentis* -Wilt of lentil

F. oxysporum f.sp. *lini* -Wilt of linseed

F. o. f.sp. *lycopersici* -Wilt of tomato

F. o. f. sp. *Melongenae* -Wilt of brinjal

F. o. f.sp. *phaseoli*-Dry rot or wilt or *Phaseolus vulgaris*

F. o. f.sp. *pisi*-Wilt of pea

F. o. f. sp. *psidii* - Wilt of guava

F. o. f.sp. *sesame* - Wilt of sesame

F. o. f.sp. *sesbaniae* - Wilt of *Sesbania aegyptiaca*

F. trachephilum - Wilt of cowpea

F. o. f.sp. *vasinfectum* - Wilt of cotton, banana, citrus, tomato and cucurbits, Damping off of tomato.

F. semitectum - Storage rot of groundnut

F. solani - Root rot and wilt of legumes, citrus and coffee

F. solani f.sp. *aurantifolia* - C*itrus aurantifolia*

F. solani f.sp. *batatae* - Wilt of sweet potato

F. solani f.sp. *coeruleum* - Wilt of clusterbeans.

F. solani f.sp. *cucurbitae* - Wilt of C*ucurbita* spp

F. solani f.sp. *enmartii* - Wilt of potato

F. solani f.sp. *fabae* - Wilt of Vicia faba

F. solani f.sp. *phaseoli* - Wilt of *Phaseolus* spp.

F. solani f.sp. *piperis* - Wilt of black pepper

F. solani f.sp. *pisi* - Wilt of peas

F. udum - Wilt of pigeonpea

F. udum f.sp. *crotalariae* - Wilt of sunnhemp

Symptoms

Enlargement of roots, club-shaped roots due to hyperplasia and hypertrophy, gradual and inconspicuous stunting, yellowing and wilting of plant.

Symptoms of leaf spots, leaf blights, root rots and wilts and disease cycles of *Alternaria*, *Helminthosporium*, *Colletotrichum*, *Pyricularia*, *Macrophomina* and *Fusarium*

Leaf Spot

In leaf spot a well marked necrotic area of grey, brown, purple or black tissues in green leaves.

i. Blast of rice - *Pyricularia oryzae*

Systematic position

Sub-kingdom : Mycota

Division : Eumycota

Sub-division : Deuteromycotina

Class : Hyphomycetes

Order : Moniliales

Family : Moniliaceae

Genus : *Pyricularia*

Species : *P. oryzae*

Symptoms: Spindle shaped spots on the leaves (leaf-blast); spots are with dark brown margin and grey centre; spots on the node and neck are black; breaking of neck of earhead (neck blast) and nodal regions in stem (nodal blast). Grain infection shows brown spots on the seed coat.

Pathogen: Mycelium is septate, branched and hyaline to olivaceous, both inter-and intra-cellular. Conidiophores emerge through stomata or by rupturing the cuticle, single or grouped (2-3), 2 to 4 septate, geniculate and olivaceous. Conidia borne sympodially, hyaline to pale olive, pyriform, three celled with a small basal appendage called **hilum**.

Disease cycle: The conidia are spread through wind and cause infection. The grasses like *Panicum repens*, *Digitaria marginata*, *Echinochloa crusgalil*, etc. act as collateral hosts (alternative hosts) and help in perpetuation of the disease and act as primary source of inoculum. The conidia from the grasses on the bunds help on initiation of the disease in the nursery or main field.

ii. Brown spot of rice- *Helminthosporium oryzae* (syn. ***Bipolaris oryzae, Drechslera oryzae;*** Perfect stage: ***Cochliobolus miyabeanus)***

Systematic position

Sub-kingdom : Mycota

Division : Eumycota

Sub-division : Deuteromycotina

Class : Hyphomycetes

Order : Moniliales

Family : Dematiaceae

Genus : *Helminthosporium*

Species : *H. oryzae*

Symptoms: Oval shaped, dark brown to black spots on the leaves; black spots on the grains.

Pathogen: Mycelium is brown, septate, branched, inter are and intracellular.

Conidiophores are long, septate, darker and geniculate. Conidia are borne singly, 2 to12 are celled, brown, slightly curved with a bulge in the middle and tapering towards the ends. Perithecia are globose, dark yellowish brown with ostiolar beak. Asci are cylindrical, slightly curved and bear 4-6 ascospores. Ascospores are hyaline, long, cylindrical and 6-15 septate

Disease cycle: The fungus overwinters in infected plant parts. The fungus survives on *Cynodon dactylon, Echinochloa colona, Digitaria sanguinalis* (collateral hosts) from which the conidia 33spread to rice crop in the nursery. Ascospores from perithecia found on dead straw in heaps, which also serve as source of infection. In the field wind-borne conidia cause secondary infection.

iii. Sigatoka leaf spot of banana- *Cercospora musae* (Perfect stage: ***Mycosphaerella musicola)***

Systematic position

Sub-kingdom : Mycota

Division : Eumycota

Sub-division : Deuteromycotina

Class : Hyphomycetes

Order : Moniliales

Family : Dematiaceae

Genus : *Cercospora*

Species : C. *musae*

Symptoms: Yellowish green streaks are formed on interveinal areas; the streaks enlarge into cylindrical spots with grey centre, brown margin and each spots surrounded by yellow halo. The lesions coalesce and leaves dry up.

Pathogen: Mycelium is hyaline, septate and branched. Conidia are elongated, narrow and multiseptate. Perithecia are dark brown to black and ostiolate. Asci are oblong and clavate. Ascospores are hyaline, two celled, obtuse to ellipsoid

iv. Early leaf spot of groundnut - *Cercospora arachidicola* (Perfect stage: ***Mycosphaerella arachidis)***

Systematic position

Sub-kingdom : Mycota

Division : Eumycota

Sub-division : Deuteromycotina

Class : Hyphomycetes

Order : Moniliales

Family : Dematiaceae

Genus : *Cercospora*

Species : C. *arachidicola*

Symptoms: Spots are irregular or circular, 1 to 10 mm in diameter (bigger), brown; chlorotic halo around the spots present; lower surface of the spot is light brown; premature shedding of leaves.

Pathogen: Mycelium is septate, branched, inter and intracellular. Conidiophores are multi septate, yellowish brown and dense. Conidia are hyaline, obclavate, 3 to 12 septate, fascicles base rounded and tip sub-acute. Perithecia are black, globose, ostiolate. Asci are cylindrical, stipitate and bitunicate. Ascospores are two celled, (upper cell larger, slightly curved), hyaline and 8 in an ascus

v. Late leaf spot of groundnut - *Phaeoisariopsis personata*

(syn. ***Cercospora personata;*** Perfect stage: ***Mycosphaerella berkeleyii)***

Systematic position

Sub-kingdom : Mycota

Division : Eumycota

Sub-division : Deuteromycotina

Class : Hyphomycetes

Order : Moniliales

Family : Dematiaceae

Genus : *Cercospora*

Species : C. *personata*

Symptoms: Spots are smaller (1-6mm), **circular and black** in colour yellow halo absent; premature defoliation.

Pathogen: Conidia are olivaceous, obclavate, usually straight or slightly curved, rounded at the apex, base shortly tapered with a conspicuous hilum, mostly 3 to 4 septate, shorter than C. *arachidicola.* Perithercial characters are similar as in C. *arachidicola.*

vi. *Alternaria* leaf spot of cotton - *Alternaria macrospora*

Systematic position

Sub-kingdom : Mycota

Division : Eumycota

Sub-division : Deuteromycotina

Class : Hyphomycetes

Order : Moniliales

Family : Dematiaceae

Genus : *Alternaria*

Species : *A. macrospora*

Symptoms: Circular to irregular brown leaf spots with concentric rings; spots coalesce resulting in blight symptom.

Pathogen: Mycelium is dark, septate, branched. Conidiophore is single or in groups, erect, simple, septate, brown. Conidia are produced singly or in chains of two, obclavate with a narrow beak (twice the length of the body), reddish brown; or with both horizontal and vertical septa (muriform conidia)

Leaf Blights

Necrosis of a larger area of leaf lamina including veins is called leaf blight.

i. **Early blight of potato and tomato - *Alternaria solani***

Systematic position

Sub-kingdom : Mycota

Division : Eumycota

Sub-division : Deuteromycotina

Class : Hyphomycetes

Order : Moniliales

Family : Dematiaceae

Genus : *Alternaria*

Species : *A. solani*

Symptoms: Circular to irregular, brown spots with concentric rings; spots coalesce leading to blighting, drying of leaves and defoliation of leaves.

Pathogen: Mycelium is light brown to dark, septate, branched and inter-and intracellular. Conidiophores are dark coloured, emerge through stomata. Conidia are beaked, muriform, dark coloured, borne singly or in chains and are with 5 to 10 transverse and a few longitudinal septa

ii. Late blight of potato and tomato - *Phytophthora infestans*

Systematic position

Sub-kingdom : Mycota

Division : Eumycota

Sub-division : Mastigomycotina

Class : Oomycetes

Order : Peronosporoales

Family : Pythiaceae

Genus : *Phytophthora*

Species : *P. infestans*

Symptoms: Brown to purplish black water-soaked lesions; enlarge rapidly; lower surface shows whitish mildew growth, severe defoliation; potato tubers show purplish, slightly sunken lesions leading to **dry rot**.

Pathogen: Mycelium is endophytic, coenocytic, hyaline, branched, inter-cellular. Haustoria club shaped. Sporangiophores are hyaline, branched, indeterminate, thick walled, arise through stomata on leaves or lenticels on tubers. Sporangia are multinucleate, thin-walled, hyaline, oval

or pear shaped with a definite papilla at the apex. Zoospores are reniform, biflagellate (anterior tinsel and posterior whiplash). Oospores are thick-walled and smooth.

Disease cycle: Primary infection is through use of infected tubers. Mycelium spreads into shoots produced from infected tubers and reaches the aerial parts of the plant. Sporangiophore emerges through stomata on stem and leaves and produce sporangia, which are spread by rain to wet potato leaves or stems and cause disease. Large number of asexual generation in a growing season kills the foliage rapidly. The zoospores found in the soil germinate, penetrate through lentils or wounds into the tubers and send intercellular mycelium and haustoria into the cells and cause infection.

iii. Northern corn leaf blight of sorghum - *Exserohilum turcicum.* (syn. ***Helminthosporium turcicum;*** Perfect stage: ***Trichometasphaeria turcica)***

Systematic position

Sub-kingdom : Mycota

Division : Eumycota

Sub-division : Deuteromycotina

Class : Hyphomycetes

Order : Moniliales

Family : Dematiaceae

Genus : *Exserohilum*

Species : *E. turcicum*

Symptoms: Narrow, **elongated spots** develop initially, later turns to **straw coloured**, lesions with **reddish brown margin**; matured spots are with several cm long; later coalesce and cause extensive drying of leaves.

Pathogen: Mycelium is inter or intracellular, multinucleate and septate. Conidiophores emerge through stomata in clusters, simple, olivaceous, septate and straight or bent. Conidia are long, spindle shaped, straight or slightly curved and 3-7 septate. **Pseudothecia** are black and globose. Asci are clavate and bitunicate. Ascospores are hyaline, fusoid, straight or slightly curved and four celled.

iv. Grey blight of mango - *Pestalotiopsis mangiferae*

Systematic position

Sub-kingdom : Mycota

Division : Eumycota

Sub-division : Deuteromycotina

Class : Coelomycetes

Order : Moniliales

Family : Melanconiaceae

Genus : *Pestalotiopsis*

Species : *P. mangiferae*

Symptoms: Minute brown spots develop at the margin and tip of the leaf initially. They gradually increase in size and become dark brown. Black dots appear at the centre of the spots represent the acervuli.

Pathogen: Mycelium is branched, septate and brown. Acervuli are black. Conidiophores are short, simple or branched, septate, hyaline and smooth. Conidia are five celled, oblong to **clavate,** upper two cells are slightly darker than the lowest olivaceous cells. Upper cell has three setulae.

Grey leaf blight of coconut - *Pestalotiopsis palmarum*

Symptoms: Minute yellow spots surrounded by greyish margin appear on leaf lets, which enlarge to become elliptical with greyish white centre, dark brown margin and yellow halo. Large number of globose / ovoid, black acervuli appear on the upper surface of the spots as black dots.Many spots coalesce into irregular grey necrotic patches. Complete drying and shrivelling of leaf blade occur giving a blighted / burnt appearance.

Pathogen: Mycelium is septate, branched, light brown, inter and intra cellular. Fungus produces acervuli as it's asexual fruiting body during sporulation. Acervuli are black, cushion shaped, sub epidermal and break open to expose conidia and black sterile structures called setae. Conidiophores are hyaline, short, simple and bear a conidium at the tip. Conidia are five celled, middle three cells are coloured, basal and tip cells are hyaline. Tip cells have 3 -5 slender elongated appendages.

Root Rot

Root rot is disintegration or decay of part or all of the root system of a plant. Pathogen belonging to *Aphanomyces, Pythium, Phytophthora, Rhizoctonia, Sclerotium, Phymatotrichum, Thielaviapsis, Macrophomina, Helicorbasidium, Ophiobolus, Armillaria,* etc. are reported to cause root rot disease in various crop plants.

i. Root rot of pulses/ oilseeds/ cotton. - *Macrophomina phaseolina* (Pycnidial stage) *Rhizoctonia bataticola* (Sclerotial stage)

Systematic position: *Macrophomina phaseoloina*

Sub kingdom : Mycota

Division : Eumycota

Sub-division : Deuteromycotina

Class : Coelomycetes

Order : Sphaeropsidales

Family : Sphaeropsidaceae

Genus : *Macrophomina*

Species : *M .phaseolina*

Systematic position: *Rhizoctonia bataticola*

Sub kingdom : Mycota

Division : Eumycota

Subdivision : Deuteromycotina

Class : Aganomycetes

Order :Aganomycetales

Family : Aganomycetaceae

Genus : *Rhizoctonia*

Species : *R.bataticola*

Symptoms: Sudden and complete wilting of plants in patches; rotting of entire root system except taproot and few laterals; shredding of barks of roots; presence of minute black bodies on the surface of the infected bark of roots/stem which represents the sclerotia of the pathogen; stem near the soil level shows large number of black pycnidial bodies.

Pathogen: Mycelium is septate, branched, stout and brown; lateral branches from main hypha are constricted at the point of origin. Selerotia are dark brown or black, round, mustard-like. Pycnidia are small, dark brown, globose, ostiolate, found on stem, erumpent, solitary or gregarious. Pycnidiospore are hyaline, obovoid, single celled and borne on hyaline, cylindrical conidiophores (phialides).

Disease cycle: It survives as sclerotia in the infected debris in soil. Primary spread is through seed-borne and soil-borne sclerotia. Secondary spread is through wind-borne pycnidiospores.

Surviving sclerotia or pycnidia in the soil or in the seed initiate the infection. They germinate and penetrate the host directly. Fungus produces cellulolytic, pectinolytic and other enzymes, which kill and disintegrates the tissues in advance of penetration, resulting in rotting of tissues. It is a facultative saprophyte and it lives saprophytically in the dead tissue and produce greyish white, inter and intracellular, septate, thick walled mycelium, which branches at right angles near the septum. During asexual reproduction, it produces dark brown, globose **pycnidia** with an ostiole on the surface of the stem above ground level. Inner wall of the pycnidium is lined with **pycnidiophore** and pycnidiospore.

Pycnidiophores are hyaline, short and rod shaped. **Pycnidospores** are hyaline, single celled, oval shaped and thin walled. Pycnidia will act either as secondary inoculum for the spread with in the field or as primary inoculum for the initiation of the disease after period of survival in the seed or plant debris. At the end of the growing season the fungus produces spherical, black and smooth walled **sclerotia** (resting bodies) on the inner walls of the root bark. At this stage the roots exhibit bark shredding with numerous sclerotia. Sclerotia survive and initiate new infection.

Stem Rot

In stem rot the stem tissues show disintegration and decay

i. **Stem rot of rice - *Sclerotium oryzae*** (perfect stage: ***Leptosphaeria salvinii)***

Systematic position

Sub-kingdom : Mycota

Division : Eumycota

Sub-division : Deuteromycotina

Class : Hyphomycetes

Order : Aganomycetales

Family :Aganomycetaceae

Genus : *Sclerotium*

Species : S. *oryza*

Symptoms: Initially small, blackish, irregular lesions are observed on the outer leaf sheath near water line at later growth stages of plant. The lesions enlarge as the disease advance, the fungus penetrates the inner leaf sheath and finally the leaf sheath rots and sclerotia are formed. Later, the infection spreads to stem. One or two internodes of the stem rot and collapse. These infected

stems lodge. Small black sclerotia are seen near on the inner side of the culm amidst greyish weft of mycelium.

Pathogen: Mycelium is hyaline, septate and branched. Sclerotia are spherical, smooth and black. Perithecia are globose and black. Asci are clavate and short stalked. Ascospores are eight in each ascus, fusiform, three septate, middle cells larger and dark and the end cells lighter.

Disease cycle: The fungus is found to survive under unfavorable conditions in the selerotial stage. The sc1etoria germinates from rice stubbles under favorable conditions and is carried from field to field by irrigation water. The sc1etoria can cause primary infection .

Foot-Rot

In foot rot the basal portion of the stem is infected and shows rotting.

Foot-rot of rice - ***Fusarium moniliforme*** (Perfect stage: ***Gibberella fujikuroi)***

Systematic position

Sub-kingdom : Mycota

Division : Eumycota

Sub-division : Hyphomycetes

Class : Deuteromycotina

Order : Moniliales

Family : Tuberculariaceae

Genus : *Fusarium*

Species : *F. moniliforme*

Symptoms: The most conspicuous and common symptom is the bakanae, an abnormal elongation of the plants in the nursery of the field. The infected plants are taller than normal plants, lean lanky and yellowish green. A whitish or pink fungus growth may appear on the lower portion of the drying plants. The basal portion of the infected plant becomes black and rotten. The infected seedlings reveal formation of aerial adventitious roots from the nodes above the ground level. Root system becomes fibrous and bushy. Infected seedlings die in large numbers in patches. In the transplanted crop the plants are killed before earhead formation or even if the inflorescence is formed it will be sterile. If the culm is split open brown discolouration of spongy tissues in nodular region is seen.

Pathogen: Mycelium is hyaline, septate and well branched. Microconidia are hyaline, single celled or two celled, oval and borne in chains. Microconidia are hyaline, 3-5 septate, sickle -

shaped formed on sporodochia. Chlamydospores are absent Perithecia are dark blue, spherical or ovate. Asci are cylindrical, piston shaped and 4-6 spored. Ascospores are two celled.

Disease cycle: The diseases in externally seed-borne and the seeds contaminate with the spores form the primary source of infection. It is also soil-borne (survives for four months as hyphae are macro conidia). The fungus mycelium and micro conidia infect seedlings at an early stage of their development. It becomes systemic in the plants infection also takes place through conidia and mycelium left in the water used for soaking seeds. The funguses in the seedling grow upward and produce mycelium and conidia and infected plant parts. The fungus infects hosts like sorghum, maize, sugarcane, *Panicum miliaceum* and *Andropogon sorghum.*

Lecture 11

Prokaryotes: classification of prokaryotes according to Bergey's Manual of Systematic Bacteriology. General characteristics of bacteria and examples of phytopathogenic bacteria, fastidious vesicular bacteria, phytoplasmas and spiroplasmas

Phytoplasma

Phytoplasmas are small, unicellular, gram-positive non-motile bacteria like prokaryotes intermediate between viruses and bacteria. They differ from true bacteria in the absence of cell wall. **Phytoplasma is first observed in the phloem of the mulberry plants infected with dwarf disease.**Highly pleomorphic and their size range from small spherical bodies to large irregularly tubular to filamentous-branched structures (175 – 250mm). They are bounded by a triple layer unit lipoprotein membrane of 10 nm thickness without a rigid cell wall (wall-less prokaryotes) and lack the ability to synthesis cell wall materials. They have cytoplasm, ribosome and a strand of nuclear material devoid of nuclear membrane. Both DNA and RNA are present.

They are free living, parasitic and saprophytic and reproduce by budding and binary fission. They are filterable through bacterial filters and require sterol for their growth. They are sensitive to antibiotics like tetracycline, chloramphenicol and erythromycin and highly resistant to penicillin. On artificial media, they form **poached egg or fried egg shaped colonies** with central nipple. They are usually transmitted by grafting, dodder and by mechanical means. Beside this, Leafhoppers, plant hoppers and psyllids act as vectors. The phytoplasma disease are characterized by yellowing, chlorosis or bronzing of foliage, shortening of internodes, reduction in leaf size, proliferation of auxillary buds, phyllody and virescence, proliferation of secondary roots and abnormal fruits and seeds. Flowers from diseased plants are often sterile. Symptoms in a disease may show few or many of the above symptoms. The important symptoms are:

Little leaf

In little leaf auxillary buds are induced to form very small chlorotic leaves in clusters giving the plant a bushy appearance.

Little leaf of brinjal

Symptoms

The most characteristic symptoms is the reduction of leaf size, Both the petiole and lamina are involved in the reduction. The leaves become almost sessile. The1eaves become thin, soft, glabrous and pale green in colour. The

growth of axillary buds including buds is stimulated and this is accompanied by the shortening of internodes. The plant presents a characteristic pushy appearance, are absent floral parts whenever they are found. But they are modified into green structures. As a rule the affected plants are sterile and do not bear fruits.

Phytoplasma

Ovoid or spherical, 40-300 nm in diameter and lack a rigid cell, wall.

Vector

Jassid- *Hishimonas phvcitis.*

Phyllody

Floral parts are hypertrophied and transformed into, green leafy structures. This is also known as **phyllody** or **green flowering**.

Phyllody of sesame

Symptoms

The affected plants are stunted. The entire inflorescence is replaced by a growth consist of green, short, twisted leaves closely arranged on the stem with very short internodes. The calyx becomes polysepalous and shows multicostte veination against gamosepolous nature of healthy flowers. The sepals become leaf-like and found to remain smaller in six. The corolla become polypetalous and deep green. The veins of flower parts become thick and conspicuous. The anthers become green' and contain abnormal pollen grains. The carpels are transformed into leafy outgrowth which forms a pesudosyncarpotis ovary by their fusion at the margins. The ovary becomes very enlarged and flattened.

Vector

Leafhopper- *Orosius albicinctus.*

Grassy shoot

In grassy shoot disease the shoot becomes thinner with narrow and numerous chlorotic leaves resembling grass plants.

Grassy shoot of sugarcane

Symptoms

The disease is characterized by the production of numerous lanky tillers with small and narrow leaves, with or without albinism (white leaf). Shoots grow from diseased setts remain dwarfed or stunted. Diseased plants exhibit varying degrees of loss of chlorophyll, ranging from total green to white; premature and excessive tillering gives a crowded (grass-like) appearance to the clump. Affected clumps are stunted and exhibit premature proliferation of auxiliary buds. Canes are thin with short internodes. Canes are not millable.

Phytoplasma

Ovoid, spherical and irregular. 300 to 400 nm in diameter.

Vector

Proutista moesta

Witches' broom

Witches' broom is the broom-like erect growth or mass proliferation caused by dense clustering of branches.

Potato witches broom

Symptoms

The infected plants: Pave spreading type, numerous filamentous colourless stems bearing small, simple leaves and aerial tubers. Plant growth is, suppressed. Affected plants do not produce tubers or, it may produce small, size tubers which develop hairy sprouts

Vector

Leaf hopper- *Aleurodes dravidanus.*

Spike

In spike, leaves are reduced in size and branches become stiff and pointed spike-like structure.

Sandal spike

Symptoms

Sandal spike is a yellows type disease with witches, broom effect. Two types of symptoms are produced in this disease.

a. Rosette spike

Internodes are shortened and leaves become very small in size. This results in crowding of leaves in the leaf bearing, branches. Developing new leaves are further reduced in size. Such leaves in diseased trees stand out stiffly on the branches like spike. Phylloid flowers are produced in the trees.

b. Pendulous spike

In this apical growth of branches are continuous without proper thickening leading to dropping of branches. Dormant buds do not develop or grow and hence no rosette appearance.

Vector

Leafhoppers – *Nephotettix virescens.*

Yellowing

In yellowing the leaves are yellow and plants are stunted.

Yellow dwarf in rice

Symptoms

The characteristic symptoms are general chlorosis, stunting and excessive tillering. The chlorotic leaves are pale green or pale yellow. Plants infected early may die prematurely. They produce very poor panicles or none at all.

Vector

Green leafhopper - *Nephotettix cincticeps, N. virescenes* and *N.nigropictus.*

Spiroplasma

Spiroplasmas are helical mollicutes. The first known spiroplasma is com stunt *(Spiroplasma kunkelii)* and spiroplasma first cultured *in vitro* is citrus stubborn *(S. citri).* These spiroplasmas infect their respective leafhopper vectors. Spiroplasmas are cells that vary in shape (pleomorphic). They may be spherical to slightly ovoid (100 to 250 nm in dia), helical filaments (helical filaments i*n vitro* measure 3000 to 5000 nm in length and 100 to 200 nm in dia) and non-helical filaments. Unlike phytoplasmas, spiroplasmas can be obtained from their host plants or their insect vectors and cultured on nutrient media. They require cholesterol for their growth. They produce fried egg appearance (0.2 mm in dia) on solid media.

They produce mostly helical forms in liquid media. . They multiply by binary fission. They lack a true cell wall and are bounded by a triple layered membrane. The helical filaments are motile. They move by a slow undulation of the filament and by a rapid, rotary screw motion of the helix. There are flagella but intracellular fibrils are present. They are resistant to the antibiotic penicillin but inhibited by tetracycline. Spiroplasmas in plants are found in phloem tissues and are spread by leafhoppers.

Symptoms of spiroplasma

Stunt

Stunting of plant with shorter internodes giving the plant a bunchy appearance at the top.

i. **Com stunt - *Spiroplasma kunkelii***

Symptoms

Faint **yellowish streaks** appear on the youngest leaves. As the plant matures, leaves first become yellow, later the leaves turn red to purple. Internodes are shortened and the plant gives **bunchy appearance** at the top. The plants are **stunted**. Infected plants have more cobs than healthy plants. But the **cobs are smaller and bear little or no seed**. Tassels of infected plants are usually sterile.

Vector Leafhoppers *Dalbulus elimatus, D.maidis, Graminella nigrifrons*

Citrus Stubborn Disease

In some Mediterranean countries and in California, stubborn is regarded as the greatest threat to production of sweet oranges and grapefruit. The trees produce fewer fruits and many of them are too small and not to be marketable. In California, approximately two million orange, grapefruit, and tangelo trees are so severely affected that they are practically worthless.

Symptoms

Affected trees show a bunchy upright growth of twigs and branches. Internodes are shorter. Shoots are found in large numbers. Multiple buds and sprouts are common. Some of the affected twigs show die back. The bark is thickened and sometimes pin holed. The trees show stunting and appear flat topped. The leaves show yellowing and blotching, mottling and become abnormally small.Excessive winter defoliation is common. Affected trees bloom at all seasons,

especially in the winter. Flowers become very small. The infected trees bear only fewer fruits. Some of the fruits are very small, lopsided, or otherwise deformed. Such fruits have normally thick rind from the stem end to the fruit equator.Fruits tend to drop prematurely. Many fruits become mummified. Fruits are usually sour or bitter and have an unpleasant odour and flavour. Fruits have many poorly developed, discoloured and aborted seeds. In severely infected plants, the roots die, leading to lethal wilting.

Pathogen

Spiroplasma citri. It is found in the sieve tubes of stubborn – diseased citrus phloem. *Spiroplasma citri* was the first mycoplasma like organism of a plant disease to be cultured. In phloem sieve tubes it is present as spherical, ovoid or elongated forms and occasionally as helical filaments. In liquid cultures, it appears primarily as motile helical filaments. The pathogen is Gram-positive.The pathogen is insensitive to penicillin but is highly sensitive to tetracycline and less to amphotericin, neomycin and digitonin. The pathogen has a sharp optimum temperature for growth at about 30 to 32ºC

Host-range

S. citri attacks *Citrus* spp.,Madagascar periwinkle, lettuce, black mustard, horse radish, cabbage, water melon, cherry, peach, onion, leek and pear.

Transmission

Citrus stubborn disease is transmitted by leafhoppers belonging to at least six species in three genera (*Circulifer*, *Macrosteles* and *Scaphytopius*.).

Lecture 12

Plant viruses-general characteristics and examples of plant diseases caused by viruses

Virus is a submicroscopic, transmissible, intercellular, obligate parasite and consists of nucleic acid (either RNA or DNA), which is typically surrounded by a protein coat. They are less than 200 millimicron and cannot be grown in artificial media and require living host cell for multiplication. They have both living and nonliving properties. Living characters include their ability to cause disease, reproduce, mutate and have genetic materials. Non-living characters are the lack of cellular structure; enzymatic activities, respiratory activities and they can be crystallized by physical means. Nearly half of the plant virus may be of elongated (rigid rod /flexuous threads) and spherical (isometric / polyhedral) and the remaining are cylindrical bacillus like rods in shape and small enough pass through bacterial filters but too small to be seen under light microscope.

1. Rigid rod: (E.g.) *Tobacco Mosaic Virus* (TMV) and *Tobacco rattle Virus* (TRV)

2. Flexuous rod: (E.g.) *Potato Virus* X (PVX), *Bean Common Mosaic Virus* (BCMV).

3. Filamentous rod: (E.g.) Tenuiviruses likes *Rice Grassy Stunt* (RGSV) and *Rice Stripe Virus* (RSV).

4. Isometric: (E.g.) *Rice Tungro Spherical Virus* (RTSV), *Cucumber Mosaic Virus* (CMV), *Tomato Spotted Wilt Virus* (TSWV).

5. Bacilliform: (E.g.) *Rice Tungro Bacilliform Virus* (RTBV), *Banana streak virus* (BSV) and *Cocoa Swollen Shoot Virus* (CCSV).

Protein forms a protective coat (**capsid**) around the nucleic acid in a virus. Plant viruses have only one kind of protein. Individual protein subunits are called as **capsomers**. Protein subunits are spirally arranged in elongated viruses and packed on the side of polyhedral particles of spherical viruses. Proteins provide the basis for serological differentiation of viruses and other strains. Like all proteins, viral protein is made up of amino acids. Sequence of amino acids within a protein is detected by the sequence of nucleotides in the nucleic acid.

Nucleic acid may be of RNA / DNA and never both. Most of the plant viruses have RNA. But some plant viruses have DNA (e.g. *Cauliflower mosaic virus* (CaMV), *Rice tungro bacilliform virus, Bean golden mosaic virus* and *Banana bunchy top virus*). Nucleic acid **(RNA / DNA)** may be either single stranded (**ss**) or double stranded **(ds**) .Viral nucleic acids are quite small (1 – 3 x 106dalton) when compared to bacteria (1.5 x 109dalton). Nucleic acid may be present as a single

continuous strand **(monopartite)** in one particle or it may be present as two **(Bipartite)** or more pieces (**multipartite**) in the same or different particles made up of same protein subunit. Bi- or multipartite viruses are called as **split genome viruses**. All types of particles with different segments of the genome must be present in the plant for the successful infection. Nucleic acid and protein coat makes up 5 – 40% and 60 – 95% of the virus respectively.

Elongated viruses have less quantities of nucleic acid while the spherical viruses contain more nucleic acid.Some ssDNA viruses appear as twin particles as a result of partial fusion together of two of isometric particles and they are called as **geminiviruses** (E.g. *Maize streak virus, Bean golden mosaic virus* and *Beet curly top virus*)**.** Some group of viruses has outer lipid envelop around the protein coat (E.g. *Tomato Spotted Wilt Virus*)**.**

Multiplication of virus is different from fungi and bacteria. First step in the multiplication is the separation of nucleic acid from the protein coat in the host cell by the enzymes of host cell. Nucleic acid itself involve in the synthesis of new nucleic acid and protein coat by utilizing the amina acids, ribosome and transfer RNA of the host. Once the new nucleic acids and proteins subunits are formed, the nucleic acid arranges the protein subunit around it to form the **complete virus particle** or **virons. Transmission of viruses is** through **vegetative propagation** (E.g. *Banana bunchy top virus* and *Indian cassava mosaic virus),* **seeds** (E.g. *Bean common mosaic virus),* **pollen** (E.g. *Prunus necrotic ringspot virus),* **sap** (E.g. *Cucumber mosaic virus, Potato virus X* and *Tobacco mosaic virus)* and by vecto

Vector

Vector is an organism that carries and transmits a pathogen (inoculum) to a plant. Vectors may be insect, nematodes, fungi, etc.

Symptoms

Symptoms like chlorosis, mosaic, streak, vein clearing, vein banding, leaf crinkle, leaf curl, enation, necrosis, dwarfing, rosette, bunchy top, twisting etc. are produced in crop plants.

Symptoms of viral diseases

Chlorosis

Yellowing of normally green tissues due to chlorophyll destruction or failure of chlorophyll formation is known as chlorosis.

i. Infections chlorosis of banana - Cucumber Mosaic Virus (CMV)

Symptoms

Severe mosaic symptoms in young growth showing broadly streaked chlorotic or yellowish green bands (from margin to midrib) and patches or chlorotic mottling distributed in patches over the leaf lamina; leaves are narrow and smaller than normal and the infected plants are dwarf; rolling of leaf margins twisting and bunching of leaves at the crown and a rigid erectness in newly emerged leaves.

Vector

Aphids - *Aphis gossypii* and *A. maidis*

Mosaic

Intermingling patches of green and light green or pale green or yellowish colour on the leaves is known as mosaic.

Mottling and streaking of banana leaves and flowers due to cucumber mosaic virus

Tobacco mosaic-*Tobacco mosaic Virus (TMV) / Nicotiana Virus 1*

Symptoms

Leaves develop characteristic light and dark green pattern on the lamina. Dark green areas are usually associated with the veins, which later develop into irregular crumpled swellings / blisters due to more rapid growth. Dark brown necrotic spots develop under hot weather (mosaic burn).

Virus

Rod shaped ss RNA.

Transmission

Sap, farm equipments and by contact.

Cowpea aphid-borne mosaic virus (CAMV) on cowpea

Symptoms

Chlorosis, dark green and light green patches alternated on leaves; distortion of leaves.

Vector

Aphids - *Aphis gossypii, A.craccivora, Myzus persicae.*

Cassava mosaic virus on cassava (Tapioca)

Symptoms

Mosaic mottling on leaves; chlorosis of leaves; distortion of leaves; twisting of leaves; stunting of plants and tuber splitting.

Vector

White fly - *Bemisia tabaci*

Yellow mosaic of greengram and blackgram caused Mungbean Yellow Mosaic Virus (MYMV)

Symptoms

Small yellow patches or spots intermingled with green patches on the leaves initially, later entire leaf changes yellow in colour, in severe infections discolouration of pods and seeds to yellow.

Vector

Whitefly - *Bemisia tabaci*

Sterility mosaic of pigeonpea - Pigeonpea sterility mosaic virus

Symptoms

Intermingling of light green and dark green patches in the leaves, reduction in leaf size; small leaves clustering near the tip of the plants, shortening of internodes, stimulation of auxillary buds giving a bushy appearance. No flower and pod formation leading to sterility of affected plant. Plants remain green till harvest.

Sterility mosaic disease symptoms, mild (left) to severe (right), on pigeonpea leaves caused by *Pigeonpea sterility mosaic virus*

Vector

Eriophyid mite - *Aceria cajani*

Stripe

Stripe is characterized by elongataed or areas of pale green to yellow or white, of indefinite length, on leaves with parallel venation or on stems.

i. Barley stripe mosaic - Barley stripe mosaic virus

Symptoms

Light green stripes on the leaves and stunting of plants.

Streak

Development of chlorotic streaks on leaves.

Maize streak - Maize Streak Virus

Symptoms

Elongated chlorotic stripes appear on one side of mid rib near its base, which later become necrotic. Plants are stunted and produce small ear heads.

Virus

Isometric with ss DNA geminate particles and monopartite genome.

Vector

Leaf hopper -*Peregrinus maidis*

Vein clearing

Yellowing of veins or clearing of the tissues in or immediately adjacent to the veins is called vein clearing.

i. Vein clearing or yellow vein mosaic of bhendi - Bhendi yellow vein mosaic virus (BYVMV)

Symptoms

Initially light yellow streaks along with the smaller veins, later all the veins become yellow giving **yellow network of veins**. Chlorosis of interveinal areas, reduction in size of leaves and small and fibrous fruits.

Virus

Isometric with ssDNA geminate particles and bipartite genome.

Vector

Whitefly *Bemisia tabaci*

Vein banding

The tissues along the veins are dark green than the tissues between the veins is called vein banding.

i. Potato vein banding - Potato vein banding virus.

Symptoms

Veins only remain green and interveinal areas become bleached to yellow. Newly emerged leaves are smaller and show crinkling, rolling upward to form cap like structures and distortion. Affected plants are stunted and leaves are brittle.

Virus

Filamentous particle with 1 or 2 ss RNA

Vector

Myzus persicae (Aphid).

Leaf crinkle

In leaf crinkle the surface of leaves is not uniform and is with undulations.The leaves are thick and brittle and remain green till harvest.

i. Leaf crinkle of blackgram - urdbean leaf crinkle virus (ULCV)

Symptoms

Crinkling and curling of leaves, stunted and bushy plants and malformed inflorescence with sterile flowers.

Virus

Isometric with ssDNA, geminate particles and bipartite genome.

Vector

Whitefly - *Bemisia tabaci*

Leaf curl

In leaf curl the leaves curl from the margins backward bringing the centre of the lamina upward.

i. Tomato and tobacco leaf curl - Tobacco leaf curl virus. (TLCV)

Symptoms

Leaves curled, twisted and puckered, leafy outgrowth called enations can be seen on the under surface of leaves, thickening and greening of veins in the leaf and calyx, mottling and vein clearing, stunted plant growth, inflorescence greatly condensed and complete or partial sterility.

Vector

Whitefly - *Bemisia tabaci*

ii. Black gram leaf curl- *Tomato Spotted Wilt Virus (TSWV)*

Symptoms

Lateral veins show chlorosis near the leaf margin and the lamina curl downwards slowly. Infected leaves are brittle and sometimes vein necrosis present on the under surface of the leaves, which extends up to the petiole. Plants may produce few small and malformed pods

Virus

Spherical with negative ss RNA and are enveloped with a lipid membrane.

Vector

Thrips-*Thrips tobaci, Frankliniella schultzii*

Enation

Enations are leaf-like outgrowth from the veins on the under surface of the leaves diseased by different viruses.

Tomato and tobacco leaf curl-*Tomato Leaf Curl Virus (TLCV)*

Symptoms

Leaves become warty, rough, puckered with downward curling. Leafy outgrowth like structure is noticed on the veins in the lower surface of the leaves.

Virus

Isometric with ss DNA geminate particles and monopartite genome.

Vector

Bemisia tabaci (white fly)

Tobacco and tomato leaf curl - Tobacco leaf curl virus (TLCV)

Necrosis

Necrosis (death of cells) of tissues in the growing shoots due to virus infection.

i. Bud necrosis of groundnut - Tomato spotted wilt virus (TSWV).

Symptoms

Young leaves show chlorotic spots or mottling and necrosis of terminal buds which spreads downwards and covers the entire plant or part of the plant; reduction in leaflet size; distortion of lamina and **shoe-string** formation stunting and bushy appearance of plants.

Virus

Spherical with negative ss RNA and are enveloped with a lipid

Vector

Thrips - *Frankliniella schultzei, Thrips tabaci* etc.

Dwarfing

A decrease in overall size without alteration of the proportions between parts of the plant is known as dwarfing.

i, **Rice dwarf - Rice dwarf virus.**

Symptoms

Yellowish white to white specks are seen along the veins of young leaves; on succeeding leaves specks develop in more numbers and are connected to form continuous streaks along the veins; plants are extremely stunted with: shol1ned internode and innumerous unproductive tillers giving a rosette appearance.

Vector

Green leafhoppers - *Nephotettix cincticeps.*

Rosette

In rosette shortening of internodes with reduction in leaf size is seen. The plants show stunting with bushy appearance.

i. Groundnut rosette - Groundnut rosette virus (GRV)

Symptoms

Stunting of plants with chlorotic, twisted and distorted leaflets.

Vector

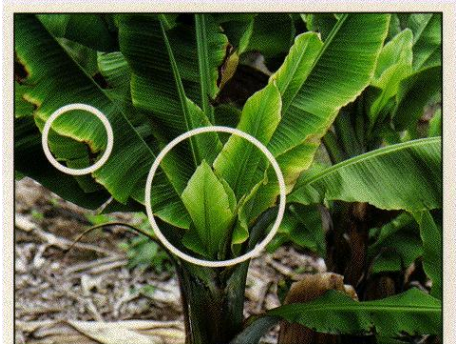
Aphids- *Aphis craccivora*

Bunchy top

In bunchy top extreme stunting of the plant with bunching of small, erect and brittle leaves at the crown of plants is seen.

i. Bunchy top of banana - Banana bunchy top virus (BBTV)

Symptoms



Leaves with broken green, bands parallel to, veins; small and brittle leaves with short petiole crowding of small leaves at the crown coupled with stunting of plants giving a bunchy appearance; the infected plants are normally 30-60 cm in height; plants do not produce bunches.

Virus

Isometric with ss DNA geminate particles and monopartite genome.

Vector: Banana aphid- *Pentalonia nigronervosa* var. *typica.*

Lecture 13

Viroids - general characteristics and examples of diseases caused by viroids

Viroids area covalently closed circular RNA molecules. Viroids were the first circular RNAs to be discovered in nature. These are the smallest known infectious agents. Potato spindle tuber viroid was the first viroid reported, and it is widely prevalent in different potato growing areas. Citrus exocortis viroid is wide spread in citrus production areas where trifoliate ornage(Poncirus trifoliate)is used as root stock. Hop stunt viroid has a wide range of hosts. Mechanism of viroid pathogenesis in plants has been elucidated recently.

Structure of Viroids

Viroids are nucleic acids that exists naturally with no protein coat. They consist of ribonucleic acid (RNA). These mini viruses are the smallest known causal organisms of infectious diseases. They are subviral and their size ranges from 246 to 388 nucleotides in length. The RNA structure of viroids is different from transfer RNA (t RNA), ribosomal RNA(r RNA) and messenger RNA(m RNA). Viroids are the first circular RNA's to be discovered in nature.

Important viroids causing diseases

The following are viroids that cause diseases in important crops:

Apple scar skin viroid

Australian grapevine viroid

Avocado sunblotch viroid

Chrysanthemum chlorotic mottle viroid

Chrysanthemum stunt viroid

Citrus exocortis viroid

Coconut cadang cadang viroid

Coconut tinangaja viroid

Cucumber pale fruit viroid

Grapevein viroid

Grapevine yellow speckle viroid

Hop latent ciroid

Hop stunt viroid

Potato spindle tuber viroid

Tomato apical stunt viroid

Tomato planta macho viroid

Potato spindle tuber viroid

Potato spindle tuber viroid - stiff and upright growth habit on infected potatoes

Hop Stunt viroid

Cadang Cadang disease

Citrus exocortis viroid

Grapevine yellow speckle viroid

Viroid Infection Process and Management

Infection process

The viroid RNA does not code for any genes. Viroid replication and pathogenesis may depend completely on the enzyme systems of the host. The viroid RNA is dependent upon the host for its replication as well as intraplant movement. The functions necessary for propagation of the viroids are derived completely from the host. The viroids are associated with and replicate in either the nucleus or the choloroplasts of the plants. They are replicated by the host encoded RNA polymerases. They do not encode proteins. Viroids replicate within the nucleus of infected cells without a helper virus. Viroids are transported into the plant nucleus and typically potato spindle tuber viroid (PSTV) possesses a sequence or structural motif for nuclear transport. Phloem proteins may be involved in systemic transport of viroids in the plants. Phloem protein 2 a dimeric lectin, is the abundant component of phloem exudates of cucumber. This protein interacts with the viroid RNA and facilitates the systemic movement of hop stunt viroid.

Symptoms

Infection with viroids does not result in obvious macroscopic symptoms. Common symptoms of viroid diseases include retardation of plant gowth and stunting. Potato plants infected with the potato spindle tuber viroid are smaller than healthy plants. However, tuber symptoms are prominent. The diseases tubers are spindle shaped. Citrus trees infected with the citrus exocortis viroid are stunted. Symptoms of the disease include scaling of the bark below the graft union. Stunted trees crop well for their size, and the fruit is normal. Stunting is the important symptom of tomato plants affected by the tomato bunchy top viroid, hop plants infected by the hop stunt viroid and chrysanthemum plants infected by the chrysanthemum stunt viroid and the chrysanthemum chlorortic mottle viroid.

Mode of spread

Viroids are highly contagious and mechanically transmitted. They are spread by leaf contact. Viroids are spread also by contaminated planting and cultivating equipments. They may be disseminated mostly as a result of cultural operations through contaminated knives, tools and hands. Some reports indicate that viroids are transmitted by insects. Potato spindle tuber viroid has been reported to be transmitted by aphids, grass hoppers, flea beetles, tarnished plant bugs,

larvae of Colorado potato and leaf beetle. However, the transmission of viroids by insects is negligible and mechanical transmission is more important.

Viroid disease management

Because viroids are spread mechanically, disease free planting materials should be used for planting. Cutting knives and all planting and field equipment should be cleaned scrupulously. Commercial cultivars with high resistance to the diseases are lacking.

Virusoids (Encapsidated, viroidlike, satellite RNA's)

Some viruses contain a viroid like satellite RNA in addition to a linear, single stranded molecule of genomic RNA. Such viroid – like satellite RNA's are called virusoids. They show little sequence homology with viroids, but they do show significant homology with the linear satellite RNA associated with Tobacco ringspot virus. The virusoids in infefcted plants exist almost solely as circular molecules, either free or encapsidated within virion of the helper virus. Virusoids do not code for any polypeptides.

Lecture 14

Definition and objectives of Plant Pathology - History of Plant Pathology

Definition and History of Plant Pathology

Plant Pathology

Plant pathology or phytopathology is the science, which deals with the plant diseases. It is concerned with health and productivity of growing plants. Phytopathology (Greek *Phyton* = plant + *pathos* - disease, ailments + *logos* = discourse, knowledge) is the branch of agricultural, botanical or biological science which deals with the cause, etiology (aetiology), resulting in losses and management methods of plant diseases.

Plant pathology can also be defined as the study of the nature, cause and prevention of plant diseases. Plant pathology is related to most of the old and new sciences like biology, physics, chemistry, physiology, mathematics, genetics, soil science, biochemistry, biotechnology etc. Plant pathology has the following major objectives.

1. To study biotic (living), mesobiotic and abiotic (non-living and environmental) causes of diseases or disorders
2. To study the mechanisms of disease development by pathogens
3. To study the plant (host)-pathogen interaction in relation to environment
4. To develop methods of management of plant diseases

Plant diseases

Plant diseases are recognized by the symptoms (external or internal) produced by them or by sick appearance of the plant. The term plant disease signifies the condition of the plant due to disease or cause of the disease. Plant disease is mainly defined in terms of the damage caused to the plant or to its organ. The other definitions for the term disease are:

1. Disease is a malfunctioning process that is caused by continuous irritation, which results in some suffering producing symptoms. This definition is accepted by both American Phytopathological Society and British Mycological Society.

2. Disease is an alteration in one or more of the ordered sequential series of physiological processes culminating in a loss of coordination of energy utilization in a plant as a result of the continuous irritation from the presence or absence of some factor or agent.

3. A plant is said to be ‘diseased’ when there is a harmful deviation from normal functioning of physiological process (Federation of British Plant Pathologists, 1973).

4. The disease can also be defined as 'any disturbance brought about by a living entity or non-living agents or environmental factors which interfere with manufacture, translocation or utilization of food, mineral nutrients and water in such a way that the affected plant changes in appearance with or without much loss in yield than that of a normal healthy plant of the same variety. In general disease is an interaction among the host, parasite and the environment.

Man became painfully aware of plant diseases in the early times of antiquity. This is evidenced by the inclusion of blasting and mildew in the Old Testament. Our ancient religious literature gives informations on plant diseases much before their mention by the Greek philosopher, Theophrastus. *Rigveda, Atharvanaveda* (1500-500 B.C.), the *Artha Shashtra* of *Kautilya* (321-186 B.C.), *Sushrute Samhita* (200-500 A.D.), *Vishnu Puran* (500 A.D.), *Agnipuran* (500-700 A.D.) and *Vishnudharmottar* (500-700 A.D.) are some of the ancient books from India where diseases and other enemies of plants are mentioned. In *Rigveda*, classification of plant diseases and germ theory of disease were discussed.

The learned men during Vedic period were aware that the diseases are caused by microbes. The book *"Vraksha Ayurveda"* written by *Surapal* in ancient India contained information on plant diseases. This is the Indian book, which gave first information on plant diseases. He divided plant diseases into two groups *viz.*, internal and external. Plant diseases like rust, smut, downy mildew, powdery mildew and blight were mentioned in the Bible.

The Greek Philosopher, *Theophrastus* (370-286 B.C.) was the first to study and write about the diseases of trees, cereals and legumes. In his book *'Enquiry into plants'* Theophrastus has recorded his observations, imaginations and experiences but they were not based on any experiments. He had mentioned that plants of different groups have different diseases, which are autonomous or spontaneous *i.e.*, no external causes were associated with the plant diseases.

The history in several aspects of plant pathology is given as below:

Mycology

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

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

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

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

1821 - E. M. Fries published Systema Mycologicum for naming of fungi; he was named as Linnaeus of Mycology.

1821 - Robertson of England stated that sulphur is effective against peach mildew.

1845 - Irish Potato famine due to *Phytophthora infestans* caused starvation of million and immigration of 1.5 million people.

1858 - J. G. Kuhn published first textbook in Plant Pathology – The Diseases of Cultivated Crops, their Causes and their Control.

1861 -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.

1865 – Anton de Bary reported heteroecious nature of wheat stem rust.

1869 – England loses coffee production to coffee rust, forced to grow tea.

1874 -Robert Hartig published a book entitled, "Important Diseases of Forest Trees".

1875-1912 - 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.

1877 – M. S. Woronin discovered and named the Club root of Cabbage pathogen as *Plasmodiophora brassicae.*

1878 – M. S. Woronin found out the life cycle of potato wart disease.

1878 -Downy mildew of grapevine was introduced into Europe from America. The disease almost ruined the wine industry.

1881 -H.M. Ward worked out the life cycle of coffee leaf rust. He is called as Father of Tropical Plant Pathology.

1882 -Robert Hartig published a textbook -Diseases of Trees. He is called as "Father of Forest Pathology".

1885 -Pierre Marie Alexis Millardet accidentally discovered the Bordeaux mixture for the control of downy mildew of grapevine.

1885 – A. B. Frank defined and named mycorrhizal associations in plant roots.

1887 -Burgundy mixture was introduced by Mason of France.

1894 -Swedish scientist Eriksson described the phenomenon of physiologic races in cereal rust fungus, *Puccinia graminis*.

1899 – 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.

1904 – A. F. Blakeslee, American Geneticist founded heterothallism in *Rhizopus*

1904 – R. H. Biffen was the first to show that resistance to pathogens in plants can be inherited as a Mendelian character; pioneer in genetics of plant disease resistance.

1912 – H. Burgeff reported that within a cell of a fungus, fusion between dissimilar nuclei can occur. He called this phenomenon as heterokaryosis.

1917 -E. C. Stakman demonstrated physiologic forms in stem rust of wheat.

1918 -E.J.Butler published book on *Fungi and Disease in Plants*; he made exhaustive study on Indian fungi and the diseases caused by them. He is called as the Father of Modern Plant Pathology in India; He joined as the first Director of Imperial Bureau of Mycology (Commonwealth Mycological Institute, CMI) now CAB International Mycological Institute in Kew, England in 1920. He began the journal *Review of Applied Mycology*; with S.G. Jones he wrote, *'Plant Pathology'* in 1949.

1929 -Sir Alexander Fleming isolated the antibiotic, Penicillin from the fungus, *Penicillium notatum*.

1932 – H. N. Hansen and R. E. Smith were the first to demonstrate the origin of physiologic races through heterokaryosis.

1934 -W. H. Tisdale and I. Williams studied the organic fungicides by discovering alkyl dithiocarbamates.

1938 – H. N. Hansen found out dual phenomenon in Fungi Imperfecti.

1942 – H. H. Flor developed gene-for-gene hypothesis in flax rust.

1943 – Great Bengal Famine due to *Helminthosporium oryzae* caused death of 2 million people in India.

1943 -Dimond, Heuberger and Horsfall discovered the ethylene bis dithiocarbamates.

1945 -J. G. Horsfall explored the mechanism of fungicidal action.

1948 -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.

1951-57 -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.

1952 -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.

1953 – Pontecorvo and his associates demonstrated parasexualism in fungi.

1956 -J. G. Horsfall published a book entitled "Principles of Fungicidal action"

1957 – E. C. Stakman with J. G. Harrar wrote a book *Principles* of *Plant Pathology.*

1963 - J. E. Van der Plank found out vertical and horizontal types of resistance in crop plants.

1966 -van Schmeling and Marshall Kulka were the first to find out systemic fungicides (oxathiin compounds – carboxin and oxycarboxin).

1970 -S. D. Garrett investigated the management of root diseases and he is the pioneer worker in the field of biological control. 1972 – G. Rangaswami wrote a book on Diseases of Crop Plants in India.

Plant Bacteriology

1683 – Anton von Leeuwenhoek first observed bacteria.

1876 -Louis Pasteur and Robert Koch -They proved that anthrax disease of cattle was caused by specific bacterium.

1876 -Robert Koch of Germany described the theory called "Koch's postulates." He established the principles of pure culture technique.

1876 -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.

1882 -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*).

1901-1920 E.F.Smith of U.S.A gave the final proof of the fact that bacteria could be incitants of plant diseases. He also worked on the bacterial wilt of cucurbits and crown gall disease. He is also called as "Father of Phytobacteriology". Chilton and his coworkers demonstrated that crown gall bacterium transforms plant cell to tumour cell by introducing into them a plasmid.

1910 -C. O. Jensen related crown gall of plants to cancer of animals.

1952 -J. Lederberg coined the term plasmid 1952 – S. A. Waksman won Nobel prize for the discovery of streptomycin.

1952 – Zinder and J. Lederberg discovered transduction in bacteria 1962 – H. Stolp discovered bdellovibrios.

1972 – P. B. New and A. Kerr success in biological control of *A. radiobacter* strain K.

1972 – I. M. Windsor and L. M. Black observed a new kind of phloem inhabiting bacterium causing clover club leaf disease.

1974 – I. Zanen et al. demonstrated Ti plasmid in *Agrobacterium tumefaciens*.

1980 – D. W. Dye et al. introduced the pathovar in the taxonomy of plant pathogenic bacteria.

Plant Virology

1886 -Adolf Mayer described a disease of tobacco called mosaikkranheit (tobacco mosaic). Adolf Mayer demonstrated the sap transmission of Tobacco Mosaic Virus disease.

1892 -Dimitri Ivanowski demonstrated that the causal agent of tobacco mosaic could pass through bacterial filter.

1895 -E.F. Smith of U.S.A. showed the peach yellows was a contagious disease.

1898 -M.W. Beijerinck -a Dutch microbiologist and founder of virology proved that the virus inciting tobacco mosaic is not a microorganism. 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.

1929 -F. O. Holmes provided a tool by which the virus could be measured by showing that the amount of virus present in a plant sample preparation is proportional to the number of local lesions produced on appropriate host plant leaves rubbed with the contaminated sap.

1935 -W. M. Stanley proved that viruses can be made as crystals. He got Nobel Prize in 1946.

1936 -F. C. Bawden and, N.W. Pirie (Britain) found that the crystalline nature of the virus contains nucleic acid and protein.

1939 -Kausche and colleagues first time saw the TMV virus particles with the help of Electron microscope.

1956 -Gierer and Schramm proved that the nucleic acid fraction of the virus is actually the infectious agent.

1959 -Munday succeeded in inducing TMV mutations.

1966 -Kassanis discovered the satellite viruses.

1971 -T. O. Diener discovered viroids, which only consist of nucleic acids. Smaller than viruses, caused potato spindle tuber disease (250-400 bases long of single-stranded circular molecule of infectious RNA).

Phytoplasma

1967 – Doi *et al* and Ishiie *et al*, the Japanese scientists found that mycoplasmalike organisms (MLO) could be responsible for the disease of the yellows type. Doi observed that MLO's are constantly present in phloem while Ishiie observed MLO's temporarily disappeared when the plants are treated with tetracycline antibodies.

Spiroplasma

1972-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.

Lecture 15

TERMS AND CONCEPTS IN PLANT PATHOLOGY. SURVIVAL AND DISPERSAL OF PLANT PATHOGENS

Terms and concepts in plant pathology

Introduction

Plant diseases in the landscape and garden are very important and can be a significant source of frustration and loss to the gardener. There are about 30,000 diseases of economic importance. Plant pathology is the study of the biotic and abiotic agents that cause disease in plants; of the mechanisms by which these causal agents induce disease in pants and of the methods of preventing or controlling disease and reducing the damage caused.

Plant Diseases in History

Certain diseases have had tremendous impacts on our society. Perhaps foremost among these is *Phytophthora* late blight which caused the potato famine (1845) in Ireland. It is estimated that 1.5 million Irish died from starvation and just as many immigrated to the United States. Two forest tree diseases which caused great economic losses in America are Dutch elm disease andchestnut blight. Both were introduced accidentally to the United States and while the former continues its destruction, the latter completely destroyed valuable trees in the Appalachians. These examples are prominent because they caused so much damage. In reality, total crop loss due to plant disease is rare. Most disease loss in the garden is due to endemic diseases.

Disease Defined

Diseases result from more or less continuous irritation of the plant tissues by a primary causal agent. Disease is a process that takes time, is physiological in nature, abnormal, and detrimental. Diseases cause damage by reducing yield and/or quality of plants and/or plant products.

Types of Plant Diseases

There are two types of plant diseases: those whose primary causal agents are biotic (infectious), and those that are abiotic (not infectious). The causal agent of infectious diseases is called the pathogen, and the susceptible plant the suscept. Diseases caused by microorganisms or microbes, are infectious. Diseases caused by parasitic plants are also infectious. Diseases may involve more than one causal agent and often involve secondary causal agents.

Noninfectious (Abiotic) Diseases

Examples of abiotic diseases include:

Nutrient Deficiencies -- A lack of essential elements such as iron or zinc may cause plant foliage to yellow.

Lack of or Excess Soil Moisture -- A plant can become dehydrated during drought periods, and may suffocate when poor drainage cuts out oxygen around the roots.

Too Low or Too High Temperature -- Plants grown out of their adapted habitat can be injured or killed by extremes in temperature.

Air Pollution -- Ozone, sulfur dioxide and automobile exhaust fumes can injure plants.

Soil Acidity or Alkalinity -- Adverse soil pH can injure plants

Mechanical Damage - *G*irdling from roots, nylon twine or wire; injury from construction

Biotic Diseases

Biotic (infectious) diseases occur when a host plant is invaded by a living organism. Most of these organisms are microbes, and can also be referred to as parasites which attack plants. A **host** is a plant which has been invaded by a parasite. A parasite is an organism which obtains its nutrients from living organisms, often plants. In the process of feeding, the parasite not only consumes plant tissue, which weakens the host, but also produces toxins, enzymes, and growth regulating substances which disturb the normal metabolic processes in the plant. In some cases the parasite actually blocks the movement of food and water in the plant's conducting tissue. Any of these disorders caused by a parasite will result in a diseased plant. Microbes are the major biotic pathogens of plants. The four major groups of microbial plant pathogens are fungi, bacteria, nematodes, and viruses. Less commonly, phytoplasmas (bacteria-like) and viroids (virus-like) also cause diseases. Parasitic flowering plants are also pathogens.

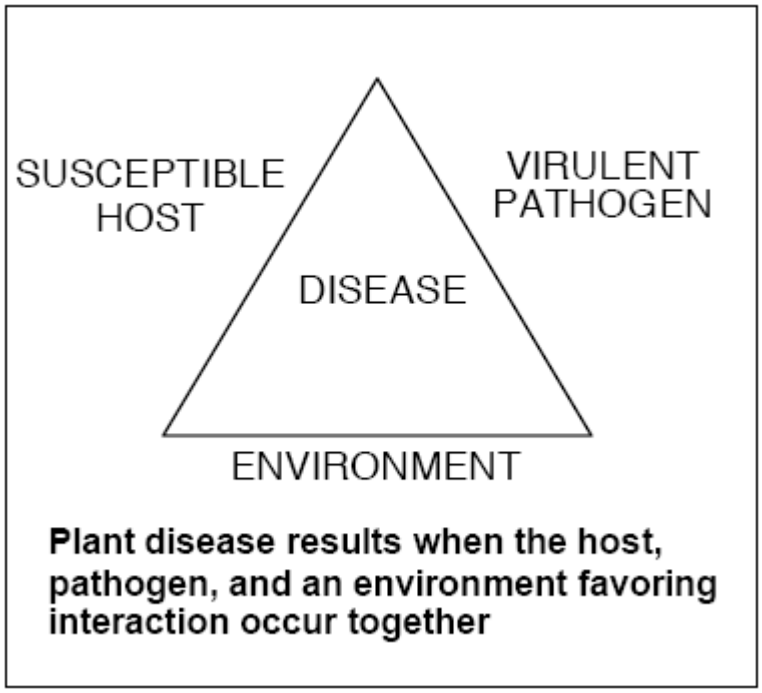
Much can be learned by studying the pathogens as groups, and a working knowledge of those groups is needed for an understanding of plant pathology. Knowing how a pathogen obtains nourishment is important to understanding the disease process and developing control strategies. Most microbial pathogens are primarily parasites, but some are mainly saprophytes and can sometimes cause disease. Saprophytes usually feed on non-living organic matter. Most microbial pathogens have some saprophytic abilities, which are important in survival and in the disease process. Pathogens with saprophytic ability can be cultured away from their host plant.

Some pathogens can only grow in nature on their live host, (e.g. powdery mildew and rust fungi) and are called obligate parasites. Obligate parasites feed and reproduce on living plant material.

Conditions Necessary for Disease

In order for disease to occur, three conditions must be met. First it is necessary to have a susceptible host plant. Each species of plant can be infected by only some pathogens. The plant must also be in a stage of development susceptible to infection by the disease agent.

The second requirement is the presence of an active pathogen. If there is no pathogen present, there can be no disease. Also, the pathogen must be in a stage of development conducive to infecting or affecting the host plant. The third condition is an environment suitable for the pathogen to cause disease of the plant. The interaction of host, pathogen, and environment can some times be represented by a triangle. The "disease triangle" cannot be constructed unless all 3 legs are present simultaneously. Break any leg of the triangle, and there is no disease. Disease control strategies can be based on breaking a leg of the triangle.



Plant disease results when the host, pathogen, and an environment favoring interaction occur together

Diseases Caused by Fungi

A fungus is a multicellular organism made of thread-like material known as mycelium. Fungi cannot make their own food, so in the process of obtaining food from higher plants, fungi injure roots, stems, leaves, and fruit. This action causes what we know as plant diseases. Not all fungi, however, cause disease.

Types of Fungi

There are many types of fungi. Many saprophytic fungi are beneficial to mankind. Beneficial fungi rot leaves, cause fermentation in the manufacture of alcohol and cheese, and produce antibiotics used to treat human infections. Yeasts, which are used in fermentation, and *Penicillium*, an important antibiotic producer, are fungi. Thousands of species of parasitic or pathogenic fungi cause plant diseases. Some species attack only one plant; others attack many different plants. Some plants are susceptible to more than 50 fungal diseases. Fungi are mainly composed of mycelia. Mycelial threads resemble spider webs in appearance. Bread mold is a fungus and is typical of the vegetative structures fungi produce.

How Do Fungi Reproduce?

Fungi reproduce by forming spores, sclerotia and mycelial fragments. These fungal parts provide a means for the fungus to be moved from diseased to healthy plants and for the fungus to survive from one season to the next.

Spores: Fungus spores can be compared to seed in higher plants. A fungus can produce millions of spores which are too small to be seen with the naked eye. Each fungus species produces a spore or group of spores which is different from that of all other species. A fungus can be identified by the spore it produces, just as an individual can be identified by finger prints. Spores come in a variety of shapes or colors and can have one cell or be multi-cellular. Some types of fungi mate and form sexual spores, but most fungi are asexual, and fertilization is not necessary for reproduction. Some fungal spores are short-lived, and some are resting spores which can last many years even under adverse conditions.

Sclerotia: The mycelium of some fungi becomes hard and forms reproductive structures known as sclerotia. These sclerotia or hard bodies will remain dormant in the soil for several years or until a susceptible crop is planted. *Sclerotium rolfsii*, which causes crown rot of vegetables, is a good example of a fungus with this kind of reproduction.

Mycelial Fragments: Some fungi are spread from one area to another by fragments of their mycelium. This form of reproduction is similar to vegetative reproduction in higher plants. *Rhizoctonia*, which causes damping off of seedlings, is spread by mycelial fragments.

Where Are Spores Produced?

In Soil Water: Some fungal-like organisms (Oomycota) produce motile spores with flagella, known as zoospores, that move from root to root in soil water. Other members of the Oomycota

which form motile spores such as *Pythium* and *Phytophthora* thrive in low wet areas and cause such diseases as root rots and stem rots.

Special Structures: Some fungi produce spores in special structures inside the infected plant tissue. Numerous spores are produced inside these fruiting bodies, and upon maturity the spores are discharged on the surface of the diseased plant where they can be carried away by air currents or splashed into the air by raindrops.

Stalks or Conidiophores: Many fungi produce their asexual spores on exposed stalks known as conidiophores. Fungi on the surface of the plant tissue form stalk-like structures which produce numerous spores known as conidia. A conidiophore resembles a small plant with fruit hanging on it. This type of spore is usually carried away by air currents since it is produced on the surface of plant tissue.

Penetration of Plant Tissue

In order for infection to occur, the spore must germinate and penetrate the plant tissue. When a spore germinates on moist tissue, it enters the tissue by direct penetration, through natural openings such as stomata or lenticels, or via wounds.

***Direct Penetration*:** In direct penetration, the spore forms a germ tube which penetrates using enzymes and physical pressure. Young, tender leaves, roots, and blooms are more likely to be invaded by direct penetration. Many foliage infections occur in early spring while the new growth is tender. Some fungi penetrate only the cuticle layer (outer layer) of leaves or fruit. The disease

apple scab is a good example of a subcuticular infection. Other fungi such as powdery mildew penetrate only the epidermal layers.

Penetration through Stomata: Some fungi penetrate through stomata (natural openings). Fungi which enter through stomata can attack older and tougher leaves. Rust fungi such as cedar apple rust or bean rust penetrate via stomata.

Penetration Through Wounds: Some fungi enter plant tissue only through wounds. Pruning wounds make an excellent avenue of penetration. Many fruit rots occur when fungal spores come in contact with bruised areas.

Factors Necessary for Infection

There are millions of fungus spores in our environment but infection does not occur every time the spores are deposited on plant tissue. Certain favorable factors are necessary before infection can occur.

Moisture: In order for most fungus spores to germinate and penetrate plant tissue, free water must be available on the plant surface. If the leaf is dry, infection will not occur. A dry spring can reduce disease development for the entire season since the dry weather protects the young tender tissue from fungus infection. If sufficient moisture is available later in the season, the foliage may be tough and spores less numerous. Thus, free moisture especially early in the season favors most diseases.

Temperature: Some crops grow at a temperature below which fungi can infect, but most crops grow at temperatures most suitable for fungal reproduction. Most fungi grow well at temperatures between 70^{o} and 90^{o} F and are dormant in winter. Diseases are more common, and more damaging, in tropical climates than the temperate climates.

Stage of Plant Growth: Fungi infect susceptible plant tissue. Some fungi attack any young, tender leaves. Others prefer new shoot growth, young feeder roots, or ripe fruit. If the plant passes through this susceptible stage before spores are available or during unfavorable weather conditions, then it might escape injury for the entire season.

Disseminating Agents: Fungus spores must be carried from infected to non-infected tissue by some agent such as wind, insects, man, transplants, or seed. A disease spread by wind or blowing rain might not reach epidemic proportions during calm, dry periods. The spores of downy mildew can be spread all the way across the continent by wind currents. Dutch elm disease is spread from tree to tree by insects.

Duration of Spore Release: Some fungi produce spores during the entire spring or summer, but others produce only one crop of spores during a short period in early spring. A fungus which produces spores for only a few days can be more easily controlled since the infection period is very short and the plant might not be in a susceptible stage of growth when spores are available. Dispersal of fungal spores frequently occurs daily and corresponds closely to current critical environmental events that favor infection or pathogen reproduction, e.g., moisture, temperature, etc.

Diseases caused by Bacteria

Bacteria are minute one-celled microbes closely related to fungi. Plant pathogenic bacteria do not produce spores. They reproduce by simple cell division. The tiny rod-shaped cells reproduce very rapidly. Cells may divide every 20 to 30 minutes. At this rate, one cell will give rise to 17 million cells in 12 hours. This rapid growth rate accounts for the seemingly explosive nature of bacterial diseases. Large cell numbers confer great bacterial cell surface area for release of enzymes, toxins, or slime. These bacterial products are responsible for much of the damage caused by bacterial infection.

How Are Bacteria Spread?

Blowing Rain: Bacteria ooze out of infected tissue and form a mass of sticky material on the plant surface. Rain drops hit the bacteria and splatter them to new infection sites.

Insects: In the process of pollinating plants, bees crawl through the bacterial ooze and then deposit the organism in blooms. This is the primary means of spreading fire blight of apple and pear from tree to tree. Some bacteria live inside insect vectors and are spread from plant to plant.

People: While picking beans or suckering tomatoes, people can come in contact with bacteria and transfer them from plant to plant on their hands. Never work in the garden when plants are wet.

Seed: Bacteria can live from year to year inside seeds. When infected seeds are shared between gardeners, bacterial diseases can spread. This is why seeds grown in a dry western climate are clean. Avoid saving seeds from your garden unless you are preserving a unique variety.

Diseases caused by Viruses

Viruses are very tiny particles of nucleic acid and protein which can multiply only inside living cells. Virus particles in the cell disrupt normal cell functions and can affect the production of chlorophyll and starch. Infected plants may become yellow or be distorted due to malfunctioning cells. Other symptoms include mottled or puckered leaves, streaks on the leaves or, in some cases, distorted fruit.

How Are Viruses Spread?

Mechanically: Virus diseases can be spread from plant to plant on tools or hands. Some tobacco products may contain tobacco mosaic virus. Gardeners who use tobacco should wash their hands with soap and water, or in milk, before handling plants.

Insects: Insects remove virus particles from infected crop or weed plants when they suck out plant material. The insect can later inject the virus into another plant nearby or some distance away.

Seed: A few viruses are seedborne and are spread when infected seeds are planted.

Diseases caused by Nematodes

Nematodes are very tiny, eel-shaped worms which live mainly in the soil. These tiny worms cannot be seen by the naked eye. Many nematodes feed on plant roots, causing root injury which interferes with the movement of food and water in the plant. Other nematodes may not feed on roots. The pine wilt nematode mainly inhabits and feeds in the resin canals of pine stems and branches. Most nematodes go through several life stages including egg, larva, and adult.

How Do Nematodes Feed?

Nematodes have a spear-like mouth part that works like a hypodermic needle. The nematode inserts this spear or stylet into the root tissue, injects a chemical substance, and then withdraws plant material as it feeds. Root feeding sometimes causes root galls. Root knot and cyst nematodes are examples of root gall forming nematodes. Root feeding by nematodes causes plant tops to be stunted, yellowed, or wilted.

Where Are Nematodes Found?

Nematodes are found in many garden soils. Nematodes can be brought into the garden in the roots of transplants. Once garden soil is infested, the nematodes will generally remain there year after year for the life of the garden since most vegetables make ideal hosts.

Plant disease symptoms and Signs

Symptoms are the plant's expression of being diseased. Examples of symptoms include: blights, cankers, galls, rots, necrosis, and spots. Symptoms are expressed either locally or systemically, and they frequently reflect the structural, functional, or physiological systems disturbed. Diseases that produce few noticeable symptoms are termed "symptomless". Signs are the physical evidence of the pathogen (primary or secondary, vegetative and/or reproductive structures). Some examples include: conks, mildew, mycelium, ooze, pycnidia, and rhizomorphs. Diagnosis of plant disease is based on looking for symptoms and signs.

A dictionary of Plant disease Symptoms and Signs

blight: sudden death of twigs, foliage, and/or flowers.

blotch: large and irregular-shaped spots or blots on leaves, shoots, and stems.

Canker: dead places on bark and cortex of twigs or stems; often discolored and raised or sunken.

Chlorosis: yellowing of normally green tissue due to reduced chlorophyll content, such tissue is *chlorotic*

Conks: fungal fruiting structures formed on rotting woody plants (shelf or bracket fungi).

Damping-off: destruction of seeds in the soil, or seedlings near the soil line, resulting in reduced stand, or the seedling falling over on the ground

Decline: progressive, gradual weakening and death of a plant or population of plants

Dieback: progressive, gradual weakening and death of individual branches of a plant, often leading to decline

Distortion: malformed plant tissues

Flagging: the loss of rigidity and drooping of leaves and tender shoots preceding the wilting of a plant.

Fleck: a minute spot

Galls: abnormal, localized swellings or tumors, on leaf, stem or root tissue

Gum: complex of sugary substances formed by cells in reaction to wounding or infection

gummosis: production of gum by or in a plant tissue

Inoculum: amount of pathogen available for infection

Leaf spot: a self-limiting lesion on a leaf

Lesion: a localized area of discolored, diseased tissue

Malignant: tissue that divides and enlarges autonomously, forming a tumor or gall

Masked symptoms: virus-induced plant symptoms that are normally, but appear when the host is exposed to certain environmental conditions of light and temperature

Mildew: a plant disease in which the pathogen is seen as a growth on the surface of the host; e.g., downy mildew, powdery mildew, caused by very different fungi, but both having the name Mildew.

Mosaic: symptom of certain viral diseases of plants characterized by intermingling patches of normal green and light green or yellowish colors

Mottle: an irregular pattern of indistinct light and dark green areas

Mummy: a dried shriveled fruit

Mycelium: masses of fungal threads (hyphae) which compose the vegetative body of the fungus

Necrosis: death of tissue

Necrotic: dead or discolored brown to black

Ooze: a mass of bacterial cells usually embedded in a slimy matrix appearing on the diseased plant surface, often as a droplet; or, a flux, a viscid mass of juices composed of host and parasite substances occasionally found exuding from a diseased plant

Pycnidia: minute, usually globose and black, fungal asexual fruiting structures formed on plant surfaces

Rhizomorphs: string-like strands of fungal mycelia sometimes found under bark of trees

Ring spot: a circular area of chlorosis with a green center; a symptom of many virus diseases

Rot: the softening, discoloration, and disintegration of succulent plant tissue as the result of fungal or bacterial infection

Russet: brownish roughened areas on skin of fruit as a result of cork formation

Rust: a type of disease caused by a specific group of fungi, often producing orange-red "rust" colored spores.

Scab: a roughened crust-like diseased area on the surface of a plant organ; a disease in which such areas form

Sclerotia: tough structures produced by fungi for long-term survival.

Scorch: burning of leaf margins as a result of infection or unfavorable environmental conditions

Shot-hole: a symptom in which small diseased fragments of leaves fall off and leave small holes in their place

Signs: visible evidence of the pathogen; signs are not the same as symptoms

Spots: circular or irregular lesions on above ground tissue

Tip blight: death of shoot tips

Tumor: a malignant overgrowth of tissue

Vein banding: retention of bands of green tissue along the veins while the tissue between veins has become chlorotic

Vein clearing: destruction of chlorophyll adjacent or in the vein tissue as a result of infection by a virus or other pathogen

Wilt: loss of rigidity and drooping of plant parts generally caused by insufficient water in the plant

Witches' broom: broom-like growth or massed proliferation caused by the dense clustering of branches in woody plants

Yellows: a group of systemic mycooplasma-caused diseases often resulting in wilt, witches broom, or decline

Controlling Diseases

Control of a disease is basically aimed at suppressing the pathogen by altering one or more sides of the disease triangle. This requires knowing as much as possible about a disease. Disease forecasting would be of great value for disease control, but it requires greater knowledge of the disease situation than is available in most cases. Biological, environmental, cultural and chemical controls are all useful, but have their limitations. Thus, it is often necessary to integrate several practices to get good disease control. Plant disease control in the garden is practiced on the population level as well as on the individual plant level. All production practices have some influence on the disease situation, and the disease situation often can be changed dramatically through changes in cultural practices. People are the hardest factors to manipulate in most disease situations. Disease control is a cost to consider in gardening: financially and ecologically.

The importance of understanding the disease development process becomes obvious when considering control options. By the time symptoms are expressed, the pathogen (with few exceptions) is already inside the host plant and is relatively safe. Therefore, control efforts in most cases must occur before penetration has taken place. The overall principle in effective disease control is to keep the inoculum density of the pathogen at very low levels. Success in controlling plant disease will occur when a combination of the following methods of control are used

Avoidance -- A grower can avoid certain diseases by choice of geographic area or by choice of planting site in a local area. Diseases can be avoided by planting at a time that does not favor disease development. Using disease-free planting stock or modifying cultural practices also helps to avoid disease.

Exclusion -- A grower can inspect planting stock for signs of disease and reject or treat any which is suspect. Plant quarantines are designed to exclude certain pests from areas that are free of that pest. Elimination of insect vectors can exclude a disease.

Eradication -- Once a disease is established in an area, eradication is unlikely. However, significant reduction in disease inoculum can be attained by destroying diseased plants or alternate hosts, by rotating crops, or by certain soil treatments.

Protection -- Spraying or dusting plants with fungicides or bactericides is done to protect them from disease. Sometimes modifying the environment or cultural practices may protect the crop. Control of insect vectors will also protect plants.

Resistance -- Breeding and selection are used to develop resistant crops, and resistance can be enhanced through proper culture of a crop. Resistance is not immunity. Improper culture of a resistant variety may negate that resistance. Plants resist pathogens naturally by a variety of defensive measures, both active and/or passive. Resistance to a specific pathogen is the rule, while susceptibility is the exception. Disease resistance follows Mendelian genetic principles. Disease resistance can be either specific or general in nature.

Therapy -- Surgical removal of diseased parts of a plant will sometimes control the disease. There are a few diseases which can be treated with chemicals or heat to gain a degree of control. Familiarity with crops and the diseases and insects that affect them is useful in planning control programs. Some diseases occur every season; others occur sporadically. Some can be controlled easily by using proper methods; others must be tolerated. Knowing which problem falls into which category comes with experience.

Controlling Plant Diseases during the Resting Stage

Many plant disease organisms have a dormant or overwintering stage coinciding with plant dormancy. Where the organism overwinters and how it is disseminated have a considerable influence on the kind of control developed. The following are practical suggestions for controlling disease causing microbes at rest.

Organisms Over wintering on Soil Surface

Many organisms survive on old leaves, branches, mummied fruit, and other debris on the soil surface. Certain control measures are designed specifically to handle surface organisms.

Mulch: Placing a pine needle or leaf mulch beneath shrubs or between the rows in the garden forms a barrier which prevents organisms from moving from soil to plants. Before a new mulch is laid, all diseased debris should be removed.

Cultivation: Cultivating under fruit trees destroys old, mummied fruit and prevents the organism from reproducing and infecting the new crop.

Deep Plowing: When soil is turned four to six inches deep, organisms on the soil surface are buried so deeply that they cannot come in contact with plants.

Sanitation: Removing all old leaves and stems from beneath trees and shrubs eliminates most of the disease organisms on the soil surface. Many diseases reproduce in dead tissue on the soil surface.

Organisms Living in the Soil

Certain organisms live their entire life in the soil, and practically all soil contains parasitic organisms. Most pathogens can live in the soil from 1 to 4 years in the absence of a susceptible host. However, a few pathogens can live in the soil for 30 years without feeding. Crop rotation is a procedure in which non-host crops are used until the pathogenic organisms die out and susceptible crops can once again be grown. This works very well in areas where pathogens die within one to four years in the absence of a susceptible host. Some soil organisms attack only certain crops so these crops should not be grown in the same part of the garden each year. Resistant varieties are the only solution to soil organisms that can live in the soil for 20 to 30 years without a susceptible host. Wilt-resistant tomatoes are a good example of this kind of disease control. Always select disease-resistant vegetable varieties. Chemicals can be used to treat soil in cases where crop rotation is ineffective or when resistant varieties are not available.

Organisms Living in Dead Wood

Several diseases which attack apples, stone fruits, grapes, and many woody landscape plants live and reproduce in dead wood. Pruning all diseased and dead wood will destroy a major portion of this inoculum. Less spraying is necessary when this source of infection has been removed.

Organisms Disseminated by Wind

Many diseases are brought into the garden from great distances by the wind. The only means of controlling diseases spread in this way is to protect the foliage with chemicals. Since we do not know when the wind might blow spores into the garden, we should use protective chemicals on a regular basis. When spores are blown into the garden during dry weather, they do not germinate and penetrate the tissue, so less fungicide is needed during dry weather. Wind-blown spores need a wet surface in order to germinate. For this reason, it is best not to water the garden in late afternoon, allowing the foliage to remain wet during the night. Some spores can penetrate wet tissue in 12 to 15 hours.

Organisms in Seeds

Organisms can easily live in seed and are often spread from garden to garden in this way. For this reason, unless a unique garden variety is being preserved, gardeners should not save seeds from their garden, but should purchase seeds that were produced in parts of the country where diseases do not occur. Seedborne diseases can also be greatly reduced by using a chemical seed treatment.

Survival of Plant Pathogen

Any pathogen can cause disease under favourable conditions. The only requisite factor is that the pathogen must come in contact with the host for the development of the disease. Pathogen itself or its parts that are capable of causing disease when brought near a host is called inoculum. Fungal pathogens are diversified, where the vegetative body (hyphae), dormant mycelium, (embedded in the embryo of seeds or other plant parts), special reproductive structures (rhizomorphs, sclerotia, chlamydospores), various types of asexual spores (sporangia, sporangiospores, zoospores, conidia) and sexual spores (oospores, zygospores, resting spores, ascospores, basidiospores, *etc.),* serve as inocula. In the case of viruses and plant pathogenic bacteria, the individuals are acting as inocula, since they do not produce any special type of infective units like resting spores or endospores, *etc.* But in the case of *Streptomyces* sp. (Actinomycetes), fragments of filaments and spore-like cells serve as inocula. In phanerogamic parasites, seeds are the potential inocula.

Seeds in the soil survive for longer period. *Orobanche* seeds survive for about 13 years. Seeds are abundantly produced for their multiplication, which could attack the host plants. But dodder is an exception because broken bits of shoot can attack host plant. In any locality a time lag exists between harvest of a crop and subsequent sowing. Year after year, diseases appear in the newly sown crops. There should be some link between the previous crop and the subsequent new crop to revive or continue the life cycle. The existence of the pathogen between the two crop seasons is the vulnerable period in its life cycle. Hence knowledge of the survival ofthe pathogen in the off-season is useful for the plant pathologists to device effective control measures.

The establishment of a plant pathogen in a geographical location presupposes its ability to survive, not only during its parasitic relations with its hosts, but also during off-seasons in which the hosts are not growing. In temperate zones, plant pathogens must be adapted for survival overwinters or oversummers, like the powdery mildew pathogen that attacks fall-seeded

wheat. In the Torrid Zone, plant pathogens must be able to survive the dry seasons, during which susceptible plants are not growing.

These sources of survival of pathogens or the sources for renewal of infection chain can be grouped as follows:

1. Survival by means of specialized resting structures
2. Survival as saprophytes
3. Survival in vital association with living plants
4. Survival in association with nematodes and fungi
5. Survival in association with insects
6. Survival on agricultural materials
7. Survival on surface water

1. Survival by means of specialized resting structures

Enduring structures of plant pathogens may be as simple as conidia or as complex as perithecia. Apparently, ascospores or conidia derived from them, serve to carry the pathogen causing peach-leaf curl *(Taphrina deformans)* over the winter. Conidia of *Alternaria solani*, the pathogen of early blight of potato and tomato, survive for eighteen months in dried diseased leaves. Specialized thick-walled chlamydospores of *Fusarium* and other Imperfect fungi, spores of many smut fungi and the amphiospores, uredospores and teliospores of certain rust fungi also are important enduring structures. The resting spores of *Plasmodiophora brassicae* may survive for ten years in soils infested upon the disintegration of clubbed roots. The oospores of downy-mildew fungi survive in the soil between growing seasons. In fact, oospcres of the fungus that causes onion mildew do not germinate until several years after their formation.

Some fungi survive unfavourable seasons in the form of sclerotia. Those produced by the omnivorous cottony-rot fungus, *Sclerotinia sclerotiorum,can* survive for years in a dry atmosphere. They decay rapidly, however, in warm moist soil. Cold induced dormancy probably accounts for their ability to survive winters in temperate zones. Some powdery mildew fungi and other ascomycetes survive with plant refuse. Parasitic phanerogams survive in the form of seeds and as eggs, cysts and larvae of parasitic nematodes serve as overseasoning structures.

2. Survival as saprophytes

The ability to live saprophytically enables many plant pathogens to survive in the absence of growing susceptible plants. Saprophytic survival usually occurs in the soil. Waksman (1971)

distinguished between soil inhabitants soil invaders; the former comprise the basic fungal flora of the soil, whereas the latter are short-lived exotics. As applied to the root infecting fungi soil inhabitants are unspecialized parasites with a wide host range that are able to survive-indefinitely in the soil as saprophytes; soil invaders (root inhabiting fungi) are more specialized parasites that survive in soils inclose association with their hosts. Most plant pathogenic fungi and bacteria are soil invaders, but some pathogens, notably *Rhizoctonia solani* and *Pythium debaryanum* that cause seedling blights and root rots, live saprophytically in the soils.

The microbiological balance in the soil markedly affects the survival of saprophytic plant pathogens there. Apparently, Sanford (1926) was the first to suggests that control of potato scab by green manuring with grass might be due antagonistic action of saprophytic organisms flourishing on the green manure. Not only do soil saprophytes antagonize other microorganisms by toxic but also some such as *Trichoderma Iignorum* actually parasitize Rhizoctonia *solani* and other soil-borne pathogens. Despite antagonism and parasitisim by other organisms, many plant pathogens survive in the soil as inhabitants or invaders. The special conditions that favour biological control of plant pathogens in sterilized soil or in culture are nonexistent in field soil, in which there is a complex microflora and a low concentration of nutrients.

Certain plant pathogens survive between growing seasons as saprophytes in the dead tissues of susceptible plants. Such organisms are only incidentally associated with the soil, and live only as long as tissues of susceptible plants are available to supply nutrients. Most plant-pathogenic bacteria and many specialized parasitic fungi survive in this manner. The apple scab pathogen *(Venturia inaequalis)* lives parasitically in leaves and fruits during the growing season, but becomes saprophytic in fallen leaves. Perithecia form in these leaves during the winter, but ascospores do not form until spring. Ascospores of certain other ascomycetes mature during the winter, but are protected from adverse conditions by perithecial walls. Soil inhabitants include obligate saprophytes and facultative parasites and they are exo - pathogens. Whereas soil invaders (root inhabitants) include facultative saprophytes and obligate parasites and they are endopathogens (root infecting fungi).

Plant pathogenic bacteria can saprophytically survive or actively multiply in the rhizosphere or rhizoplane of healthy host and non-host plants. *Erwinia carotovora* subsp. *carotovora* has been considered to survive in soil. However, some recent studies have shown that soft rot *Envinia cannot* persist for a long time in fallow soil. *E. carotovora* subsp. *carotovora*

multiplies in the rhizosphere of many cruciferous plant species, where the population can readily increase from 10^2 cells/g in fallow soil to 10^4 to 10^6 cells/*g* in soil subjected to the rhizosphere effect of chinese cabbage. *Pseudomonas glumae*, the causal agent of bacterial grain rot of rice, remains on rhizosphere and / or rhizoplane of the rice plant from germination to tillering stage. *Burkholderia solanacearum* and species of *Agrobacterium* are best known with a prolonged soil phase, which can be regarded as the true soil-borne pathogens.

3. Survival in vital association with living plants

Survival of the plant pathogens in vital association with living plants is grouped into

a. Seed

The pathogen of loose smut of wheat, *Ustilago nuda tritici,* enters the stigma and style and infects the young seed, in which it survives as mycelium. The seed-infecting pathogens that cause loose smut of wheat and loose smut of barley are strikingly different from other smut fungi that attack cereal crops. Most of the others survive from season to season either in non-pathogenic association with seed or as spores in the soil. *Colletotrichum lindemuthianum,* the causative organism of bean anthracnose, can also infect the seed; unless the seed is killed, the fungus in newly sprouted bean seedlings initiates new infections. The bacteria that cause bean blights and bacterial blight of cotton survive the winter in infected seed. In Mexico, the fungus of late blight of potatoes *(Phytophthora infestans)* produces oospores but in colder regions of the world, the fungus overwinters as mycelium in diseased tubers.

Lenticels of potato tubers may carry soft rot *Erwinia* at the maximum level of 100 cells/lenticel, although the infested tubers do not necessarily develop soft rot in the field. Examples of the plant pathogenic bacteria that survive in seed/planting materials are given in the following Table 1.

Table 1. Plant pathogenic bacteria surviving in seeds and planting materials.

SI. No	**Disease**	**Bacteria**
	a. Seed	
1.	Bacterial canker of tomato	*Clavibacter michiganensis* subsp *michiganensis.*
2.	Bacterial brown stripe of rice	*Pseudomonas avenae*
3.	Bacterial blight of cotton	*Xanthomonas axonopodis* pv.

		malvacearum
	b. Planting material	
3.	Ring rot of potato	*Clavibacter michiganensis* subsp. *sepedonicus*
4.	Bacterial wilt of carnation	*Pseudomonas caryophylli*
5.	Bacterial wilt of potato and ginger	*Burkholderia solanacearum*

b. Collateral hosts

Collateral hosts are those, which are susceptible to the plant pathogens of crop plants and provide adequate facilities for their growth and reproduction of these pathogens. Weeds, which survive and live during non-cropping season provide for the continuous growth and multiplication of the pathogen. For example, the fungal pathogen for blast disease of rice, *Pyricularia oryzae* can infect the grass weeds like *Bracguarua mutica*, *Dinebra retroflexa*, *Leersia hexandra*, *Panicum repens*, etc., and survive during off-season of rice-crop. As soon as a fresh rice crop is raised, the conidia (inoculum) liberated from the weed host disseminated by wind infect the fresh rice crop. Thus the weed hosts help to bridge the gap between two rice crops. Hence the pathogen can be able to line continuously in the vicinity on these hosts inspite of the non-cropping period intervening between two cropping periods. Intensive cultivation of particular crop repeatedly and constantly also provides perpetual inoculum. Powdery mildew and viral diseases of cucurbits are also best examples, where, number of cultivated crops serves as collateral hosts.

The survival of the plant pathogens on collateral hosts/ alternative hosts which include the weed hosts also. The collateral/weed hosts which are present in the field and in the bunds harbour the plant pathogens during cropping season. But the collateral/weed hosts present in the bunds harbour the plant pathogens during off-season. The pathogens can survive in active sporulating stage on wild collateral hosts and from their wind or insect to primary inoculum. Plant pathogenic bacteria may be able to disseminate in the parasitic form on annual and perennial weeds. For example, the long-term survival of *Pseudomonas avenae* in Florida is attributed to *the* association with a perennial grass, *vasey* grass *(Paspalum urvillei), through* repeated infection of its vegetative *growth as* well *as* seed transmission. Bacterial leaf *blight* of

maize may have its origin in the infected vasey *grass* distributed in *the* field. *This* list of collateral weed *hosts* for the plant pathogens is given in the Table below:

Table: Collateral *hosts* (alternative *hosts)* of plant pathogens

Pathogen	**Disease**	**Principal *host***	**Collateral *hosts* / Alternative hosts**
	1. Fungal diseases		
Sclerospora graminicola	Downy *mildew*	Pearlmillet, Fox-tail, *Millet*	*Echinochloa* sp., *Euchlaena* sp., *Panicum* sp.
Peronosclerospora heterogoni	Downy mildew	Com	*Euchlaena* sp., *Heteropogon* sp.
P. sorghi	Sorghum downy mildew	Corn, Sorghum	*Andropogon* spp., *Euchlaena* sp., *Heteropogon contortus, Panicum trypheron*
Erysiphe cichoracearum	Cucurbit powdery mildew	Cucurbits weeds	Many cucurbitaceous
Rhizoctonia solani	Web blight	Cowpea	*Amaranthus spinosus, Aspilia africana*
	Bacterial diseases		
Xanthomonas oryzae ov oryzae	Bacterial leaf blight	Rice	Cyperus spp Leersia hexandra
Pseudomonad rubrilineans	Red stripe anad top rot	Sugar cane	Sorghum halepense S. sudanense
X. axonopodis pv. malvacearum	Bacterial blight	Cotton	Eriodendron anfructuosum, Jatropha curcas Lochnera curcas Thurbaria thespesoides
	Virus and Phytoplasma diseases		
Cucumber mosaic	Mosaic	Saffflower	Amaranthus blitum, datura

virus			metel Physalis minima Solanum nigrum
Rice tungro virus	Rice tungro	Rice	*Oryza* spp, *Echinochloa colona*, *E. crusgalli*, *Leersia hexandra*
Bhendi yellow vein mosaic virus	Bhendi yellow vein mosaic virus	Bhendi	*Hibiscus tetraphyllus*
Tomato spotted wilt virus	Ring mosaic	Groundnut	*Bidens pilosa* *Tagetes* sp.
Phytoplasma	Little leaf	BrinjaI	*Datura* sp., *Catharanthus* sp.

c. Alternate hosts

The role of alternate hosts is not important as of collateral hosts. However, when a pathogen has very wide host-range and is tolerant to wide range of weather conditions the alternate hosts become very, important source of survival of the pathogen. These alternate hosts are very important for the completion of the Iifecycle of heteroecious rust pathogens. e.g. in temperate regions the alternate host *Berberis vulgaris* of *Puccinia graminis tritici* (black/stem. rust pathogen on wheat), the barberry bush, grows side by side with the cultivated host, wheat. In such areas this wild host belonging to a different family is important for survival of the fungus. It helps in completion of heterogeneous infection chain of the rust fungus. The list of alternate hosts for important plant pathogenic survival is given in the Table 4.

Table 4. Alternate hosts of plant pathogens

Fungal pathogen	**Disease**	**Primary host**	**Alternate host**
Puccinia graminis tritici	Stem rust / Black rust	Wheat	*Barberis vulgaris*
Puccinia recondita	Leaf rust / Brown rust/ Orange rust		*Thalictrum flavum*

Puccinia coronata	Crown rust	Oat	*Rhamnus*
Puccinia anomala	Brown rust	Barley	Lily
Puccinia dispersa	Brown rust	Rye	*Anchusa* sp
Puccinia purpurea	Rust	Sorghum.	*Oxalis corniculata*
Puccinia substriata var. *penicillariae*	Rust	Pearl- millet	Brinjal
Puccinia sorghi	Leaf rust	Maize	*Oxalis corniculata*
Cronartium ribicola	Blister rust	Currant	Pine
Gymnosporangium juniperi-virginianae	Cedar rust	Cedar	Apple

d. Self sown crops

Self-sown plants, voluntary crops and early sown crops are reservoirs of many plant pathogens e.g., groundnut rust pathogen, *Puccinia arachidis* and ring mosaic of groundnut caused by tomato spotted wilt virus. Self-sown rice plants harbour the pathogen as well as vector. e,g., rice tungro virus and its vector, *Nephotettix virescens.*

Perennial crops also playa major role in the survival of the plant pathogens. Pathogens, which infect perennial plants, can survive in them during low winter temperature and/or during the hot, dry weather of the summer. They survive in the lesions on perennial host plants, which may be actively growing or are donnant. Disease like bunchy top of banana survives continuously in the suckers produced by the mother plants. In citrus canker the bacterium, *Xanthomonas axonopodis* pv. *citri* survives in the cankers formed on the leaves and twigs of the standing tree. They mostly survive in mild or vigorous active form on hosts, *Citrus* sp. Other examples are *Erwinia amylovora* and *Xanthomonas campestris* pv. *pruni.*

e. Ratoon Crops

Sometimes ratoon crop also harbour the plant pathogens e.g., sugarcane mosaic.

f. Survival by latent infection

Latent infection refers to the conditions in which the plant pathogens may survive for a long time in plant tissue without development of visible symptoms. Eg. *Pseudomonas syringae* pv. *syringae* and *X axonopodis* pv. *citri* can survive in apparently healthy bark tissues of their tree hosts. *Xylella fastidiosa,* the causal agent of Pierce's disease of grapevine and leaf scorch

disease of various fruits and leaf ornamental trees infect diverse kinds of weeds without developing visible symptoms. Because these weeds are usually favourable habitats for the vector insects, latently infected weeds become an important source of the carrier insects.

g. Survival as residents

S.No	Disease	Bacteria
1.	Fire blight of apple and pear	Erwinia amylovora
2.	Soft rot of chinese cabbage	*Erwinia carotovora subsp.carotovora*
3.	Bacterial grain rot of rice	*Pseudomonas glumae*
4.	Bacterial blight of soybean	*Pseudomonas· syringae pv. glycinea*
5.	Angular leaf spot of cucurbits	*Pseudomonas syringae* pv. *lachrymans*
6.	Bacterial canker of stone fruits	*Pseudomonas syringae pv. morsprunorum*
7.	Bacterial brown spot of bean	*Pseudomonas. syringae* pv. *syringae*
8.	Bacterial speck of tomato	*Pseudomonas syringae* pv. *tomato*
9.	Bacterial blight of cotton	*Xanthomonas axonopodis* pv. *malvaceqrum*
10.	Bacterial blight of cassava	*Xanthomonas axonapodis pv.manihotis*
11.	Common blight of bean	*Xanthomonas campestris* pv. *phaseoli*

Plant pathogenic bacteria have the capacity to grow on the surface of host and non-host plants utilizing the small amount of nutrients that are secreted on the plant surface. Survival as residents in the phyllosphere by bacteria is given below:

4. Survival in association with nematodes and fungi

Plant viruses like wheat mosaic, wheat spindle streak virus, lettuce big vein, tobacco necrosis, tobacco rattle and tobacco ring spot viruses survive with nematodes or fungi found in the soil between crop seasons. Tobacco ring spot virus is associated with the nematode, *Xiphinema americanum.* The fungus, *Polymyxa graminis (Barley yellow mosaic, oat yellow mosaic, wheat soil-borne mosaic, wheat spindle-streak mosaic)* and Spongospora *subterranea* (potato mop top) carry the viruses internally and transmit.them through their resting spore. Viruses are retained by nematode vectors for long times (stable). *Xiphinema* sp. retained viruses for a considerable Iength of *time, while Longidorus* spp *and Trichodorus* spp. retained them for

a much less period of one or two months only.

5. Survival in association with insects

Many insects are carriers of inocula during the growing season and several important plant pathogens survive between growing seasons within insects. Some bacterial plant pathogens may survive within the insect body and over winter therein. The com flea beetle, *Chaetocnema pulicaria* Melsh carries inside its body, the com wilt pathogen, *Xanthomonas stewartii and* thus helps in its overwintering. The cucumber beetles, *Diabrotica vitata* Fabr. and *D. duodecimpunctata* Oliv., which chew the plant parts affected by *Erwiniatra cheiphila* carry the pathogen inside their body, where it over winters. In the following seasons the insect passes on the bacterial pathogen to the host plant.

These insect vectors effectively transmit the bacterial pathogen causing wilt of cucurbits. It is reported that the bacterial pathogen and the -insect vectors live in a symbiotic relationship, the insects helping the bacterium with protection from adverse weather conditions and the bacterium helping the insects with a supply of some digestive enzymes while it is inside the insect's body. Plant viruses and phytoplasmas multiply within the vectors and can overwinter in those insects. Semi-persistent viruses are retained in the vectors for periods ranging from hours to days. Example, citrus tristeza virus is retained in the aphid T*oxoptera Citricida. Persis*tent viruses retain the viruses from days to week. Most of the hopper borne viruses multiply in their vectors. Viruses are retained through the moult and the vectors frequently remain viruliferous for life important. Vectors, which retain the viruses, are given below:

Leaf hopper transmitted viruses

	Vector	**Virus**
Leaf hopper	*Circulifer tenellus*	Beet curly top virus
Plant hopper	*Cicadulina mbila*	Maize streak virus
Green leaf hopper	*Nephotettix cincticeps*	Rice dwarf virus
Brown plant hopper	*Nilaparvata lugens*	Rice grass stunt virus
Hopper	*Agallia constricta*	Wound tumour virus

Transovarial transmission of the virus to the eggs of the vectors occurs and the virus can multiply within a viruliferous hopper even if the insect is feeding on an inimune host plant. Eggs carrying viruses may overwinter and provide a source of virus to infect spring crops, even in the

absence of diseased plants. Phytoplasmas attacking plants also multiply in the insects and remain infective throughout their life period. e.g. Rice dwarf virus (RDV) is transmitted through the eggs to about 60% of the progeny of the infective female leafhopper, *Nephotettix cincticeps.* RDV passes through the eggs to six succeeding generations. Clover club leaf is transmitted through 21 generations of the leafhopper vector, *Agalliopsis novel/a* over a span of five years.

6. Survival on agricultural materials

Clavibacter michiganensis subsp. *michiganensis* has been shown to survive in air-dried conditions for 7 to 8 months on the surface of wooden stakes and boxes or wires or for 15 months in air-dried tissues of diseased tomato plants.

7. Survival on surface water

Erwinia carotovora subsp. *carotovora* is detected from water from drains, ditches, streams, rivers and lakes in mountainous upland and arable areas of Scotland and Colorado throughout the year.

Dispersal of Plant Pathogens

Transport of spores or infectious bodies, acting as inoculum, from one host to another host at various distances resulting in the spread of disease, is called dissemination, dispersal or transmission of plant pathogens. It is very important for spread of plant diseases, for continuity of the life cycle and evolution of the pathogen. The spores of some fungi are expelled forcibly from the sporophore or sporocarp by a squirting or puffing action that results in successive or simultaneous discharge of spores up to a centimetre or so above the sporophore.

The seeds of some parasitic plants are also expelled forcibly and may arch over distances of several metres. These are dispersed mechanically by various means. In bacterial diseases, the bacterial cells come out on the host surface as ooze or the tissues may be disintegrated so that the bacterial mass is exposed and then dispersed by various physical and biological agencies. Insects, mites, phanerogamic parasites nematodes and human beings transmit viral diseases, which have no such organs.

The knowledge of these methods of dispersal is essential for effective control of plant diseases because possibilities of preventing dispersal and thereby breaking the infection chain exist.

The dispersal of infectious plant pathogens occurs through two ways,

I. Autonomous or direct or active dispersal

II. Indirect or passive dispersal

I. Autonomous dispersal

It is also known as active or direct dispersal. In this method the dispersal of plant pathogens (fungi, bacteria, and viruses) takes place through soil and seed or planting materials during normal agronomic operations.

1. Soil as means of autonomous dispersal

Soil-borne facultative saprophytes or facultative parasites may survive through soil. The dispersal may be by movement of the pathogen in the soil or by its growth in soil or by movement of the soil containing the pathogen. The former is known as dispersal in soil while the latter is called dispersal by soil.

a. Dispersal in soil

The following are the three stages of dispersal in soil.

i. Contamination of soil

ii. Growth and spread of the pathogen in soil

iii. Persistence of the pathogen

i. Contamination of soil

Contamination of the soil takes place by gradual spread of the pathogen from an infested area to a new area or by introduction of contaminated soil, plant debris to a new area or by introduction of infected seed or planting materials.

ii. Growth and spread of the pathogen in soil

Once the pathogen has reached the soil it can grow and spread depending on the multiplication and spread. Multiplication and spread depends on the characters of the pathogen, presence of susceptible host and cultural practices. The adaptability of the pathogen to the soil environment includes saprophytic survival ability. The survival ability of the pathogen is governed by high growth rate, rapid spore germination, better enzymatic activity, capability to produce antibiotics and tolerance to antibiotics produced by other soil microorganisms. The active saprophytic survival of facultative saprophytes and facultative parasites in soil is affected by soil structure, moisture, organic matter, pH; antagonism etc., Specialized facultative parasites (or saprophytes) can pass their life in soil in the absence of the hOst plants, but they depend more on the residues of their host plant. e.g., *Armillariel/a mel/ea, Ophiobolus graminis, Phymatotrichum omnivorumand Fusarium.* The non-specialized facultative parasites can pass

their entire life in the soil. e:g., *Pythium* sp., *Phytophthora* sp., The soil-borne obligate parasites such as *Plasmodiophora brassicae, Synchytrium endohioticum* requires the presence of active host.

Ill. Persistence of the pathogen

The pathogens persist in the soil as dormant structures like oospores *(Pythium; Phytophthora, Sclerospora,* etc.) chlamydospores *(Fusarium)* or smut spores *(Ustilago)* or sclerotia *(Rhizoctonia, Sclerotium,* etc.)

b. Dispersal by the soil

The pathogen enters the soil, grow and spread in the soil. During the cultural operations in the field, soil is moved from one place to the nearby place through the agricultural implements and irrigation, worker's feet. Propagules of fungi or the dormant structures of fungi and the plant debris containing the fungal and bacterial pathogens thus spread throughout the field.

2. Seed and seed materials as the source of autonomous dispersal

The seeds serve as medium for autonomous dispersal of pathogens. Since most of the cultivated crops are raised from seed the transmission of diseases and transport of pathogens by seeds has much importance. The dormant structures of the pathogen (e.g., seeds of *Cuscuta,* sclerotia of ergot fungus, smut sori, etc.,) are found mixed with seed lots and they are dispersed as seed contaminant. The bacterial cells or spores of fungi present on the seed coat (such as in smuts of barley, sorghum, etc.,) are transported to long distances. Dormant mycelium of many fungi present in the seed is transmitted to long distances.

This type of dispersal is highly erratic. The most important methods of dispersal of pathogen by the soil are transfer of soil from one place to another along with plant parts or propagating materials. e.g., transfer of papaya seedlings from a nursery infested with *Pythium aphanidermatum* (the cause of stem or foot rot of papaya) C311 introduce the pathogen in new pits for transplanting the seedlings. Similarly grafts of fruit trees transported with soil around their roots can transmit pathogens present in the nursery to the orchards. By this method, pathogens are not only spread from field to the field but also from district to district, State to State and often from country to country. There are three types of dispersal by seed *viz.*,

a. Contamination of the seed

b. Extemally seed - bome, and

c. Intemally seed - bome

Contamination of the seed

Seed -borne pathogens move in seed lot as separate contaminants without being in intimate contact with the viable crop seeds. The seeds of the pathogen or parasite and the host are getting mixed during harvest of the crop. In many cases, the identity ofthe seeds of the two entities (host and the parasite) is difficult to separate. e.g., smut of pearl millet *(Tolyposporium penicillariae),* ergot of rye and pearlmillet *(Claviceps purpurea* and C. *jusiformis* respectively). Smut soil and ergots mix easily with the seed lots during harvest or threshing. In many smuts such as Kamal bunt of wheat *(Neovossia indica)* and bunt of rice *(Neovossia horrida)* the infected kernels containing smut sori are mixed with the seed. In leaf smut of rice *(En tyloma oryzae)* leaf pieces containing smut sori are mixed with the seed.

Externally seed-borne

Close contact between structure of the pathogen and seeds is established in diseases like covered smut and loose smut VI Daney, snoll smut ot sorghum, stinking smut of wheat and bacterial blight of cotton where the pathogen gets lodged in the fomi of donnant spores or bacteria on the seed coat during growth of the crop or at the time of harvest and threshing. In many pathogens the externally seed-borne Structures such as smut spores can persist for many years due to their inherent capaCity for long survival. The spores of *Tilletia caries* (stinking smut of wheat) remain viable even after 18 years and those of *Ustilago avenae* (oat smut) for 13 years.

Internally seed-borne

The pathogen may penetrate into the ovary and cause infection of the embryo while it is developing. They become internally seed-borne. Internally seed borne pathogens like *Usti/ago nuda tritici* are viable for more than 15 years. Other examples include *Helminthosporium oryzae, Sclerospora graminico/a,* etc. The bacterial pathogens include *Xanthomonas oryzae* pv. *oryzae* on rice, *Pseudomonas syringae* pv. *syringae* in cucurbits, *Xanthomonas campestris* pv. *campestris* on crucifers, etc.

Mainly man distributes seeds of cultivated crops. Sometimes animals and birds also help in distribution of crop seeds. Man and animals are the main agencies of dispersal of pathogen through seed. The pathogens thus mixed with the seed or on the seed are transmitted.

Passive dispersal

Passive dispersal of plant pathogens happens through

I. Animate agents

a. Insects

b. Mites

c. Fungi

d. Nematodes

e. Human beings

f. Farm and wild animals

g. Birds

h. Phanerogamic parasites

II. Inanimate agents

a. Wind

b. Water

1. Animate agents

a. lnsects

Insects carry plant pathogens either externally or internally. Gaiiman (1950) used the terms epizoic and endozoic respectively for these two types of transmission. The external transmission of plant pathogens is of special interest in those fungi, which produce their conidia, oidia and spermatia in sweet or honey secretions having attractive' odours. Some Qfthe well known diseases of this type are the ergot, the *Sc1erotinia* brown rot of pear and apple, the honey dew stage in the 'sugary disease' of sorghum and pearlmillet in parts of India and the pycnial nectar in the cluster cup stage of rusts. The spermatial oozing at the mouth of spermagonia in the Ascomycetes attract various types of insects, flies, pollinating bees and wasps which playa dual role *viz.*, pollination and transmission' of pathogens. The fire blight organism *(Erwinia amylovora)* pathogens and citrus canker bacterium, *(Xanthomonas axonopodis* pv. *cirri)* are also carried in this manner, the former by flies (bees) and ants and the latter by the leaf miner. The black leg of potato caused by *Erwinia carotovora* is disseminated by maggots, wilt of com caused by *X. stewartii,* gummosis of sugarcane caused by *X vasculorum* are the other examples for bacterial diseases transmitted by insects.

Ingenious transmission of pathogens, of an internal nature (endozoic) is provided by the

Dutch elm disease *(Ceratostomella ulmi)* and the olive canker *(Bacillus savastano i).* The former is transmitted by the elm bark beetles and the latter by the olive fly *(Olea . europaea).* These insects, unlike the epizoic group, appear to have a close biologic relationship with the pathogens, as they have not been reared without the contaminating pathogens.

Insects spread few important plant pathogenic bacteria. The cucumber wilt bacterium, *Erwinia tracheiphila* is spread by the striped cucumber beetles *(Acalymma vitata)* and the spotted cucumber beetle *(Diabrotica undecimpunctata).* When the beetles are feeding on the diseased plant, the bacterium contaminates the mouthparts and passes into the gut of the insect. During the winter season, the bacterium overwinters inside the beetle. Thus the beetle helps the bacteria in two ways, i.e. in their transmission and survival.

Different types of insects spread more than 80 per cent of the viral and phytoplasmal diseases. The insect, which act as specific carriers in disseminating the diseases, are called insect vector.

Both aphids (Aphidae) and leafhoppers (Cicadellidae or Jassidae) in the order Homoptera contain largest number and the most important insect vectors of plant viruses. Certain species of mealy bugs and scale insects (Coccoidae), whiteflies (Aleurodidae) and treehoppers (Membracidae) in the same order (Homoptera) also transmit virus diseases. Insect vectors of plant viruses are few in true bugs (Hemiptera), thrips (Thysanoptera),beetles (Coleoptera) and grasshoppers (Orthoptera). Aphids, leafhoppers and other groups of Homoptera and true bugs have piercing and sucking mouthparts. Thrips have rasping and sucking mouthparts. All other groups of insect vectors have chewing mouthparts and they transmit only very few viruses.

Aphids

Aphids are the most important insect vectors of plant viruses and transmit the great majority of all stylet - borne viruses. As a rule several aphid species can transmit the same stylet - borne virus and the same aphid species can transmit several viruses, but in many cases the vector-virus relationship is quite specific. Aphids generally acquire the stylet-borne virus after feeding on a diseased plant for only a few seconds (30 seconds or less) and can transmit the virus after transfer to and feeding on a healthy plant for a similarly short time of a few seconds. The length of time aphids remain viruliferous after acquisition of a stylet-borne virus varies from a few minutes to several hours, after which they can no longer transmit the virus. In few cases of aphid transmission of circulative viruses, aphids cannot transmit the virus immediately but must

wait several hours after the acquisition feeding, but once they start to transmit the virus, they continue to do so for many days following the removal of the insects from the virus source. In aphid transmitting stylet-borne viruses, the virus seems to be borne on the tips of the stylets, it is easily lost through the scouring that occurs during probing of host cells, and it does not persist through the moult or egg. The examples of aphid transmitted plant viruses are given in the following Table.

S.No	Virus	Vector	Type of transmission
1.	Bean common Mosaic	*Acyrthosiphon pisum*	Non persistent
2.	Bean yellow mosaic	*A. pisum*	Non - persistent
3.	Citrus tristeza	*Toxoptera citricida*	Non - persistent
4.	Pea enation mosaic	*A. pisum*	Persistent
5.	Beet yellows	*M. Persicae*	Semi persistent

Leaf hoppers

Leaf hoppers are phloem feeders and acquire the virus from the phloem region. All leaf hoppers, transmitted viruses are circulatory. Several of these viruses multiply in the vector (propagative) and some persists through the moult and are transmitted through the egg stage of the vector. Most leaf hopper vectors require a feeding period of one to several days before they become viruliferous, but once they have acquired the virus they may remain viruliferous for the rest of their lives. Usually there is an incubation period of 1 to 2 weeks between the time a leaf hopper requires a virus and the time it can transmit it for the first time.

b. Mites

Mites belonging to the families eriophyidae (eriophid mite) and tetranychidae (spider mite) transmit plant viruses.

c. Fungi

C. Fungi

Some soil - borne fungal plant pathogens transmit plant viruses. *Olpidium brassicae, Ploymyxa graminis, P. betae* and *Spongospora subterranea* are the fungi involved in transmission of virus disease. The viruses are apparently borne in or on the resting spores and the zoospores, which upon infection of new host plants introduce the virus and cause symptoms characteristic of the virus they transmit. All these fungi are pathogens of the host, which carry of

viruses. The zoospores of the fungi are released from the host and the zoospores carry the virus and transmit it to the susceptible hosts during their infection process. In some cases plant viruses are carried on the outside of the fungi. Examples are tobacco necrosis virus and cucumber mosaic virus.

The viruses like lettuce big vein virus are found inside the zoospores. They persist for years in viable resting sporangia. The types of transmission by fungi can be considered as non-persistent and persistent transmission. The list of fungi and the virus diseases transmitted by them are given in the following table.

S.No	Fungal vector	Disease
1.	Olpidium brassicae	Lettuce big vein, Lettuce necrosis, Tobacco stunt, Tobacco necrosis satellite
2.	Synchytrium endobioticum	Potato virus
3.	Spongospora subterranea	Potato mop top

d. Nematodes

Nematodes are soil borne organisms. Some of the nematodes act as agents for dissemination of pathogenic fungi, bacteria and viruses. For example, the bacterium *Corynebacterium tritici* that causes yellow ear rot of wheat is disseminated by ear cockle nematode. Similarly, some pathogenic fungi such as, *Phytophthora, Fusarium, Rhizoctonia*, etc., are carried on the body of nematodes. Nematodes help these pathogenic fungi to enter into the host through punctures for their own entry and enter into hosts along with the nematodes. Plant nematodes play a vital role as vector in transmitting certain virus diseases. Nematode vectors transmit viruses by feeding on roots of infected plants and then moving on roots of healthy plants. Larvae as well as adult nematodes can acquire and transmit viruses, but the virus is not carried through the larval molts or through the eggs. After moulting, the larvae or the resulting adults must feed on a virus source before they can transmit again. Xiphinema, Longidorus and Trichodorus transmit both the polyhedral and tubular type of viruses. The important viral diseases transmitted by nematodes are given below:

Virus group	Virus	Vector
Tobra virus (Tobacco rattle group virus)	Pea early browning, Tobacco rattle	Paratrichodorous sp. Trichodorous spp
Nepo virus (Nematode transmitted polyhedral virus)	Grapevine chrome virus Tobacco Ringspot Tomato ringspot	Xiphinema index X. americanum X. americanum

e. Human being

Man is the most important factor responsible for short distance and long distance dispersal of plant pathogens. He helps in dissemination unknowingly by his usual agricultural practices. Human being's role in dissemination of plant pathogens is more direc of plant pathogens by human beings is known anthropochory. The ways and means by which human beings help in dispersal are as follows.

i. Transportation of seeds (Seed trade)

Seed trade is one of the different means of dispersal of plant pathogens in which man plays an important role. The import and export of contaminated seeds without proper precautions lead to movement of pathogens from one country to another or from one continent to another. Through this way pathogens of soybean and sugarbeet hither to not prevalent in India got introduced. Human agencies of individual, official and unofficial have transported new plants and plant products, the seed, the tubers, the propagating stock and fruits, which carried the plant pathogens, many times in a latent condition and which ultimately lead to the outbreaks of new diseases in places, hither to free from them. The diseases which are amenable to such transmission are mainly those that are carried in or on the propagative parts and seed such as late blight of potato, the downy mildew of grapevine, citrus canker, chestnut blight, Dutch elm disease, *Fusarium* wilt of banana, Katte disease of cardamom and buncilY top of banana. A few such diseases together with their places of origin and years and introduction are given in Table below:

Disease	Original home	Introduced country	Year of introduction
Citrus canker	Asia	USA	1907
Fireblight of apple	USA	New Zealand	1919

Powdery mildew of grape vine	USA	Europe	1845
Downy mildew of grapevine	USA	France	1878
Late blight of potato	South America	USA	1830
Panama disease of banana	Panama Islands	Bonbay	1920
Bunchy top of banana	Sri Lanka	South India	-

Many of these diseases, not very destructive in their homelands, have brought in ruin and devastation. The sale of seeds for crops badly affected by a seed-borne pathogen is a common method of dispersal of destructive pathogens e.g. loose smut of wheat *(Ustilago nuda tritici),* grain smut of sorghum *(Sporisorium sorghi),* ergot of pearl millet *(Claviceps fusiformis)* and Kamal bunt of wheat *(Neovossia indica).*

ii. Planting diseased seed materials (vegetatively propagated materials)

Planting diseased bulbs, bulbils, corns, tubers, rhizomes, cutting etc. of vegetatively propagated plants such as potato, sweet potato, cassava, sugarcane, banana, many ornamentals and fruit trees etc. help in dispersal of pathogens from field to field, orchard to orchard, locality to locality or from one country to another.

iii. By adopting farming practices

Human beings (men and women) engaged in preparatory cultivation, planting, irrigation, weeding, pruning etc. help in dispersal of plant pathogens. The fungal spores (oospores, chlamydospores), dormant structures like sclerotia are carried by worker's clothing, shoes, hand etc. from field to field. Men or women engaged in intercultivation in tobacco field spread the dreaded tobacco.

iv. Through clothing

Palm workers engaged in cleaning coconuttrees spread bud rot disease.

v. By use of contaminated implements

Pathogens are transferred from one area to another through implements used in various cultural operations (weeding, hoeing thinning etc.) in the field. e.g: root rot of pulses and cotton

(Macrophomina phaseo/ina, bacterial angular leaf spot of cucumber *(Pseudomonas /achrymans)* and bacterial canker of tomato *(Corynebacterium michiganensis).* Cutting knives and pruning knives help in dissemination from one plant to another e.g., Bunchy top of banana.

vi. By use of diseased grafting and budding materials

Grafting and budding between healthy and diseased plants is the most effective method of distribution of pathogens of horticultural crops (fruit trees, ornamentals etc.) e.g., Careless selection of stocks and scions in propagation of citrus trees.

f. Farm and wild animals

Farm animals (cattles) while feeding on diseased fodder ingest the viable fungal propagules (spores or oospores or sclerotia) into their digestive system. Animals which feed on downy mildew affected pearlmillet or sorghum take the oospores along with the fodder. Oospores pass out as such in the dung. This dung when used as manure spread in the field and act as source of inoculum. Smut fungi like grain smut of sorghum, loose smut and head smut of sorghum are carried from field to field through the alimentary canals of farm animals. Soil inhabiting fungi especially sclerotia adhere to the hoofs and legs of animals and get transported to other places. Animals passing through the tobacco fields help in transmission of TMV.

g. Birds

In general, transmission by birds is of minor importance. But this method is important in dissemination of seeds of flowering parasites and certain. fungi. Many migratory birds, such as mistle thrush *(Turdus viscivorus)* in the temperate region and the crows *(Crovos brachyrhynchos)* in the tropics, take active part in the transmission of giant mistletoe *(Dendrophthoe* spp.) either through external contamination of their beaks and feathers or internally through the alimentary canals. These birds feeding on the fleshy, sticky and gelatinous berries of giant mistletoe deposit the seeds on the other trees with the excreta.

Stem segments of dodder *(Cuscuta* spp.) are carried by birds for buildingtheir' nests. Thus the phanerogamic parasites are getting transported to new locations. Spores of chestnut blight fungus, *Endothea parasitica* are disseminated by not less than 18 species of birds. Internal transmission of this pathogen is carried out by the birds, which visit such diseased plants and get contaminated by the spores. Birds are also known to carry the spores of fungi on their, body.

h. Phanerogamic parasites

Plant viruses are transmitted from one plant to another through the bridge formed

between the two plants by the twining stems of the parasitic plant dodder *(Cuscuta* spp). Dodder is yellow vine without green leaves. In this way viruses are transmitted between plants belonging to families widely separated taxonomically. The virus is transmitted in the food stream of the dodder plant, being acquired from the vascular bundles of the infected plant by the haustoria of dodder. After translocation through the dodder phloem the virus is introduced in the next plant by the new dodder haustoria produced in contact with the vascular bundles of the inoculated plant. *Cuscuta californica,* C. *campestris,* C. *subinclusa* are usually employed for dodder transmission of viruses and phytoplasmas. C. *europaea*, C. *epilinum* and C. *lupuliformis* are also employed in transmission of viruses.

2. Inanimate agents

a. Wind

The wind dispersal of plant pathogens is known as anemochory. It is one of the most common methods of the dispersal of plant pathogens. It is the most dangerous and potent mode of travel for plant pathogenic fungi. It acts as potent carrier of propagules of fungi, bacteria and viruses. Usually the fungal pathogens are light in weight and are well adapted to wind dispersal. Some pathogenic bacteria are carried along with the infected material to short distances by wind. Damping-off pathogen *(Pythium* spp.), wart disease pathogen of potato *(Synchytrium endobioticum);* root rot pathogens *(Sclerotium* and *Rhizoctonia)* and seeds of phanerogamic parasites witchweed *(Striga)* are efficiently carried by wind. Viruses and phytoplasmas are not directly transmitted by wind, but the insect and mite vectors that carry the viruses move to different directions and distances depending upon the direction and speed of air.

The adaptations for wind dispersal in fungal pathogens include, production of numerous spores and conidia, discharge of spores with sufficient force, production of very small and light spores so that they can move to long distances. The duration and periodicity of sporulation and discharge are also important factors for wind dispersal. Some fungal pathogens causing powdery mildews, downy mildews, rusts, smuts, sooty moulds, leaf spots, blast, apple scab etc., produce large number of very light spores and conidia on the surface of the host. Uredial stages of the rust fungi travel long distances through air currents and are thus responsible for destructive epidemics over wide areas.

Wind transmission involves the upward air currents, velocity and the downward movements of wind. All are equally responsible for the spread of infection and ultimate outbreak

of diseases and have been of special significance in the rust, smut and t>last fungi. Uredospores of rust fungi have been carried to long distances, both cross-wise and upwards. Christensen (1942) and Stakman (1946) determined by exposure of Vaseline slides in the upper air through aeroplane flights, that uredospores and" aeciospores of *Puccinia gramminis tritici* could be gathered in a viable condition up to a distance of 4,200 m, above infected fields, *Alternaria* sp. at 2,400 m. and those of *Puccinia tritieina* at 3,750 m. The transmission of aecial spores of *Puceinia graminis trWei* from several groups of barberry bushes to the wheat crop showed that these spores traveled successfully over a radius of 3 kms round about these bushes. The blister rust fungus, *Cronartium ribicola,* is known to travel to a distance of 500 metres or 3,750 m. inside a plantation that the range is probably more in the open. Similar observations have been made in respect of dissemination of chlamydospores ofthe smut fungi.

In long distance dissemination with intervening stages of infection, the retention of viability of spores is an important factor that determines the extent and severity of epidemics, over wide areas. The outbreaks of cereal rusts and blast of rice are examples of such dissemination. Spores differ widely in their ability to survive long distance travel through air. Uredospores of rusts, chlamydospores or smut fungi and conidia of *Alternaria, Helminthosporium, Pyricularia* and others are well adapted for long distance travel in a viable condition and are known to play a vital role in epidemiology. The conidia of downy mildews, powdery mildews and the aeciospores and basidiospores of the rust fungi are unable to withstand such long distance dissemination when they are exposed to desiccation and direct sunshine and thus are only capable of producing local epiphytotics of limited magnitude.

The bacteria causing fire blight of apple and pear *(Erwinia amylovora)* produce fine strands of dried bacterial exudates containing bacteria and these strands may be broken off and they are transmitted by wind. Bacteria and nematodes present in the soil may be shown away along with soil particles. Wind also helps in the dissemination of bacteria, fungal spores and nematodes by blowing away rain splash droplets containing these pathogens. Wind carries insects and mites that may contain _ or are smeared with viruses, bacteria or fungal spores to short or long distances. Wind also causes adjacent plants or plant parts to rub against each other. The wound created in this manner help the spread by contact of bacteria (citrus canker), fungi, some viruses (Tobacco mosaic virus) and viroids and possibly of some nematodes.

b. Water

Transmission of plant pathogens by water (hydrochory as called by Gaiimann, 1950) is not as significant as wind transmission. Although water is less important than air in long-distance transport of pathogens, water dissemination of pathogens is more efficient, in that the pathogens land on an already wet surface and can move or germinate immediately. In case of some diseases the surface flow of water after heavy showers of rains or irrigation water from canals and wells carries the pathogens to short distances. Soil inhabiting fungi like, *Fusarium, Ganoderma, Macrophomina Phytophthora, Plasmodiophora, Pythium, Rhizoctonia, Sclerotium, Sclerotinia, Sporisorium, Ustilago, Verticillium* etc., in the form of mycelial fragments, spores or sclerotia, soil-bone bacteria and nematodes carrying viruses are transmitted through the above process. They are transmitted through rain or irrigation water that moves on the surface or through the soil.

All bacteria and the spores of many fungi are exuded in a sticky liquid and depend for their dissemination on rain or (overhead) irrigation water, which either washes them downward or splashes them in all directions.

Raindrops or drops from overhead irrigation pickup the fungal spores (uredospores of *Hemileia, Puccinia* and *Uromyces* and bacteria (bacterial blight pathogen of rice, *Xanthomonas Olyzae* pv. *oryzae;* bacterial leaf streak pathogen, *X oryzae* pv. *translucens;* citrus canker pathogen, X *axonopodis* pv. *citri;* tomato bacterial blight pathogen, *Ciavibacter michiganensis* and cotton bacterial blight pathogen, *X.axonopodis* pv. *malvacearum* present in the air and wash them downward where some of them may land on susceptible plants.

Lecture 16

Phenomenon of infection – pre-penetration, penetration and post penetration

The "infection process" can be divided into three phases: **pre-entry**, **entry** and **colonisation**. It encompasses the germination or multiplication of an infective propagule in or on a potential host through to the establishment of a parasitic relationship between the pathogen and the host. The process of infection is influenced by properties of the pathogen, the host and the external environment. If any of the stages of the infection process is inhibited by any of these factors, the pathogen will not cause disease in the host.

While some parasites colonise the outside of the plant (ectoparasites), pathogens may also enter the host plant by **penetration**, through a natural opening (like a stomatal pore) or via a wound. The symptoms of the diseases produced by these pathogens result from the disruption of respiration, photosynthesis, translocation of nutrients, transpiration, and other aspects of growth and development.

Pre Entry

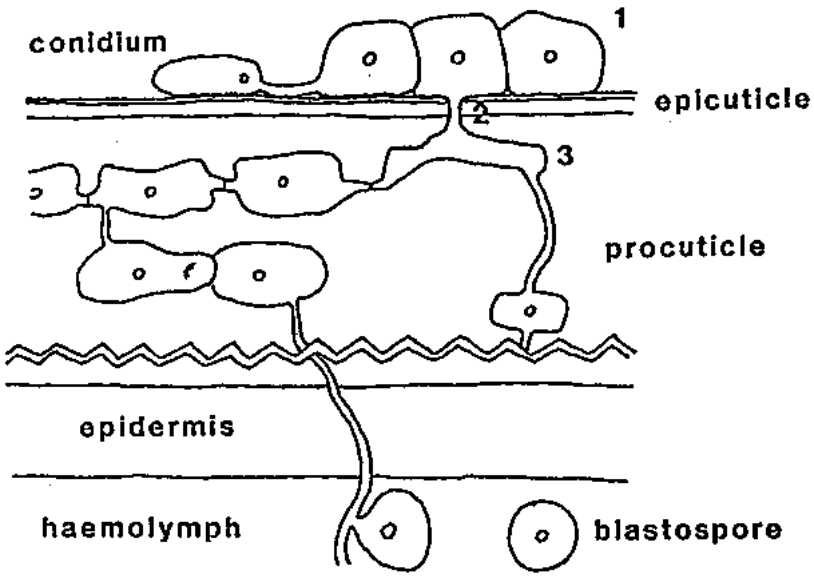
Before a pathogen can penetrate a host tissue, a spore must germinate and grow on the surface of the plant. In the case of motile pathogens, they must find the host and negotiate its surface before entering the host. Some pathogens develop specialised penetration structures, such as appressoria, while others utilise pre-existing openings in the plant's surface, such as wounds or stomatal pores. Plant viruses are often transported and introduced into the plant via vectors such as fungi or insects.

The initial contact between infective propagules of a parasite and a potential host plant is called **inoculation**. Pathogens use a variety of stimuli to identify a suitable entry point. Several fungi use topographical cues on the plant surface to guide them towards a likely stomatal site. Once the hypha reaches a stoma, volatile compounds escaping from the pore appear to provide a signal for the formation of a specialised penetration structure, the **appressorium**. Sugars, amino acids and minerals secreted by plants at the leaf surface can non-specifically trigger spore germination or provide nutrition for the pathogen. Some pathogenic spores will not germinate in the absence of these substances.

Pathogen development is influenced by temperature, moisture, light, aeration, nutrient availability and pH. The conditions necessary for survival and successful infection differ between pathogens.

Entry

Pathogens exploit every possible pathway to enter their host, although individual species of pathogen tend to have a preferred method. Fungal pathogens often use **direct penetration** of the plant surface to enter the host. This requires adhesion to the plant surface, followed by the application of *pressure* and then *enzymatic degradation* of the cuticle and cell wall, in order to overcome the physical barriers presented by the plant's surface. During the degradation of the cuticle and wall, a succession of genes are switched on and off in the pathogen, so that cutinase, followed by cellulase, then pectinase and protease are produced, attacking the cuticle, cell wall, and middle lamella in the order that they are encountered. The pressure needed for the hypha to penetrate the cell wall is achieved by first firmly attaching the appressorium to the plant surface with a proteinaceous glue. The cell wall of the apressorium then becomes impregnated with melanin, making it watertight, and capable of containing the high turgor pressure that builds up within the appressorium. The point of the appresorium that is in contact with the cuticle is called the penetration pore, and the wall is thinnest at this point. The increasing turgor pressure causes the pore to herniate, forming a **penetration peg**, which applies huge pressure to the host cuticle and cell wall.



Penetration of host cuticle by a Deuteromycetes entomopathogens
1 = appressorial complex, 2 = penetration peg, 3 = penetration plate

The alternative pathway for pathogen entry is via a **pre-existing opening** in the plant surface. This can be a natural opening or a wound. Pathogenic bacteria and nematodes often enter through stomatal pores when there is a film of moisture on the leaf surface. Fungi can also penetrate open stomata without the formation of any specialised structures. Some fungi form a swollen appressorium over the stomatal aperture and a fine penetration hypha enters the airspace inside the leaf, where it forms a sub-stomatal vesicle, from which infection hyphae emerge and form **haustoria** in surrounding cells. Also vulnerable to pathogen invasion are **hydathodes**, pores at the leaf margin that are continuous with the xylem. Under particularly humid conditions, droplets of xylem fluid (guttation droplets) can emerge at the surface of the leaf where they can be exposed to pathogenic bacteria, which then enter the plant when the droplet retreats back into the hydathode as the humidity decreases. Lenticels are raised pores that allow gas exchange across the bark of woody plants. They exclude most pathogens, but some are able to enter the plant via this route. Some specialised pathogens can also use more unusual openings, such as nectaries, styles and **ectodesmata**. Entry through a wound does not require the formation of specialised structures, and many of the pathogens that utilise wounds to enter the plant are unable to penetrate the plant surface otherwise. Most plant viruses entrer through wounds, such as those made by their insect vectors.

Colonisation

A successful infection requires the establishment of a parasitic relationship between the pathogen and the host, once the host has gained entry to the plant. There are two broad categories of pathogens are **biotrophs** (those that establish an infection in living tissue) and **necrotrophs** (those that kill cells before colonising them, by secreting toxins that diffuse ahead of the advancing pathogen). These two kinds of pathogens are also sometimes known as 'sneaks' and 'thugs', because of the tactics they use to acquire nutrients from their hosts. The toxins produced by necrotrophs can be specific to the host or non-specific. Non-specific toxins are involved in a broad range of plant-fungus or plant-bacterial interactions, and will therefore not usually determine the host range of the pathogen producing them. Necrotrophs often enter the plant through wounds and cause immediate and severe symptoms. An intermediate category of parasite is the **hemibiotrophs**, which start off as biotrophs and eventually become necrotrophic, employing tactics from both classes of pathogen.

Pathogens that colonise the surface of plants, extracting nutrients through haustoria in epidermal or mesophyll cells are termed **ectoparasites**. The haustoria are the only structures that penetrate the host cells. Some parasites colonise the area between the cuticle and the outer wall of the epidermal cells, penetrating host epidermal and mesophyll cells with haustoria. These are called **sub-cuticular infections**. Pathogens can also form colonies deeper in the plant tissues. These are **mesophyll and parenchyma infections,** and can be necrotrophic, hemibiotrophicor biotrophic relationships. Necrotrophs do not produce specialised penetration structures. Instead, they kill host cells by secreting toxins, then degrade the cell wall and middle lamella, allowing their hyphae to penetrate the plant cell walls and the cells themselves. In hemibiotrophic infections, intercellular hyphae can form haustoria in living mesophyll cells, but as the lesion expands under favourable conditions, those heavily parasitised cells at the inner, older part of the colony collapse and die. A similar sequence of events can take place in plants infected by burrowing nematodes. Viruses, mildews and rusts develop specialised biotrophic relationships with their hosts. Intercellular hyphae of downy mildew colonise host mesophyll cells and form haustoria. The mildew sporulates and the infected cells eventually die, although necrosis is delayed and contained, compared to that caused by necrotrophic pathogens. Rust fungi can also delay senescence in infected cells while they sporulate. **Vascular infections** usually cause wilting and discoloration as a result of the physical blockage of infected xylem vessels. True vascular wilt pathogens colonise the vascular tissue exclusively, although other pathogens can cause the same symptoms if they infect the vascular system as well as other tissues. There are a few pathogens that manage to achieve **systemic infection** of their host. For example, many viruses can spread to most parts of the plant, although not necessarily all tissues. Some downy mildews can also systemically infect their host by invading the vascular tissue and growing throughout the host, causing deformation, rather than necrosis. Finally, there are some pathogens that complete their entire life cycle within the cells of their host, and may spread from cell to cell during cytokinesis. These are **endobiotic infections**.

Disease Physiology

While necrotrophs have little effect on plant physiology, since they kill host cells before colonising them, biotrophic pathogens become incorporated into and subtly modify various aspects of host physiology, such as respiration, photosynthesis, translocation, transpiration and growth and development. The **respiration** rate of plants invariably increases following infection

by fungi, bacteria or viruses. The higher rate of glucose catabolism causes a measurable increase in the temperature of infected leaves. An early step in the plant's response to infection is an oxidative burst, which is manifested as a rapid increase in oxygen consumption, and the release of reactive oxygen species, such as hydrogen peroxide (H_2O_2) and the superoxide anion (O_2^-). The oxidative burst is involved in a range of disease resistance and wound repair mechanisms.

LINK to Rapid Active Defense

In resistant plants, the increase in respiration and glucose catabolism is used to produce defence-related metabolites via the pentose phosphate pathway. In susceptible plants, the extra energy produced is used by the growing pathogen.

Pathogens also affect **photosynthesis**, both directly and indirectly. Pathogens that cause defoliation rob the plant of photosynthetic tissue, while necrotrophs decrease the photosynthetic rate by damaging chloroplasts and killing cells. Biotrophs affect photosynthesis in varying degrees, depending on the severity of the infection. A biotrophic infection site becomes a strong metabolic sink, changing the pattern of nutrient **translocation** within the plant, and causing net influx of nutrients into infected leaves to satisfy the demands of the pathogen. The depletion, diversion and retention of photosynthetic products by the pathogen stunts plant growth, and further reduced the plant's photosynthetic efficiency. In addition, pathogens affect water relations in the plants they infect. Biotrophs have little effect on **transpiration** rate until sporulation ruptures the cuticle, at which point the plant wilts rapidly. Pathogens that infect the roots directly affect the plant's ability to absorb water by killing the root system, thus producing secondary symptoms such as wilting and defoliation. Pathogens of the vascular system similarly affect water movement by blocking xylem vessels. **Growth and development** in general are affected by pathogen infection, as a result of the changes in source-sink patterns in the plant. Many pathogens disturb the hormone balance in plants by either releasing plant hormones themselves, or by triggering an increase or a decrease in synthesis or degradation of hormones in the plant. This can cause a variety of symptoms, such as the formation of adventitious roots, gall development, and epinasty (the down-turning of petioles).

Lecture 17

PATHOGENESIS – ROLE OF ENZYMES, TOXINS, GROWTH REGULATORS AND POLYSACCHARIDES

The term pathogenesis means step by step development of a disease and the chain of events leading to that disease due to a series of changes in the structure and /or function of a cell/tissue/organ being caused by a microbial, chemical or physical agent. The **pathogenesis** of a disease is the mechanism by which an etiological factor causes the disease. The term can also be used to describe the development of the disease, such as acute, chronic and recurrent. The word comes from the Greek *pathos*, "disease", and *genesis*, "creation".

There are several chemical weapons secreted by pathogens that are utilized as they carry out their activities. These weapons include enzymes, toxins, growth regulators and polysaccharides.

Enzymes

Cutinases, cellulases, pectinases and lignases are often secreted by the pathogenic organism. Fungi, nematodes and bacteria are all known to produce one or more of the above enzymes in specific pathogen-host combinations. Viruses and viroids are generally not considered to secrete enzymes, although some viruses may encapsidate an enzyme in their particle.

Pathogenic organisms either continually secrete enzymes or upon contact with the host plant. As we mentioned in class on Tuesday, the first surface an organism comes into contact with is cuticle and the cell wall of the plant. As we also mentioned, the cuticle is comprised of a complex wax, cutin, which impregnates the cellulose wall. The cell wall is comprised of cellulose, which makes up the structural framework of the wall, along with the matrix molecules hemicellulose, glycoproteins, pectin and lignin. Thus, penetration into living parenchymatous tissues and degradation of middle lamella is due to the action of one or more enzymes which degrade these chemical substances. Cutinases degrade the cutin on the cuticle layer presoftening the tissue for mechanical penetration or as a first step in tissue degradation. Studies have shown that several fungi and at least one bacterial species produce cutinases. Further, evidence indicates that cutinases are continually produced, albeit in low concentrations, with degradation products often inducing even higher levels of cutinase secretion. Studies have shown that in some organisms, cutinase production may be linked to virulence. Pectic substances comprise the

middle lamella and also form an amorphous gel between the cellulose microfibrils in the primary cell wall. Pectin degrading substances often termed pectinases or pectolytic enzymes include pectin methyl esterases (PME). polygalacturonases (PG) and pectin lyases or transeliminases. Pectin methyl esterases remove small groups such as methyl groups (CH3) often altering solubility and thus affecting the rate of chain splitting by polygalacaturonase and pectin lyase. Polygalacturonases split chains by adding a molecule of water, while pectin lyases split chains by removing a water molecule from the linkage. Pectin degrading enzymes are involved in a wide range of plant diseases particularly in the soft rot diseases (Examples: bacterial soft rot due to Erwinia carotovora, leaf drop of lettuce and water soft rot of crucifers (Sclerotinia sclerotiorum) and damping off in various seedlings due to Rhizoctonia solani). Organisms such as these, as well as, elaborate pectic enzymes lead to tissue maceration. In fact, these enzymes are sometimes referred to as macerating enzymes.

Cellulases

Cellulose is the major framework molecule of the plant cell wall existing as microfibrils with matrix molecules (glycoproteins, hemicelluloses, pectins, lignins) filling the spaces between the microfibrils and cellulose chains. Cellulases have been shown to be produced by many pathogenic fungi, bacteria and nematodes. Cellulolytic enzymes play a role in softening and disintegration of cell walls. No doubt cellulolytic enzymes are involved in the invasion and spread of the pathogen, but also are instrumental in the collapse of cells and tissues. As pointed out in Agrios text, indirectly cellulolytic enzymes participate indirectly in disease development by releasing soluble sugars that may be used as nutrients by pathogens and also may be involved in the release of materials in the vascular system interfering with transport or translocation of water.

Hemicellulases

Hemicelluloses are complex polysaccharide polymers that link the ends of pectic compounds to cellulose microfibrils. Since hemicelluloses are such a diverse group of polymers such as xyloglucans, glucomannans, glactomannans, arabinoglucans, etc., several hemicellulases have been identified in many plant pathogenic fungi. The mechanism by which they participate in cell wall breakdown is not clear, nor is it known how they contribute to pathogenesis.

Ligninases

Lignin is a phenylpropanoid which is found in the middle lamella and secondary cell wall of plants. More than anything else, lignin confers the tough, woody nature to woody tissues. According to Agrios text, only about 500 species of fungi are capable of decomposing wood. Most lignin degradation is by basidiomycetes known as white- rot fungi. These fungi produce ligninases that enable the fungi to utilize lignin.

Toxins as Chemical Weapons of Pathogens

Toxins have been implicated in plant disease as far back as deBary who advanced a theory of plant disease often termed the "toxin theory". A primary tenant of the toxin theory is that a toxin elaborated by a pathogen may produce all of the symptoms of the disease. As more information was developed the theory was largely discarded. As we will see a little later in this discussion, the discovery of the toxin victorin, a host specific toxin, revived interest in the toxin theory of plant disease. Toxins may act directly on living host cells, damaging or even killing the host. Some toxins are active on a wide range of plant species (non-host-specific) or in some cases, as with the toxin victorin (host-specific).

Non-Host Specific Toxins

Tabtoxin---Pseudomonas syringae p.v. tabaci

Phaseolotoxin---Pseudomonas syringae p.v. phaseolicola

Tentoxin---Alternaria alternata

Tabtoxin

This is the toxin involved in the "wildfire disease of tobacco". In this disease, leaves exhibit necrotic spots surrounded by a yellow halo. Identical symptoms of the disease may be induced by culture filtrates of the organism or purified toxins with symptoms identical to that of wildfire of tobacco. Similar effects may also be observed on a relatively wide range of hosts, thus making the toxin non-host specific. Tabtoxin chemically is a dipeptide composed of the amino acids threonine and tabtoxinine. In the cell tabtoxin is cleaved releasing the tabtoxinine moiety which is the active toxin. The inhibition of the enzyme glutamine synthetase is the primary mode of action of the toxin.

Phaseolotoxin

This is the toxin involved in one of the bacterial bean blights called "halo blight". Symptoms of the disease incited by the bacterium can be produced by the toxin alone.

Chemically the toxin is a tripeptide of ornithine-alanine-arginine with a phosphosulfinyl group. Within cells the toxin is enzymatically cleaved releasing phosphosulfinylornithine which is the toxic moiety. Cellular affects are a result of the inactivation of the enzyme ornithine carbamoyl-transferase.

Tentoxin

This is the toxin produced by Alternaria alternata. The disease induced by this organism is primarily a seedling disease in a wide range of plant species. Seedling death results when greater than one-third of the leaf area become chlorotic, and reduce vigor with less than that amount of leaf chlorosis. The toxin is a cyclic tripeptide that binds to and inactivates a chloroplast-coupling factor protein involved in energy transfer and also the inhibition of light dependent phosphorylation of ADP to form ATP.

Host-Specific Toxins

The idea that toxins play causal roles in plant diseases is attractive and dates back to the time of deBary. A very good reference on the role of toxins in plant disease is the following: "Microbial Toxins in Plant Disease" by Harry Wheeler and H. H. Luke published in Annual Review of Microbiology, Vol 17, 1963. This review gives an excellent account of the discovery of host-specific toxins. When one reduces the toxin theory to its most elementary form, it can be stated that all of the symptoms of a given disease result from the direct action of a toxic product of the pathogen in that disease. Tenents of this theory can be tested by the following criteria:

a) the toxin, applied at concentrations which could be reasonably expected in or around the diseased plant, produces in a susceptible host all the symptoms characteristic of the disease;

b) the pathogen and the toxin exhibit similar suscept (host) specificity

c) the ability of the pathogen to produce the toxin varies directly with its ability to cause disease

d) a single toxin is involved.

The first toxin isolated that fulfilled the above criteria was that produced by Cochliobolus (Helminthosporium) victoriae. "Helminthosporium leaf blight of oats appeared in 1945 with the introduction and widespread use of the oat variety Victoria' and its derivatives which contained the Vb gene for resistance to the crown rust disease. In the victoria lines, the infects the basal portions of plants, and as it infects, the fungus elaborates a toxin that is carried to the leaves, causing a severe leaf blight, and death of the plant. All other oat varieties and other plant species are either immune or sensitivity to the toxin was proportional to their susceptibility to the

fungus. In addition to the toxin producing external symptoms identical to that induced by the pathogen, internal biochemical and histochemical induced by the toxin are identical to that induced by the pathogen.

Chemically, the toxin is a complex chlorinated cyclic pentapeptide. Ultastructural studies demonstrate the primary target of the toxin is the plasma membrane. Here, it apparently binds to proteins and in some yet to be determined mechanism alters the metabolism of susceptible cells

T-Toxin

This is another good example of a host-specific toxin. The toxin is produced in common corn disease "Southern Corn Leaf Blight" incited by the fungus Cochliobolus heterostrophus formerly known as Helminthosporium maidis. T-toxin is produced by race T of the fungus that first appeared in the United States in 1968. By 1970, severe losses occured throughout the corn-belt in corn that carried the Texas male-sterile (Tms) cytoplasm. Corn varieties with normal cytoplasm were found to be resistant to the fungus and also to the toxin. The toxin, chemically, is a mixture of linear, long polyketols with 35 to 45 carbon atoms. The toxin specifically affects mitochondria of susceptible cells where ATP synthesis is inhibited.

Hc-Toxin

One other example of a host-specific toxin in the HC-Toxin produced by the fungus Cochliobolus (Helminthosporium) carbonum which incites a leaf spot disease in corn. The toxin is specific to only certain maize (corn) lines. The mechanism of action of the toxin is poorly understood at the present time, although the molecular and biochemical basis for resistance is well understood

Growth Regulators as Weapons

As you know, plant growth is the result of three factors: cell divisions, cell elongation and cell differentiation. Plant growth is controlled by a group of naturally occurring compounds with hormonal action that are often referred to as plant growth regulators, plant growth hormones, etc. The major groups of plant growth regulators are the auxins, gibberellins, kinins and ethylene. Plant growth regulators are not unlike any hormone, in that, they act is very small concentrations, with slight changes in the normal level resulting in profound changes in the growth pattern of the plant. Pathogens often cause an imbalance in the hormonal system by causing the infected plant to produce more or less hormone, or in some cases the pathogen itself elaborates hormone thus changing the hormone level. Some of the commonly observed

symptoms related to effects on plant growth regulation are: stunting, overgrowths, galling, root branching, adventitious root formation, defoliation, rosetting, leaf epinasty, etc.

Auxins

Auxins are the major growth regulator in plants and are defined as growth regulators whose major mode of action is cell elongation; they resemble indole-3-acetic acid in their activity. The naturally occurring auxin is indole acetic acid (IAA). Increased levels of auxin occur in plants infected with fungi, bacteria, viruses, molicutes and nematodes. Following are a few important diseases directly related to altered auxin levels:

Corn smut (Ustilago maydis), clubroot of crucifers (Plasmodiophora brassicae), southern bacterial wilt (Rolstonia solanacearum formerly Pseudomonas solanacearum, crown gall (Agrobacterium tumefaciens) good examples of diseases where altered auxin levels have been implicated in disease.

Gibberellins

A century ago, rice farmer in Asia noticed some exceptionally tall seedlings growing in their paddies. Before these rice seedlings could mature and flower, they grew so tall and spindly that they toppled over. In Japan, this aberration in growth pattern became known as *bakanae* (`foolish seedling disease') disease of rice. In 1926, Kurosawa, a Japanese scientist discovered that the disease was caused by a fungal pathogen, *Gibberella fujikuroi*. By the 1930s, Japanese scientists had determined that fungus produced hyper-elongation of rice stems by secreting a chemical, which was given the name gibberellin. Gibberellins are normal constituents of green plants and also produced by several other microorganisms. The best known gibberellin is gibberellic acid. In the past years, scientists have identified more than 80 different gibberellins, many of them occurring naturally in plants. Spraying of diseased plants with gibberellin overcomes some of the symptoms (stunding) caused by several virus- or mollicute-pathogens indicating that gibberellin involves in disease development.

Ethylene

Ethylene production in infected tissues can be dramatically induced. This induction is largely dependent on activation of the ethylene biosynthetic pathway in plant tissues. Genes encoding several key enzymes involved in the ethylene biosynthesis are highly activated at the transcriptional level. It has not been shown that ethylene is produced directly by plant pathogenic fungi and bacteria.

Ethylene has been considered as a signal in plant for wounding and senesces responses. Recent studies show that ethylene together with another signal component jasmonic acid may plays an essential role in plant defense responses of several pathosystems.

- Induced ethylene production in infected tissues.
- Ethylene induces expression of certain types of PR-genes and some signal components involved in defense signaling.
- Ethylene insensitive mutants block several PR-gene-expression.
- Ethylene insensitive mutants can be beneficial against some pathogens but deleterious to resistance against other pathogens in a specific a gene-for-gene manner.

Other chemical weapons include polysaccharides, plant defense suppressors, transporters etc.

Plant viruses and viroids are not known to produce any substances themselves, but they adapt, induce and manipulate the host metabolism to replicate themselves

Lecture 18

DEFENSE MECHANISM IN PLANTS - STRUCTURAL AND BIO-CHEMICAL (PRE AND POSTINFECTION)

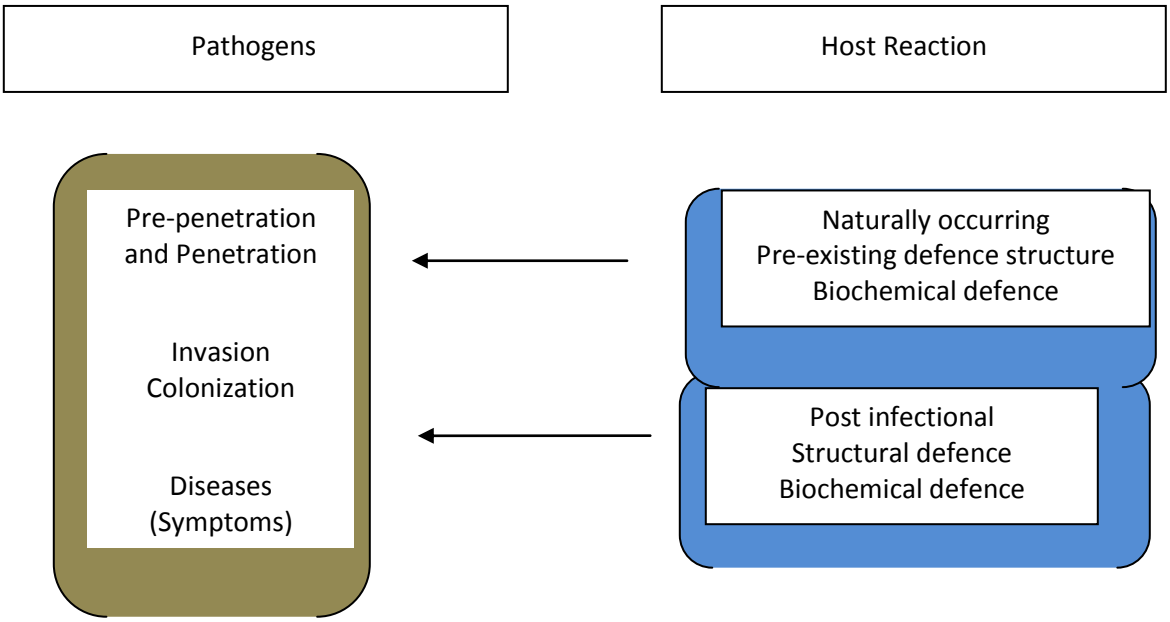
Introduction

Adjustment is probably, one of the most important virtue of a system that ensures it survival, be it host or parasite. On planet earth, the green plants (autotrophs) constitute the only biological system capable of converting solar energy (electro-magnetic radiations) into chemical energy. Plants as a biological system resist this exploitation, at all levels and by all means.The co evolution, forced by co-existence with pathogen, has led to development of defence mechanism in plants.

Thus, resistance against any 'deleterious act' has become a natural and universal response of plant system. The resistance against parasites/pathogen is the heritable trait of plants by virtue of which they resist attack by parasites/pathogens or their activities. The defence mechanism(s) has ensured the survival of plants in spite of living amongst some of the potentiality devastating pathogens in addition to abiotic stresses. Plants have also developed ability to resist/tolerate various abiotic stresses.

Pathogenesis and Host Response

Analysis of most of the host parasite relationships reveals that on the pattern of pathogenesis, the plants on their part, do exhibit defence mechanisms (structural and cnemical) as soon as challenged by the pathogen. The moment pathogen propagules come in contact with host surface. the plants due to hereditary characters have several naturally occuring physical and chemical barriers (preexisting) resisting penetration, and if at all the penetration occurs, the host reacts by different means resulting in formation of physical and chemical barriers. These two conditions are discussed in picture below:



Defense Mechanisms: Pre-existing or Passive

A Pre-existing Structural Defenses

The first line of defence in plants is present in its surface. Several characters of the plants surface function as barriers to penetration which pathogen must breach to enter the host. The pathogens enter the plant host by penetrating the epidermis along with cuticle and cuticular wax and number of natural openings existing before the onset of the pathogenesis can obstruct penetration.

If the pathogen succeeds in penetration; it encounters pre-existing internal structural barriers. The external and internal structural barriers existing before pathogen attack are also called Pre-existing defence structures or passive/static or anit-infection structures.

Wax and cuticle

The cuticle covers the epidermal cells of plants and consists of pectin layer, a cutinized layer and a wax layer. Cutin is composed of fatty acids. Waxes are mixture of long chain aliphatic compounds which prevent the retention of water on plant surface essential for spore germination. A negative charge usually develops on leaf surfaces due to fatty acids. This condition repels air-bone spore / propogules. Only few pathogens are known to dissolve cutin enzymatically. Examples: *Monilinia fructicola* penetrates cuticle of cherry leaves but not of

Gingko biloba leaves; the latter contains abundant cutin than the former. *F. solani f* sp. *Pisi* produces the enzyme cutinase production by specific antibodies and inhibitors.

Epidermal layer

Epidermis is the first layer of living host cells that comes in contact with attacking microbes. The toughness of epidermis is due to the polymers of cellulose, hemicelluloses, lignin mineral substances, polymerized organic compounds, suberin etc. Potato tubers resistant to Pythium debaryanum contain higher fibre. Silicon accumulation in epidemal walls provides resistance against fungal attack. Suberization of epidermis confers protection against plant Xanthomonas axonopodis pv. Citri because of broad cuticulat lips covering the stomata. A functional defence mechanism has been observed in some varities (cv-Hope) in which stomato open late in the day when moisture on leaf surface has dried and the infection tunes have become non fuctional.

Hydathodes are natural openings on the edges of leaves and serve to excrete excess water from the interior. They are easy entry pints of bacterial pathogens such as *X.capestris pv. capestis* (black rot of cabbage), Similar to hydathodes are the **nectarthodes** in inflorescence of many plants. They secrete sugary nectar and this serves as barrier to those organisms that cannot tolerate this condition and thus, can enter through nectarines. Leaf hairs on leaves and on nectarines also resist entry of pathogens. High hairlines of leaves and pods in chickpea is resistant character against *Ascpchyta rabei*. Groundnut varieties showing resistance to Cercospora leaf spots have thick epidemis-cum cuticle and compact paslisade layer, few and smaller stomata and high frequency or trochomes on the abaxial surface of leaf.

Lenticles are opening in outer walls involved in gaseous exchange. They are weak points in defence unless the cork cells within them are suberized. After suberizatoin and periderm formation, lenticels are more resistant to invasion by pathogens.

Pre-existing biochemical defence

Plants liberate different chemicals, which interfere with activities of the pathogen and pathogenesis, thereby preventing or reduce infection. These chemicals and the biochemical conditions that develop may act either directly through toxic or lytic effect on the invader or indirectly through stimulating antagonistic plant surface microflora. The compounds pre-existing in plants as **constitutive antibiotics** and those, which are formed in response to wounds as **wounds antibiotics**.

Release of anti-microbial compounds

Plants while growing and developing release gases as well as organic substances, from leaves and roots (leaf and root exudates), containing sugars, amino acid, organic acids, enzymes, glycoside etc. These materials have profound effect on the nature of surrounding environment, particularly the phyllosphere, rhiizosphere microflora and fauna. Although these substances are ideal nutrients for microbes and help in germination and growth of several saprophytes and parasites number of inhibitory substances is also present in these exudates. Theses inhibitory substances directly affect the microorganism, or encourage certain groups to dominate the environment and function as antagonists of the pathogen.

Inhibitors present in the plant cells

In many host-parasite interactions, pre-existing toxic substances in the cells form the basis of resistance. In resistant variety these substances life in abundance while in susceptible variety they may be less or completely absent. Several phenollic compounds, tannins and some fatty acid like compounds such as dienes pre-exisitg in high concentrations in cells have been implicated for the resistance or young tissues to parasitic fungi such as Botrytis. Many such compounds are potent inhibitors of many hydrolytic enzymes. Several other types of preformed compounds such as saponins (glycosylaled steroidal or triterpenoid compound) tomatine in tomato and avenacin in oats, have antifungal membranolytic activity. The fungal pathogens which lack enzymes (saponinases) that breakdown the saponins are prevented from infecting the host. Several preformed plant proteins have been reported to act as inhibitors of pathogen proteinases or of hydrolytic enzymes. Similarly lactins (proteins that bind to certain sugars) cause lyses and growth inhibition of many fungi. Plants surface cells also contain variable amounts of hydrolytic enzyymes such as glucanases and chitinases, which may cause breakdown of pathogen cell wall components.

Lack of essential factors

Recognition factors

The first step in infection process is the cell-to-cell communication between host and pathogens. Plants of species or varieties may not be infected by pathogen if their surface cells lack specific recognition factors. If the pathogen does not recognize the plant as one of its hosts it may not adhere to the host surface or it may not produce infection substances such as enzymes,

or structures (appresoria, haustoria). These recognition molecules are of various types of oligosaccharides and polysaccharides and glycoproteins.

Host receptors and sites for toxins

In many host parasite interactions the pathogen produces host specific toxins, which are responsible for symptoms and disease development. The molecules of toxin are supposed to attach to specific sensitive sites or receptors in the cell. Only the plants that have such sensitive sites become diseased

Essential nutrients and growth factors

The fact that many facultative saprophytes and most of the obligate parasites are host specific and sometimes are so specialized that they can grow and reproduce only on certain varieties of those species suggests that for these pathogens the essential nutrients and growth factors are available only in these hosts. Absence of these nutrients and stimulus make the other varieties and species unsuitable hosts.

Defence mechanism: Induced or active

Plants have to face the wide variety of pathogens (enemies) standing at a place. Thus a strategically designed pre-existing (structural and biochemical) defence mechanism in plants exists. The real value of this system has not been critically examined. It appears that these pre-existing defence mechanisms help plants in warding-off most of microbes as nonpathogens. But it does not seems t be sufficient.

The induced/active defence mechanism in plants may operate at different levels

- Biochemical defence
- Defence at cellular level
- Defences at tissue level

The activation or induction of defence mechanism may be both specific and non-specific type. Several structural changes are known to be induced by a range of biotic or abiotic elicitors. These dynamic defence mechanisms prevent further colonization or spread of pathogen. Active defence in plants involves cellular defences that rely upon preformed surveillance systems are encoded by resistance genes. The receptor-proteins are strategically located in cell membrane to detect the pathogen or factor translocated by pathogens. The ability of plant to mount an active defence response is again under genomic control.

Disease occurs when

1. Pre-exisiting defence mechanism are not enough to check the entry of pathogen
2. A pathogen avoids timely eliciting active defence system in plant tissue or habits active defence response by secreting metabolic toxins.

Induced structural defence

Induced histological defence

Even after the establishment of infection in plant cells, the host defence system tries to create barriers for further colonization of tissues. This may be at various levels.

Lignifications

Lignified cell wall provide effective barrier to hyphal penetration. They also act as impermeable barrier for free movement of nutrient causing starvation of pathogen.

Following are examples.

Radish: Peronospora parasitica, Alternaria japonica

Potato: Phytophtora infestans

Wheat: Septoria nodorum

Cucumber: Cladosporium cucumerium, Colletorichum lagenarium

Carrot: Botrytis cineria

Suberization

In several plants the infected cells are surrounded by suberized cells. Thus, isolating them from healthy tissue. Corky layer formation is a part of natural healing system of plants. eg. common scab of potato and rot of sweet potato are good examples.

Abscission layers

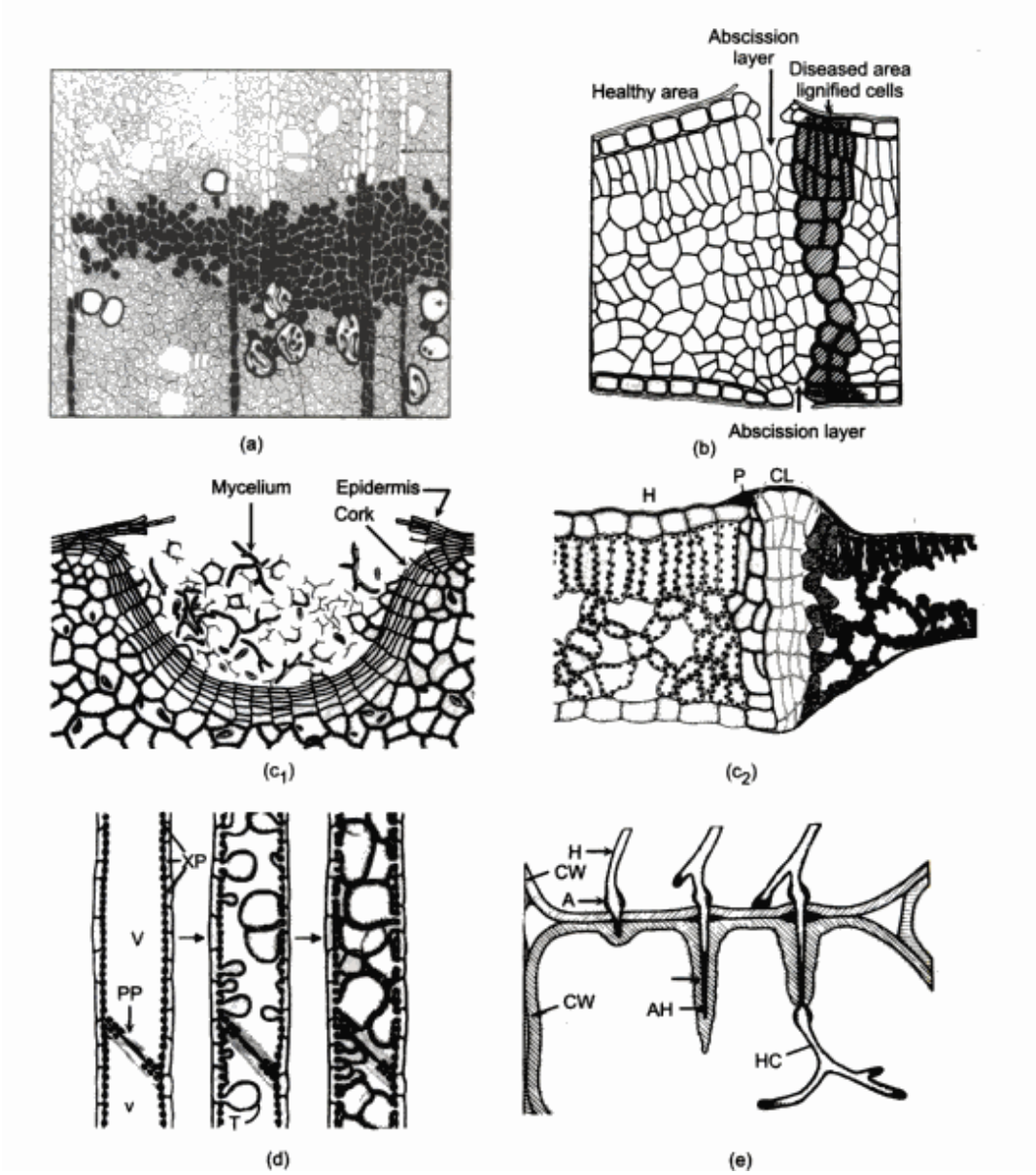
It is a gap between host cell layers and devices for dropping –off older leaves and mature fruits. Plant may use this for defence mechanism also. I.e. To drop-off infected or invaded plant tissue or parts, along with pathogen. Shot holes in leaves of fruit trees is a common feature

Tyloses

The tyloses are formed by protrusion of xylem parachymatous cell walls, through pits, into xylem vessels. The size and number of tyloses physically block the vessel. The tyloses are inductively formed much ahead of infection, thus blocking the spread of pathogen. It suggests biochemical elicitors and movement of tyloses inducing facto (TIF) up the stem. eg. Sweet potato: *Fusarium oxysporum f. sp. Batatas.*

Gum deposition

The gums and vascular gels quickly accumulate and fill the intercellular spacis or within the cell surroundings the infection thread and haustoria, which may starve or die.



Mechanism of host resistance

a. Lignification b. Abscission layer formation. C_1 & C_2 Cork layer formation, d. Tyloses formation and e. Sheathing of infection threads

Induced cellular defence

The cellular defence structures, ie. Changes in cell walls, have only a limited role in defence. Following types are commonly observed.

1. Carhohydrate apposition (synthesis of secondary wall and papillae formation)
2. Callose deposition (hyphal sheathing just outside plasma lemma around the haustorium which delays contact of pathogen (Phytophythora infestans) with host cells.
3. Structural proteins
4. Induced cytoplasmic defence that present last line of host defence and may effective against slow growing pathogens, weak parasites or some symbiotic relationship.

Induced biochemical changes

The induced biochemical changes in host plants are the last line of host defence. This may condition a plant or plant tissue from susceptible to resistant to immune status as per their genetic potential. The role of bio chemical factor in host defence is based on the following four attributes:

1. The substance is associated with protection against disease at the site where protection occurs.
2. The substance can be isolated from the host showing protection against the disease.
3. Introduction of isolated substance to the appropriate susceptible host confers protection.
4. The nature of protection so induced resembles that of the natural agents of a resistant plant.

Toxic substances produced

Rapid production/suitable modifications and/or/ accumulation of chemicals toxic to pathogen upto effective concentrations is an important component of overall active defence strategy of plants. Slow production or accumulation or low levels of similar chemicals have reported in susceptible host plants also.

Role of phenolic compounds

The phenolic compounds, viz., chlorogenic acid caffeic acid and ixidation products of floretin, hydroquinone hydroxyquionones and phytoalexins are main toxi chemical produced to inhibit pathogen or its activities. Some of these are performed toxic chemicals while others may be de novo synthesized or modified to more toxic forms. The enzymes involved in chemical pathways are present in host cell (pre-existing).

Role of phytoalexins

Most common response of plants to stress, biotic (phytoalexins/insects) or abiotic (wounding), is the production and accumulation of substrates that can inhibit the growth and

activities of the biotic factors or may help in healing process. Muller and Borger proposed the concept of phytoalexins in their study on hypersensitive reaction of potato to avirulent P.infestans strains. Phytoalexins are antibiotics produced in plant pathogens interactions or as result reposnse to injury or other psychological simulation.

Role of new protein synthesized

Post-infectional changes in host cells involve production and modification of large number of proteins (structural and enzymatic), which have important role in defence mechanism. The enzymes are required for various synthetic pathways (normal or modified) for production of resistance related substances. In addition, phenol-oxidizing enzymes have vital role. The influence of these changes may be confined to infection site or nearby cells. Increased synthesis and activity of phenyl ammonia lyase (PAL) has been reported in several bacterial and vital pathogens in resistant reaction. PAL plays key role in syntheses of phenols, phytoalexins and lignin. The effectiveness of resistance depends on speed and amount of synthesized products and their movements to neighboring healthy tissues to create defensive barriers.

Inactivation of enzymes and toxins

The role played by chemical weapons (toxin and enzymes) of pathogens during pathogenesis is well established. The necrotrophs and hemihiotrophs employ more of these substances fro causing those tissue damage as compared to speacialized obligate parasites. The defence strategy of resistant plants, through activity of phenols, tannins and protein as enzymes inhibitors, the phenolics are not anti-fungal but make pathogen ineffective by neutralizing their enzymes. In immature grape fruits catechol-tannin is known to inhibit enzymes produced by Botrytis cinerea.

Toxins are known to be involved in pathogenesis to various edtents (pathotoxins/vivotoxins). The resistance to toxins, in host, will be resistance to pathogens. This can be achieved by detoxification or lack of receptor sites for these toxins

Role of altered biosynethetic pathway

The pose inflectional metabolism of host tissue is altered (stress physiology) to cope with the advancing activities of pathogen. New enzymes (proteins) are produced in an effort to synthesize defence related substances. Most of these compounds are formed through Shikmic acid pathway and modified acetate pathway. Respiration in diseased tissue is invariably

increased; a part of glycolysis is replaced by pentose pathway, which yields four carbon compounds are formed through Shikmic acid pathway and modified acetate pathway. Respiration in diseased tissue is invariably increased; a part of glycolysis is replaced by pentose pathway, which yields four carbon compounds. It is possible that in early stages of infection the gene regulation of host cell is influenced and some specific genes.

Active defense to pathogens

Induction of host resistance, structural or biochemical seems to be universal I plants. Active defense responses have been reported against all classes of pathogens (fungi, bacteria, viruses and nematodes). Active defense response may lead to incompatible host-pathogen interaction

Summary of induced biochemical defense reactions

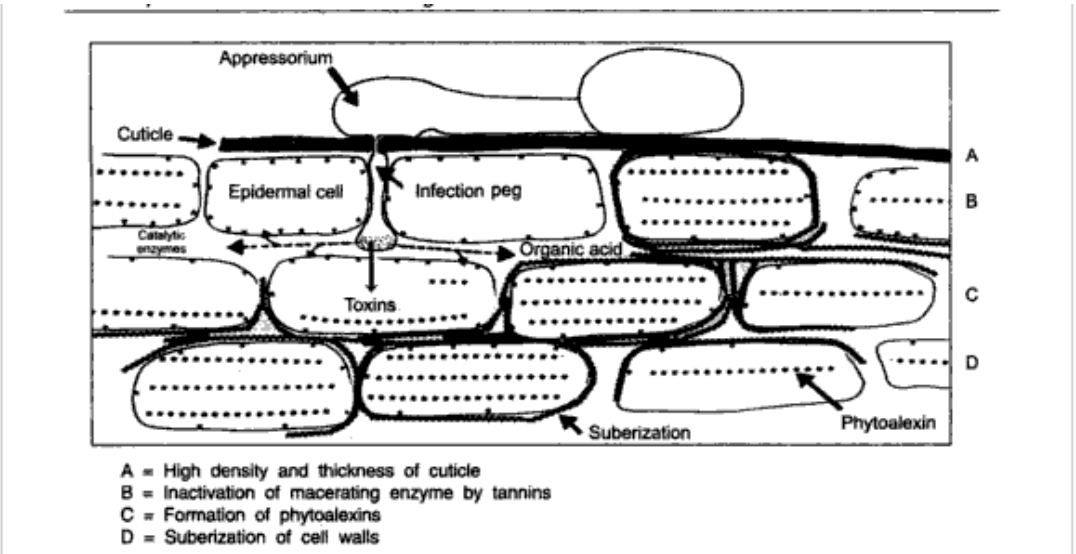
1. On entry of the pathogen, a temporary increase in cellular metabolic activities occurs in the host. Due to stress caused by increased metabolic activity cells die rapidly showing hypersensitive reaction. Rapid death of cells in correlated with increased degree of resistance in most diseased systems.

2. When the infected tissue are reaching the nectotic stage, metabolism of neighboring tissues is also increased and phenolics and other compounds are accumulated. In this process, the synthesized compounds move from healthy to diseased tissues.

3. The reactions expressed by hypersensitivity form common phenols, phytoalexins, and other abnormal substances. The oxidized products of phenolics may detoxify the toxins or inactivate other weapons of the pathogen.

4. When spread of the pathogen is checked, the neighboring healthy tissues with accelerated metabolic activities try to isolate the damaged parts by forming new tissues and eliminate the disease/pathogen.

Host defence, pre-existing or induced, is a multi-component strategy where several factors work together to fashion the final outcome. Figure below represents a case where more than on factors are responsible to condition resistance in immature grapes berries against Botrytis cinerea.



Multi component defense mechanism in young grapevine berries against *Botrytis cincerea*

Systemic acquired resistance

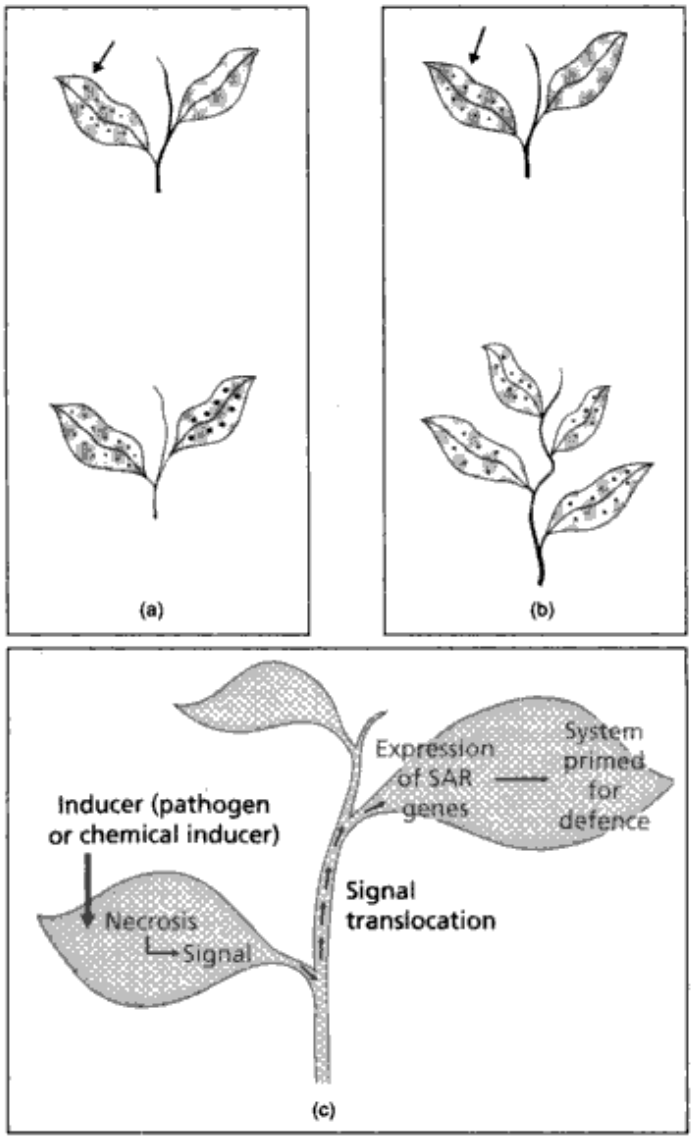
Induced resistance (cross protection) in plants is a phenomenon of significance, which has not been properly exploited for plant disease management, probably because of our poor understanding. Induced resistance,, localized or systemic, may be specific. The signal molecule, that propagates the resistance to distant places are vital in systemic induced resistance. The resistance is induced in manner comparable to immunization in mammals but the mechanism differs.

The resistance may be induced due to any of the following:

- ✓ Accumulation of PR proteins
- ✓ Activation of lignin synthesis
- ✓ Enhanced peroxidase actitivity
- ✓ Suitable changes in plant metabolism

Principle of induced resistance

Induced resistance is a phenomena where a lead treated with certain chemicals or inoculated with pathogen's avirulent strain produce a signal compounds that is transported systemically throughout the plant and activities its defence mechanism (making the entire plant resistant to subsequent infection) without its own physical presence at the site. The picture below explains a hypothetical mode to explain induction of SAR.



Representation of acquired resistance a) Local b) Systemic c) SAR

Lecture 19

Plant disease epidemiology – Meaning and importance, difference between simple and compound interest diseases – Factors affecting plant disease epidemics – host, pathogen, environment and time factor

Edpidemiology or epiphytology is the study of the outbreak of disease, its course, intensity, cause and effects and the various factors governing it. Based on the occurrence and geographical distribution they are classified as follows:

Endemic or Enphytotic

When a disease is more or less constantly occurring year after year in a moderate to severe form in a country or locality then it is called as endemic disease. eg: wart disease of potato (Synchytrium endobioticum) is endemic in Darjeeling, citrus canker (Xanthomonas axonopodis pv citri)in Asia and sorghum rust (Puccinia purpurea).

Epidemic or Epiphytotic

It is a sudden outbreak of a disease periodically over a widespread area in a devastatingly severe form causing severe losses or complete destruction. This is constantly present in a locality but it assumes severe form only on occasions. This is because of the occurrence of favorable environment responsiblefor the rapid development of disease. eg: wheat stem rust (Puccinia graminis tritici) and powdery mildew (Erysiphe graminis vor tritici), late blight of potato (phytophthora infestans), red rot of sugar cane(Colletotrichum falcatum), downy mildew of grapevine(Plasmophora viticola) and rice blast (Pyricularia oryzae).

Certain disease are endemic in one area and become epidemic in another area. Eg: Citrus canker is endemic in Asia but epidemic in the introduced place, Florida (U.S.A).The downy mildew of corn is a endemic disease in India but became epidemic in the Philippines.

Pandemic

When an epidemic disease spreads over continents or subcontinents and involves mass mortality it is considered as pandemic. The outbreak of black stem rust of wheat in India during 1947 is best example for a pandemic disease.

Sporadic

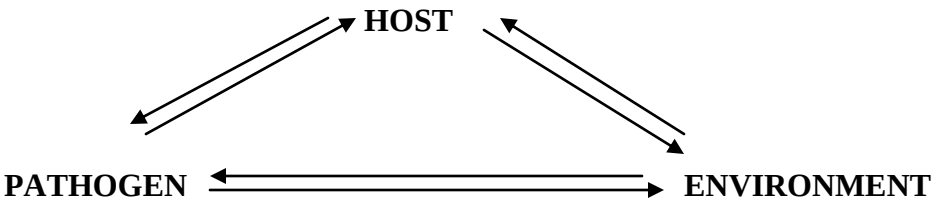
Diseases which occur at irregular intervals over limited areas or locations are called sporadic. They occur relatively in few instances. Eg: Fusarium wilt of cotton (Fusarium

oxysporum f sp. vasiinfectum) grain smut of sorghum (Sporisorium sorghi) and loose smut of wheat (Ustilago nuda).

An epidemic may cause widespread and mass destruction of crop in a short time or may persist for long periods depending upon the three following factors responsible for the disease:

1. Host
2. Pathogen and
3. Environment

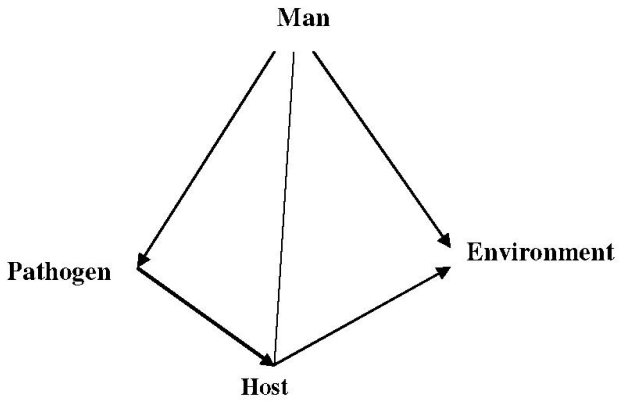
Environment flow chart



Pathogen

A course of epidemic in nature differs with the nature of the host, the pathogen and the environment. In arecanut the Koleroga fungus, *Phytophthora arecae* become destructive during monsoon period (July-Sep) and wanes away with rising temperatures and dry conditions. The above disease once again become destructive during rainy season. This type of epidemic is known as seasonal epidemic or annual epidemic. Outbreak of *Phytophthora* wilt of betelvine occurs during rainy season in South India. In temperate zone peach leaf curl and apple scab follow the similar course.

Epidemics caused as a result of introduction of new pathogens in the locality hither to free from them, appear in two phases viz., destructive phase and innocent phase (due to biologic equilibrium reached between new comer pathogen and the original inhabitant). The well known epidemics of late blight of potato in Europe and blast disease of rice in South East Asia, powdery mildew and downy mildew of grapevine in Europe, leaf rust of coffee in Sri Lanka and anthracnose of grapevine in India are examples of this category. In the above diseases the pathogens after taking heavy toll of the crops have settled down.



Factors governing epidemic or essential conditions for an epidemic

A disease is sometimes sporadic and assumes epidemic proportions under special circumstances. The essential conditions for an epiphytotic or the factors governing epidemics can be grouped under the three heads.

1. Nature of host
2. Nature of the pathogen and
3. Environment

An epidemic can only result from the cumulative effects of all the three factors mentioned above, acting simultaneously. Few pathogens are capable of assuming epiphytotic conditions while others are sporadic. The former group consists of late blight of potato, blast of rice, downy mildew diseases and rust diseases.

Host	**Pathogen**	**Environment**
Susceptibility of the host	Introduction of a new pathogen	Temperature
Aggregation and distribution of susceptible hosts	Presence of aggressive strain of the pathogen	Moisture and humidity
Introduction of new hosts	High birth rate of the pathogen	Rainfall
Introduction of	Low death rate of the pathogen	Light and

new collateral or alternate pathogen host		shade
	Easy and rapid dispersal Wind of the pathogen Adaptability of the pathogen	Wind

A. Host Factors

1. Susceptibility of the host

Plants have ability to combat disease which manifests itself as susceptibility or resistance. Plants are predisposed to the attack depending on their nature, environment and stage of growth. Presence of susceptible varieties in an area may act as one of the causes of epidemic. For example, late maturing varieties of groundnut are more susceptible to early leaf spot (*Cercospora arachidicola)* and late leaf spot *(Phaeoisariopsis)* than the early maturing varieties. Similarly late maturing varieties of wheat are susceptible to loose smut *(Ustilago nuda tritici)* than the early maturing varieties. Early sown sugarcane varieties of sugarcane are more susceptible to leaf rust in Deccan canals in Bombay area than the late sown varieties.

Wheat plant becomes susceptible to black rust *(Puccinia graminis tritici)* at the boot stage but is resistant when young. Susceptibility of rice plants to blast disease (Pyricularia *oryzae)* increases with application of heavy doses of nitrogenous fertilizers. Cottons plants are susceptible to *Fusarium* wilt (*F.oxysporum f.sp. vasinfectum)* at soil temperatures of 26 to 28°C, brinjal to *Verticillium* wilt *Verticillium dahliae* at 20°C. But crop plants are resistant to these soil-borne diseases at relatively lower or higher temperatures. Under the above conditions, the pathogen multiplies faster, cause infection and effectively uses its propagules for quick secondary spread causing epidemic.

2. Aggregation and distribution of susceptible hosts

Abundance of susceptible hosts in an area is one of the major causes of the spread of epidemics. Continuous cultivation of susceptible variety or varieties in an area, that too in a large contiguous area help in the build up of inoculum and improve the chances of epidemics. Under the above conditions the pathogen increases the rate of multiplication of its propagules and repeats the disease cycles in a short span. Wheat cultivation area in the U.S.A and Canada and

rice cultivation area in East Asian countries are exposed to a greater danger of epidemics by wheat black rust and rice blast respectively.

Destructive epidemic of early and late leaf spots of groundnut in Bombay area (Gujarat and Maharashtra States) during 1912-1913 was mainly the result of cultivation of local varieties in a larger area. Panama wilt (*Fusarium oxysporum* f.sp. v*asinfectum)* susceptible table variety, 'Son' in banana was responsible for the destructive epidemic in parts of Bombay area (Gujarat and Maharashtra) during 1936 – 1940 Countrywide cultivation of red rot (*Colletotrichum falcatum*) susceptible sugarcane varieties (local varieties like *Pundya, Khajuria* etc.,) practically made their cultivation impossible in Bombay area.

3. Introduction of new host (s)

Disease proneness in the host is induced by environment and other factors. The host is liable to vigorous attack and successful infection by the pathogen. A resistant or moderately resistant variety may become susceptible or highly susceptible. A susceptible variety may become highly susceptible when conditions favouring proneness are existing and cause severe damage. Under the above conditions the pathogen multiplies faster, cause infection and produces more propagules for secondary spread. Introduction of an exotic cotton variety (C4 (Cambodia) caused outbreak of bacterial blight (*Xanthomonas axonopodis* pv. *malvacearum)* and grey mildew *(Septoacylindrium gossypii)* in local variety, Deviraj, grown in Maharashtra area in India.

4. Introduction of new collateral or alternate hosts

Alternate hosts are those plants on which the heteroecious pathogens pass part of their life cycles. Similarly, collateral hosts are some wild plants in which the pathogen survives when primary host is not available. Both alternate and collateral hosts are important in building up the primary inoculum to the next crop. They determine the course and intensity of an epidemic.

Grass hosts (collateral hosts) of *Sclerospora sacchari, S. philippinensis (*downy mildews), *Pyricularia oryzae* (rice blast), *Ustilago scitaminea* (sugarcane smut) may produce abundant inoculum which aid in building up of epidemics. Outbreak of heteroecious blister rust of pine *(Cronartium ribicola)* in Europe and the U.S.A happened due to import or introduction of *Pinus strobus* from the USA.

B. Pathogenic Factors

1. Introduction of new pathogen

Some pathogens, epidemic in certain area, may become quite aggressive and outbreak as epidemic when introduced to new area. For example late blight of potato caused by *Phytophthora infestans* was epidemic in South America. This disease became epidemic when the infected tubers were introduced in Europe (in 1843-45). Fire blight (*Erwinia amylovora* in North America is endemic. Fire blight spread to Pacific coast fruit-growing areas of the U.S.A in 1884 and subsequently it reached Canada. It reached New Zealand in 1919 and it appeared in England in 1957. The mode of introduction had been through fruit boxes. Coffee rust (*Hemileia vastatrix)* is indigenous in Ethiopia, where *Coffea arabica* is native. The disease spread to Sri Lanka in 1869, India in 1870, Sumatra in 1876, Java in 1878 and the Philippines in 1889. It also spread from Kenya to the Congo by 1918 and reached the Cameroons. From 1950 onwards, it spread to the reminder of West Africa.

The mode of long distance transport of H. *vastatrix* is wind. Spores have been trapped at up to 1000 m above sea level up to 150 m from infected sites. Dutch elm diseases *(Ceratocystis ulmi*) first reported in 1919 in Holland, spread throughout Europe and reached Great Britain in 1927. It was introduced to the eastern United States on elm logs imported from Europe.

2. Presence of aggressive strain of the pathogen

All the strains of a pathogen are not aggressive. Only the aggressive strains are capable of causing infectious diseases which spread as epidemic. They are characterised by rapid cycle of infection and causing successful infection in new hosts. Rapid cycle of infection is essential for successful infection and it happens only by aggressive strain of the pathogen. e.g., *Puccinia graminis tritici* (wheat black rust) in India, stripe rust, bunt and loose smut of wheat in the U.S.A. and Europe. The possibility of outbreak of epidemics increases with the number of physiologic forms or pathogenic strains of the pathogen present in a locality.

3. High birth rate of the pathogen

Pathogen with high reproductive capacity and capable of rapid dissemination over wide areas mostly cause epidemics. The fungal members causing powdery mildews, downy mildews, rusts, blasts, blights etc., produce enormous amount of spores. These spores are easily dispersed by using water or insects and cause infections to new plants. The high degree of fecundity and

the enormous amounts of inoculum produced by some common plant pathogens are given in table.

Fecundity rates of plant pathogens

Sl. No	Pathogen	Extent of fecundity
	Wheat stem rust *(Puccinia graminis tritici)*	Twenty five trillion uredospores in one hectare of wheat crops.
2	Wheat stem rust *(Puccinia graminis tritici)*	64,000 million aeciospores from aecial cups in a single barberry bush
3	Cedar rust of apple	Two billion teliospores in a single gall.
4.	A corn plant infected with downy mildew	225 million sporangia in one night
5.	A. grapevine infected by downy mildew	32,000 sporangia per sq.cm
6.	Bunt of wheat	6 to 12 million smut spores in a single kernel
7.	Smut of corn	125,000 billion smut spores in one hectare
8.	Chestnut blight	150,000,000 spores in a single spore horn
9.	*Fomes applanatus*	5,460 billion spores in a single fruiting body

4. Low death rate

Epiphytotics may also be caused by low death rate diseases. These diseases are caused by agents of systemic nature which are protected by plant tissues. As they are protected by plant tissues the chances of high mortality is reduced to the minimum. In these diseases the chief source for accumulation of inoculum for epiphytotics is the diseased plant organ used for vegetative propagation (corms, setts, tubers, etc,). Here the buildup of epidemics is comparatively low compared to high birth rate diseases. When a particular area is planted and covered with diseased planting material the chances of occurrence of epiphytotics are very high. e.g., virus and phytoplasma diseases in crops propagated through vegetative plant parts.

5. Easy and rapid dispersal of the pathogen

The ability of the pathogen to cause epidemic depends both on the high birth rate and dispersal. The propagules of the pathogen produced should be dispersed for development of an epidemic. It may happen by external agencies like wind, water, insects, mites and nematodes. Fungal spores / conidia are minute and light and resistant to adverse conditions. Fungal spores are mostly disseminated by wind. Bacteria are mostly disseminated by water or insects. Virus and phytoplasma diseases are mostly transmitted by insects, mites or nematodes. Epidemics are determined by the velocity of wind, direction of wind, moisture, relative humidity, temperature, presence and number of vectors and their rate of reproduction.

6. Adaptability of the pathogen

Pathogens have the capacity to adapt to adverse conditions. Fungi produce different types of spores like oospores, ascospores and smut spores (chlamydospores) which help in tiding over adverse conditions. Bacteria survive in diseased plant parts. Viruses and phytoplasmas live in collateral hosts or insect vectors in the absence of the suitable crop hosts.

C. Environmental Factors

The environmental conditions such as temperature, relative humidity, rainfall, duration and intensity of light, etc. play very important role in causing epidemics. These are actually the deciding factors and influence almost all the stages of disease cycle. Favourable environmental conditions are needed for sporulation, liberation of spores, dissemination of pathogen, germination, infection and establishment of pathogen in the host.

For example, persistent optimum temperature and moisture are needed for spore germination and entry of germ tube in the host. Similarly optimum temperature, moisture, light and specific nutrition is required for the development of the disease and sporulation of pathogen. Compound interest diseases and simple interest diseases The terms compound interest and simple interest are for explaining rate of increase of pathogen. These terms were introduced by Van der Plank in 1963 in the book 'Plant Diseases-Epidemics and Control'. Based on the mode of multiplication of pathogen, the diseases are classified of two types:

1. Simple interest diseases
2. Compound interest diseases

1. Simple interest diseases

In simple interest diseases the increase is mathematically analogous to simple interest in money. There is only one generation of the pathogen in the life of the crop. The primary inoculum is seed-borne or soil-borne. The secondary infection rarely occurs during the crop season. That is, the pathogens do not spread from plant to plant in one growing season. Simple interest diseases are caused by seed-or soil-borne smuts, like loose smut of wheat, covered smut of barley and soil borne fungi which attack roots, like wilt *(Fusarium oxysporum)* and root rot *(Rhizoctonia* spp.) diseases.

Most of the smuts infect the seedlings, grow along with the growth of the plant and produce spores in the inflorescence on maturity of the crop. There is no secondary spread from the smutted heads. These smut diseases are mostly systemic in nature. They do not produce propagules external to the host during the active season of the crop. Dispersal of propagules of these fungi is restricted by existing climatic and biotic conditions.

2. Compound interest diseases

In compound interest diseases the rate of increase is mathematically analogous to compound interest in money. The pathogen produces enormous amount of spores at a very rapid rate. These spores are disseminated rapidly by wind and infect the other plants. Both the inoculation and sporulation period are short so that the pathogen spreads from plant to plant during the same growing season. New crop of spores is produced, disseminated and the cycle is repeated fast. Thus more generations of the pathogen are produced in the life of a crop. e.g., late blight of potato, powdery mildews and rust diseases. If we consider wheat stem rust caused by *Puccinia graminis tritici* as an example, the fungus produces uredospores in very large numbers (50,000 to 4,00,000 uredospores per uredosorus).

These spores are spread by wind and infect other plants. Each of the freshly infected wheat plant produces uredopustules within 5 to 7 days at 24°C. Thus within a week of appearance of the first pustule in the crop several thousand new pustules are formed which could repeat the process within a week. If the climatic conditions of about 24°C temperature and relative humidity remain for only few weeks, the entire crop is severely affected by the disease.

Course of epidemic

The course of epidemic follows two distinct phases viz.,

i. Progressively destructive phase and

ii. the decline phase

i. Progressively destructive phase

Some epidemics develop slowly (tardive) while others develop rapidly. Slow epidemics (or epiphytotics) usually occur among population caused by systemic pathogens. The pathogen multiplies slowly following the characters of simple interest disease. They belong to low death rate category and have less incubation period and sporulation period. However, the rapid epiphytotics are greatly influenced by environmental factors.

ii. Decline phase

During early stage, an epidemic spreads vigorously causing diseases in new hosts. After development of a saturation stage it shows a decline by itself. No epidemics may be due to non-availability of suscepts non-availability of susceptible stages of the crop, unfavourable weather conditions and reduction in aggressiveness of the pathogens. Generally the hosts are prone to the disease at a specific developing stage. Once this stage is crossed in a plant it's proneness to infections is reduced or completely lost. Under the conditions the epidemic declines. The decline in the epidemic may also be due to unfavourable weather conditions for disease development. As a result future spread of the disease will be checked and the epidemic will decline. Wheat crop in Northern India usually gets the attack of rusts in January to March.

Epidemics develop during these months. Although the plant remains prone to attack afterwards also, further development of the disease is checked because of rise in temperature which is favourable for the pathogen. Due to the above mentioned and other causes, the aggressiveness of the pathogen may be reduced. When all susceptible individuals are destroyed by the pathogen, it may try to parasitize the remaining resistant individuals of the same species. In these adverse conditions, the pathogen may lose its power of successful infection, its reproduction may slow down and the pathogen becomes less aggressive.

Slow and rapid epiphytotics

The form of epidemic is decided by the nature of the pathogen, host and the weather. Epidemic may develop slowly and is called ' tardive'. Epidemic which develops rapidly is called 'explosive'. In between these intermediate forms of epidemic may occur.

i. Slow epiphytotics

Slow epiphytotics occur among perennial (tree) populations. Infected host survives for several years before dying. Most of the characters of a simple interest disease are found in slow

epiphytotics. The causal agent is mostly systemic. The pathogen multiplies slowly. Their movement from plant to plant is much slower. They are low death rate pathogen. In slow epiphytotics, crop sanitation is the best method. e.g., Swollen shoot of cocoa.

This disease spreads very slowly from tree to tree and still less from one garden to another garden. For instance, the incidence of 31 % swollen shoot increased to 75 % over a period of 2.5 years. As stated by Van der Plank (1959) the rate of multiplication of a systemic disease of trees is about ten fold a year whereas it is 10,000 fold in respect of herbaceous plants and it is of higher

rates for local lesion pathogens e.g., late blight of potato, wheat stem rust, etc.,

ii. Rapid epiphytotics

Rapid epiphytotics occur among annual crops. It is caused by non-systemic pathogens with high birth rate. Several generations of the pathogen is produced within a short time. Rapid epiphytotics are largely governed by environmental factors compared to slow epiphytotics. Disease increase is rapid and the disease rises to a beak in short time and then show sharp decline when the weather turns unfavourable or when the host becomes resistant due to maturity or due to restricted dispersal of propagules of pathogen. e.g.,apple scab. This type of epiphytotic is controlled by protective spraying or dusting with chemicals.

Lecture 20

Plant Disease Forcasting – Meaning, advantages, methods in forecasting and examples

Disease Forecasting

Forecasting of plant diseases means predicting for the occurrence of plant disease in a specified area ahead of time, so that suitable control measures can be undertaken in advance to avoid losses. Disease forecasts are predictions of probable outbreaks or increase in intensity of disease. It involves well organized team work and expenditure of time, energy and money. It is used as an aid to the timely application of chemicals. Among the first spray warning services to be established for growers, were the grapevine downy mildew forecasting schemes in France, Germany and Italy in the 1920s. Disease forecasting methods are available for the following plant diseases.

Sl. No	**Plant disease**	**Countries**
1.	Grapevine downy mildew	Australia, France, Germany, Greece, Italy, Romania, Spain, USSR, Yugoslavia
2.	Cucurbit downy mildew	U.S.A.
3.	Potato late blight	Australia, Brazil, Finland, France, Germany, Greece, Japan, the Netherlands, Norway, Peru, U.K, the U.S.S.R.
4.	Tobacco blue mould	Canada, U.S.A.
5.	Apple and pear scab	Australia, Canada, Netherlands, New Zealand, U.S.A.
6.	Sugarbeet root rot (*Aphanomyces* sp.)	U.S.A
7.	Wheat brown (Leaf) rust	U.S.A.
8.	Corn bacterial wilt (*Erwinia stewartii*)	U.S.A
9.	Sugarbeet curly top	U.S.A.

Information's needed for disease forecasting

Forecasting diseases is a part of applied epidemiology. Hence, knowledge of epidemiology (development of disease under the influence of factors associated with the host, pathogen) is necessary for accurate forecasting. The factors of epidemic and its components should be known in advance before forecasting is done.

The informations required for forecasting are:

1. Host Factors

a. Prevalence of susceptible varieties in the given locality

b. Response of host at different stages of the growth to the activity of pathogen e.g. Some diseases are found during seedling stages while others attack grown up plants and

c. Density and distribution of the host in a given locality. Dense populations of susceptible variety invite quick spread of an epidemic. Growing susceptible varieties in scattered locations and that too in a limited area are less prone to epiphytotic.

2. Pathogen factors

a. Amount of primary (initial) inoculum in the air, soil or planting material

b. Dispersal of inoculum

c. Spore germination

d. Infection

e. Incubation period

f. Sporulation on the infected host

g. Re-dispersal / Dissemination of spores

h. Perennating stages

i. Inoculum potential and density in the seed, soil and air

3. Environmental factors

a. Temperature

b. Humidity

c. Light intensity

d. Wind velocity

Requirements or conditions for disease forecasting

There are five main requirements which must be satisfied before a useful and successful disease forecast is made.

1. The disease must cause economically significant damage in terms of yield loss or quality. Damage assessment is essential to develop strategy for controlling a disease. e.g., Annual estimation of yield loss caused by barley powdery mildew (*Erysiphe polygoni*) in England and Wales had ranged from 6 to 13 %. Potato late blight can cause a yield loss of 28% if the disease reaches the 75% stage by mid- August. Diseases like apple scab and potato common scab reduces the quality of the produce lower the value of the harvested crop and cause considerable financial loss to the growers.

2. Control measures must be available at an economically acceptable cost.

3. The disease must vary each season in the timing of the first infections and its subsequent rate of progress. If it does not, there is no need for forecasting.

4. The criteria or model used in making a prediction must be based on sound investigational work carried out in the laboratory and in the field and tested over a number of years to establish its accuracy and applicability in all the locations where its use is envisaged.

5. Growers must have sufficient man power and equipments to apply control measures when disease warning is given. Long-term warnings or predictions are more useful than short-term warning or predictions.

Methods of disease forecasting

Disease forecasting requires field observations on the pathogen characters, collection of weather data, variety of the crop and certain investigations and their correlations. Usually the following methods are employed in disease forecasting.

1. Forecasting based on primary inoculums

Presence of primary inoculum, its density and viability are determined in the air, soil or planting material. Occurrence of viable spores or propagules in the air can be assessed by using different air trapping devices (spore traps). In the case of soil-borne diseases the primary inoculum in the soil can be determined by monoculture method.

Presence of loose smut of wheat, ergot of pearlmillet and viral diseases of potato can be detected in the seed lots at random by different seed testing methods. Seed testing methods can be used to determine potential disease incidence and enable decision to be made on the need for chemical seed treatment. The extent of many virus diseases is dependent on the severity of the preceding winter which affects the size of vector population in the growing season. e.g., Sugarbeet yellows virus.

2. Forecasting based on weather conditions

Weather conditions *viz*.,temperature, relative humidity, rainfall, light, wind velocity etc., during the crop season and during the inter crop season are measured. Weather conditions above the crop and at the soil surface are also recorded.

3. Forecasting based on correlative information

Weather data of several years are collected and correlated with the intensity of the diseases. The data are compared and then the forecasting of the disease is done. Forecasting criteria developed from comparisons of disease observation with standard meteorological data have been provided for diseases like *Septoria* leaf blotch of wheat, fire blight of apple and barley powdery mildew.

4. Use of computer for disease forecasting

In some advanced countries forecasting of disease is made by the use of computers. This system gives the results quickly. One such computer based programmes in the USA is known as 'Blitecast' for potato late blight. Examples of well developed forecasting systems are given below.

a. Early and late leaf spots of groundnut

A technique has been developed for forecasting early and late leaf spots of groundnut in the U.S.A. When the groundnut foliage remains wet for a period greater than or equal to 10 h and the minimum temperature is 21°C or higher for two consecutive days or nights, the disease development is forecasted.

A computer programme has been developed in the USA. This is accurate and is widely used in the USA. The data on hours for day with relative humidity (RH) of 95% and above and minimum temperature (T) during the RH observations for the period, for the previous 5 days are fed to the computer. Calculations are rounded to whole numbers. The T/RH index for each of the five days is calculated e.g., when hours of the RH 95% equal 10 and the minimum temperature during the period equals 21.1°C the T/RH index is 2.0 .The T/RH indices for days 4 and 5 are summed. If the total index exceeds 4 disease is forecasted. If the index is 3 or less no disease is forecasted.

b. Late blight of potato

In the USA a forecasting programme has been developed for late blight of potato (*Phytophthora infestans*). The initial appearance of late blight is forecasted 7 to 14 days after the occurrence of 10 consecutive blight favourable days. A day is considered to be blight favourable when the 5 day average temperature is 25.5°C and the total rainfall for the last 10 days is more than 3.0 cm. A computerized version (Blitecast) has also been developed in the U.S.A for forecasting potato late blight. Blitecast is written in Fortran IV. When a farmer desires blight cast (blitecast) he telephones the blight cast operator and reports the most recently recorded environmental data. The operator calls for the blight cast programmes in the computer *viz*., typewriter terminal and feeds the new data into the computer. Within a fraction of second the computer analyses the data and series of a forecast and spray recommendations to the operator who relays it to the farmer.

The entire operation can be completed during standard three minutes telephone call. The system makes one of the four recommendations viz., no spray, late blight warning, 7 days spray schedule or 5 days spray schedule. The last 5 days spray schedule is issued only during severe blight weather. In West Germany, 'Phytoprog' is the programme used. It is based on measurements of temperature, relative humidity and rainfall. Phytoprog provides a negative prognose (an indication of when the usual routine spray application should be dispensed with).

c. Blister blight of tea

A system for predicting epidemics of blister blight of tea (*Exobasidium vexans*) has been developed based on the number of spores in the air in the tea plantation and the duration of surface wetness on the leaves. The duration of sunshine is negatively correlated with the duration of surface wetness. The following prediction equation has been developed. Y = 1.8324 + 0.8439 X1 + 0.9665 X2 – 0.1031 X3where, X1 = log % infection t2X2 = log % infection t2 – log infection t1Y = log of the number of spores in the air and t1 – t2 three weeksX3 = mean daily sunshine for a 7 days period preceding t2

d. Southern corn leaf blight

'Epimay' is a system for forecasting Southern corn leaf blight (*Bipolaris maydis*) based on conceptual model.

e. Rice blast

In India, forecasting rice blast (*Pyricularia ozyzae*) is done by correlative information method. It is predicted on the basis of minimum night temperature 20 to 26°C in association with high relative humidity of 90% or above. Computer based forecasting system has also been developed for rice blast in India.

f. Wheat stem rust

Forecasting wheat stem rust epidemic is done by analysing therain samples which give precise data for inoculum present in the air. Moreover several wind trajectors are also prepared to survey the air-borne primary inoculums and its deposition. It has been observed that primary inoculum comes from South India, to the plains of Central and North India.

g. Brown stripe downy mildew of corn

The forecasting of brown stripe downy mildew of corn (*Sclerophthora raysise* var. *zeae*) which is restricted to India is done on the basis of average rainfall 100 to 200 cm or more accompanied by low temperature (25°C or less). Spore trappingTechniques of acquisition of biological data for consecutive forecasting models are important. Spore traps have been widely used in to complete disease with weather conditions. Spore trapping is useful for understanding epidemiology of a disease and behaviour of the pathogens. This helps in developing models on dispersal of pathogens or on epidemiology of the disease and to formulate methods of management. Methodology of spore trapping depends on the following objectives of the worker.

1. Biology of the pathogen
2. For infection forecasting
3. Spore dispersal gradients
4. Management of the disease

In epidemics of air-borne plant diseases the number of spores of the pathogen landing on the plant which depends on the number of spores in the atmosphere above the crop is an important factor for the quantitative sampling of the atmosphere (number of spores per unit volume of air).For trapping and estimating these studies different types of traps are used. The following spore traps are usually employed in trapping of fungal spores.

Cylindrical rods or microscopic glass slides: It helps to gather data on the spore arrival in a locality. In this, the surface of microscopic slide is smeared with grease and made sticky. In the method, quantitative estimation is not possible as number of spores collected is very low.

1. Hirst's volumetric spore trap (Hirst 1952)

In this instrument, air is sucked into at a controlled rate and impinged on to a glass slide moved by a clockwork mechanism past the orifice. It gives continuous count of spores in 24 h. The number of spores per unit volume of air at any given time can thus be calculated.

2. Rotorod sampler or rotorod spore trap (Sutton and Jones 1976)

It comprises of a 'U' shaped rod attached at its mid point to the shaft of a small battery operated electric motor. In this equipment the surface of the rod is covered with a vaseline strip of transparent cellophanes to catch spores which can be taken off and mounted on a glass slide. From the area of the strip and the speed of rotation, the volume of air samples can be calculated.

3. Anderson cascade spore sampler

It is a device where Petri plates with nutrient agar are used to collect the spores.

4. Bourdillon slit sampler

Air is sucked in a chamber by vacuum pump which strikes the rotating Petri dish containing agar medium. The agar medium retains the spores sucked in the air. Concentration of viable spores is calculated after counting germinated spores in the medium.

5. Burkard's 7 day volumetric spore trap

This device records spores in the air drawn by a pump on 7 days basis on a cellophane strip wrapped on a drum rotating inside a chamber.

6. Jet spore trap

In the above sampling methods, the viability of the spores cannot be determined. To overcome this, living plants have been used as spore traps. A jet spore trap in which spores are impacted in an air jet into a column of still air, through which they fall, to settle on leaf segments exposed at the base of the chamber. In this trap, suitable cultivars of host plants can be employed to determine number of viable spores.

Lecture 21

Remote sensing – Meaning, scope, objectives, advantages

Remote sensing carries many different connotations to different individuals, ranging from photography to large satellite platforms. Each day we are provided many frames of remote sensing information through our eyes, which we use to make visual assessments of an object. These scenes provide an information source about objects from which we judge certain characteristics, e.g., size, condition, or change. The local TV weather report uses remote sensing of clouds to show the passage of storms. Plant pathologists have used remote sensing tools for a number of years and were among the first to use color infrared photography to assess the presence of disease in trees. The application of remote sensing via airborne cameras provided an answer to a question that would not have been possible through ground surveys. In many aspects we have progressed rapidly to our current state of knowledge about the utility of remote sensing. The intent of this address is to arouse the interest of individuals in discovering how remote sensing could be applied to plant pathological problems of today and tomorrow.

Regions of The Spectrum

The spectrum of electromagnetic radiation ranges from the from short, high energy wavelengths to the long radio waves. As a receptor, the human eye only measures a relatively small portion of the spectrum in the visible wavelengths from 0.4 to 0.7 gtm. Remote sensing instruments, on the other hand, have utilized wavelengths extending in the microwave region for a variety of applications. For this discussion, we will confine the wavelengths to the region from 0.4 to 14 /im. The region from 0.4 to 5 /Mm can be represented as the reflected wavelengths. Reflection is that phenomenon in which an impinging beam of radiation of a particular wavelength is reflected back away from the object without any change. This can be contrasted to emittance, which is the emitting of radiant energy at a particular wavelength due to the temperature of an object. Surfaces at the temperature of the earth (300' K) emit mostly in 10-12 4m waveband, while the sun at 6000^0K emits in the 0.5 pm region. Both reflectance and emittance provide information that can be utilized in applying remote sensing to agricultural problems.

Reflection from Leaves

Reflection from individual leaves is not constant across the wavelengths from 0.4 to 2.5 ym. Leaves have a low reflectance in the visible (0.4-0.7 /m), a high reflectance in the near-

infrared (0.7-1.2 Mm), and a low reflectance in the middle and far infrared (1.2 *Mm)* wavebands. This variation in leaf reflectance has allowed for the differentiation of leaves from soil, which tends to show little variation in reflectance across these wavelengths.

Reflectance from leaves is species dependent and sometimes cultivar dependent. The primary variation among species is in the visible reflectance and is due to species or leaf age. Reflectance tends to increase in individual leaves as the leaf matures; however, the changes are wavelength dependent. These changes are due to changes in intracellular water content and chlorophyll content. Lesions and reduction in chlorophyll content created by a disease also cause an increase in reflectance. Water stress by reducing the internal water content increases the reflectance from an individual leaf. Information gathered from individual leaves provides a basic set of information about the mechanism of the changes occurring within a plant; however, to be of practical application it must be extended to a canopy or field level.

Reflection from Canopies and Fields

Composites of leaves or canopies exhibit the same reflective properties of individual leaves; however, there are a series of variables that now must be considered. Leaf orientation, i.e., the arrangement of leaves on the stem and orientation to the sun, provides a source of variation when viewing a canopy compared with an individual leaf. Also, all leaves are not exposed to the same level of incoming radiant energy and often do not reflect back to the sky due to distortions in the leaf surface. Leaf surfaces often act as polarizing filters and reflect back to portions of the sky that are not always detected by viewing the canopy only the vertical direction. However, the information contained in bidirectional and polarized reflectance has yet to be fully exploited in the evaluation of canopy response to stress. Leaf fluorescence is another attribute that has been observed in all plants and can be related to the efficiency of the photosynthetic process. It is possible that leaf fluorescence could be used to assess the impact of diseases on the physiological status of the plant. This technique has only been used on individual leaves; however, it could be extended to canopies through the use of laser-induced fluorescence. This procedure will have to be adapted to plant canopies but may become a powerful and useful research tool.

Canopies of plants are grown in fields with varying soil, and soil also has some unique reflective properties. The variation across wavelengths is less for soil than for leaves; however, the reflectance changes in response to modifications in the surface. The addition of organic

matter as residue on the surface reduces the reflectance. Soils vary in reflectance due to mineral composition and weathering of the minerals. However, across the visible and near-infrared wavelengths the reflectance from soil remains relatively constant within a given soil type. Changes in water content in the upper 2 mm cause the largest variation in reflectance. Water has a low reflectance and the addition of a water film around the soil aggregate causes an increased absorption of the incident radiation. As a soil is wetted there is a darkening in the color, which lightens as the soil dries. This variation in the reflectance from soils due to changing soil water adds, complexity to the reflectance from canopies, particularly when there is less than complete ground cover by the plant, i.e., exposed soils when viewed from above the plant. Since there is a changing amount of plant material both in the adding of new leaves or the senescence of the older leaves, there is a continually changing scene to be viewed. This challenge must be faced and understood if we are to develop the tools that allow us to assess the effect of a disease or any other stress on the plant.

Instruments available for the measurement of reflected radiation adaptable to remote sensing range from the portable spectro-radiometer, which measures all wavelengths between 0.4 and 1.1 /tm to radiometers with multiple channels set for discrete wave- bands. Instruments with individual channels mimic the wavebands available on the current satellites. A rapidly emerging technology that has yet to be applied is the use of multiple waveband video cameras. This system offers a capability not possible with other radiometers, in that the data are readily available for viewing without intense signal processing and manipulation. Video camera systems may provide a practical tool for disease assessment.

Vegetative Indices

To use the information contained in the reflectance across wavelengths, several vegetative indices have been proposed and evaluated. These indices are based primarily on the ratio or difference between the reflectance in the near-infrared and red wavelengths. The approaches range from simple ratios of near-infrared/- red)/(near-infrared + red)] is more appropriately related to the interception of photosynthetically active radiation. To account for the soil background the perpendicular vegetative index was developed to account for a changing soil background due to sur- face soil water content changes. There have been several other indices developed to describe how the changing reflective proper- ties change with growth of the plant.

Observed changes in the vegetative index, in particular, the ratio vegetative index and the normalized vegetative index have shown unique seasonal patterns. The patterns of both indices show an increase with the developing canopy and a hysteresis effect during senescence because plant material remains standing in the field, which has different reflective properties than the soil in the background. Over fields of seemingly uniform conditions there is considerable variation in the observed signal whether the data are collected with hand-held, boom-mounted, or aircraft-mounted systems. The variation is typically 10% of the field mean. However, the change in spatial variability may be one of the methods that could be effectively used to monitor the changes that occur within fields as a result of disease. Most diseases do not infect a whole field uniformly and thus could induce a change in the field pattern. Even on a single sample event this method could provide valuable information given a priori knowledge about the expected level of field variability.

Emitted Radiation

All objects that have a temperature emit radiation according to Planck's Law. Soil and plant canopies emit energy, and given the temperatures found on the earth's surface, range in the 10-14 **bm** waveband. Temperature of a plant canopy can be described by the temperature of individual leaves, the temperature of foliage, or the temperature of the canopy that includes the soil. Leaf temperatures that have been measured relative to the ccurrence of Verticillum wilt or brown rot of soybeans *(Phialo- phora gregata* Gans) have been measured with attached leaf thermocouples. Other measurements of Verticillum wilt have been made with infrared thermometers. Each method has provided a unique relationship of describing the change in leaf temperature relative to the presence of a disease.

Energy Exchange Processes

Temperatures of the leaf, foliage, or canopy are a result of the energy exchange process. The observed temperatures are a result of the partitioning between the sensible and latent heat exchanges and therefore are a balance between the energy impinging on the leaf or foliage and the water available for evaporation. Simply stated then, a surface with a free water surface will be as cool as possible given the meteorological conditions while one without water will be the warmest possible under a given set of conditions. It is this relationship that has allowed foliage temperature to be effectively used in the estimation of transpiretion from canopies. Also, any factor that disrupts this water flow to the leaf, e.g., vascular diseases, root diseases, or diseases

that disrupt the stomatal action, will cause the foliage temperature to be higher than that observed in healthy foliage. We have been successful in using foliage and canopy temperature in evapotranspiration models for a variety of crops. In well-irrigated crop canopies, the variation across a field is relatively uniform and the variation increases with increasing soil water deficits. As with the reflected radiation, the change in field variability may be useful in defining the characteristics of a given field.

Crop Stress Indices

To improve the efficiency of using foliage temperatures, several crop water stress indices have been proposed and evaluated since the middle 1970s. These became possible at this time due to the leaf area index, while the normalized difference [(near-infrared development of the accurate, portable, hand-held infrared thermo- meter. At first, the comparison was made between the foliage and air temperature (Tf - Ta**),** since this form was the integral part of the energy exchange process. It was found that although the Tf - Ta differences were related to crop yield induced by water stress, the relationships were site dependent. Further development and study revealed that other environmental variables were needed to fully interpret foliage temperatures and develop less site-specific relationships. The primary variables were net radiation, wind speed, and vapor pressure deficit. These stress indices have been based on the energy exchange principles between the foliage and the surrounding atmosphere. Any factor that affects the rate of water movement to the leaf has an impact on the foliage temperature. For example, the addition of high salt content irrigation even in large amounts causes the foliage temperatures to be warmer than those plants irrigated with the same volume of salt-free water.

Recent research has identified that plants have biochemical. temperature optima that define the optima temperature for plant growth. Combining foliage temperature with these predetermined optima temperatures provides another description of plant stress. It has been found that plants with maximum growth in a particular environment have the minimum amount of time outside of this predetermined thermal range. For cotton, this range was deter , mined to be 23-30 C and for wheat 18-25 C. This range has been defined as the thermal kinetic window and is based on the biochemical efficiency of a particular plant. The utility of this stress index has yet to be fully evaluated; however, it offers a method of linking the plant response to an observed parameter. Eg: foliage temperature.

Other methods that can be used are to calculate the canopy resistance to water vapor exchange. It is known that many diseases affect the stomatal resistance and the combination energy balance and observed foliage temperature provide a method of estimating canopy resistance. These techniques, however, are yet to be applied to any measure of disease. They may offer the potential of quantifying the degree of stress or level of infection in ways that have not been possible before.

The instruments available for measuring the foliage temperature range from hand-held portable units, to fixed, battery-powered systems to airborne or satellite thermal scanners systems. The coverage is obtained, e.g., NOAA or GOES satellites. Smaller areas are covered with systems that provide less frequent coverage, e.g., **LANDSAT** or **SPOT.** The variation within a scene of data obtained with an airborne or satellite system will not permit the reliable detection of the onset of a disease. The handheld or fixed units on the ground may be useful in a research setting to determine the casual relationships and the development of a monitoring program where a problem is suspected. Each of these instruments require some training to most properly collect and interpret the data.

Temporal and Spatial Variation

Both the temporal and spatial attributes of remote sensing techniques detect unique features about the surface being ob- served. Satellites that provide repeated coverage of the earth have allowed assessments to be made of the changes that have occurred over a period of months or years. The same factors apply when applying remote sensing to the monitoring of agricultural fields, forests, and native or managed grasslands. The value of repeated coverage has provided for a unique glimpse at the ecosystem that we are trying to monitor.

Temporal variations can be large because the system to which we are applying may be changing due to the normal progression of growth. However, we know what patterns to expect and deviations away from that pattern provide an investigative tool. Likewise, changes in the spatial patterns may signal a potential problem within a given field or ecosystem. The interpretation of the temporal and spatial pattern will require some experience but may provide an indication of a problem not possible before this information was made available.

Integrating Remote Sensing Into Plant Pathology

There are two avenues in which remote sensing information, either reflected or emitted radiation, can be incorporated into disease monitoring. The two approaches involve either direct

or indirect methods of evaluating the disease occurrence and extent. Given the number of factors that cause variation in both the reflected and emitted radiation signals it is unlikely that the direct monitoring method will be useful. Both the indirect and direct methods require a priori knowledge that a condition may exist.

Given this knowledge then, one may use a direct monitoring program to measure the extent of a disease. eg: *Phytophthora* spp. on soyabeans or *Fusarium* spp on beans, which cause a reduction in leaf area. The spatial sampling capability provides an assessment not possible with ground monitoring.

The indirect method would involve interpretation of deviations from the expected case either in temporal or spatial patterns. For example, an increase in foliage temperature in a field with an adequate soil water supply would signal a potential problem that could invoke a monitoring effort. An unexplained change in leaf area or wilting resulting in a change in reflectance could signal a problem before complete infestation. The utilization of both indirect and direct methods will require imagination and dedication to the problem by a number of researchers.

Lecture 22

General principles of plant diseases management – Importance, general Principles – Avoidance, exclusion, eradication, protection and therapy, immunization

Information on etiology, symptoms, pathogenesis and epidemiology of plant diseases are intellectually interesting and scientifically justified but most important of all they are useful as they help in formulation of methods developed for successful management of disease and thereby increasing the quantity and improving the quality of plant and plant products. Practices of disease management vary considerably from one disease to another depending upon the type of pathogen, the host and the biotic and abiotic factors involved. Contrary to management of human and animal diseases where every individual is attended, the plants are generally treated as populations and measures used as preventive rather than curative.

Methods for plant diseases control were first classified by Whetzel (1929) into exclusion, eradication, protection and immunization. Further advances in plant pathology leading to development of newer methods. Two more principles - avoidance and therapy were created (NAS, 1968)

Avoidance

It involves avoiding disease by planting at time when, or in areas where inoculums is absent or ineffective due to environmental conditions. The major aim is to enable the host to avoid contact with the pathogen or to ensure that the susceptible stage of the plant does not coincide with favourable conditions for the pathogen. The main practices under avoidance are choice of geographical area, selection of the field, choice of sowing/ planting time, selection of seed and planting material, short duration / disease escaping varieties and modification of agronomic/cultural practices. The potato cultivation at high altitude is relatively free from viruses; as prevailing environmental conditions do not permit the buildup of vector populations. Similarly, early planting of potato or wheat, in indo Gangetic plains may escape late blight or stem rust damage respectively.

Exclusion

It means preventing the inoculums from entering or establishing in a field or area where it does not exist. Seed certification, crop inspection, eradication of inoculums and / or insect vectors, and quarantine measures are some of the means of preventing the spread for pathogens.

Eradication

The process of reducing, inactivating, eliminating or destroying inoculums at the source, either from a region or from an individual plant in which it is already established is termed as eradication. Eradication involves eliminating the pathogen from infested areas; the magnitude of the operation involved may vary considerably. On eof the most extensive eradication operations carried out so far was to get rid of the citrus canker (xanthomonas axonopodis)in the USA during 1927- 35. As many as 4 million citrus trees were cut and burnt at a cost of about 2.5 million dollars to eradicate the pathogen. The practices invariably employed to achieve eradication of inoculums include eradication of alternate and / or collateral hosts, crop rotations, field sanitations, heat or chemical treatments of plant materials or soil, biological control etc.

Protection

The protection of infection courts against the inoculums of many fast spreading infectious pathogen, brought by wind from neighboring fields or any other distant place of survival. Principles of avoidance, exclusion and eradication may not be sufficient to prevent the contact of host with pathogen, thus development of the disease is imminent. Measures are necessary to protect host plants from invading inoculums. It can be achieved by creating toxic barrier between the plant surface and the inoculums. Methods employed to achieve such results are chemical sprays, dusts, modification of environment, and modification of host nutrition.

Host resistance

It utilizes in – built mechanism to resist various activities of pathogen. The infection or subsequent damage by pathogen can be rendered ineffective through genetic manipulation or by chemotherapy. The host resistance can also be induced by use of certain biotic and abiotic factors. The discovery of Mendelian laws of inheritance and developments in plant breeding techniques have helped in developing crop varieties resistant to specific pathogen or group pf pathogens. The classical breeding techniques include selection, mutation and hybridization. Use of biotechnological tools such as tissue culture, genetic engineering and protoplast fusion are being used to develop resistant cultivars of various economically important crops.

Therapy

It is the treatment of infected host plant, which is attempted in case of economically important horticulture plants. As a principle of plant disease control, it provides an opportunity to cure or rejuvenate the diseased host plant by use of physical or chemical agents. The first five of

these principles are mainly preventive (prophylactic) and constitute the major components of plant disease management. They are applied to the population of plants before infection takes place. Therapy is a curative procedure and is applied to individuals after infection has taken place. Under the concept of disease management these principles have been classified into following five categories:

1. Management of physical environment (cultural control)
2. Management of associated micro biota (biological antagonism)
3. Management of host genes (host resistance)
4. Management with chemicals (Chemical control)
5. Management with therapy (Physical, chemical etc)

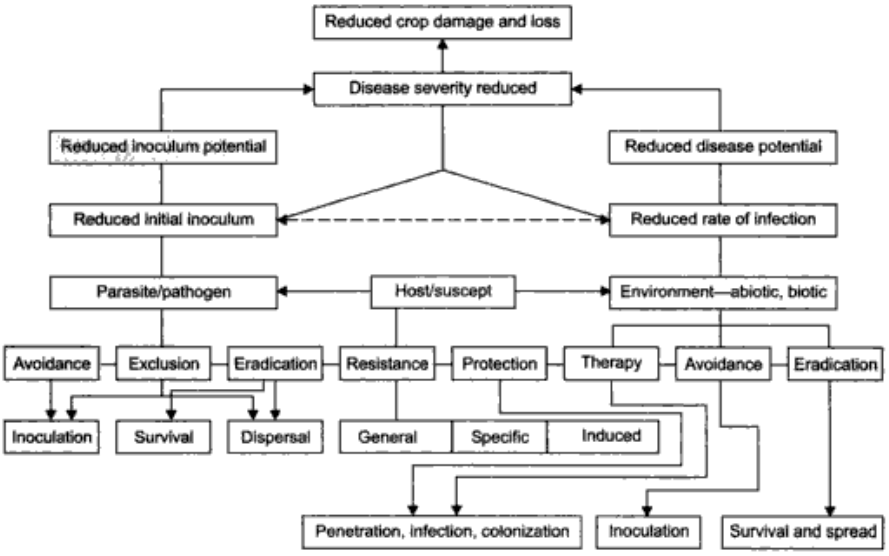
The six principles that characterize the modern concept of plant disease management should be viewed from three stand points

(a) Reduction in the initial inoculums or the rate of disease development.

(b) Management of the pathogen population, the cure or induce defense of the suscept or modify the environment as it influences disease and

(c) Interruption of dispersal, survival or the course of disease development.

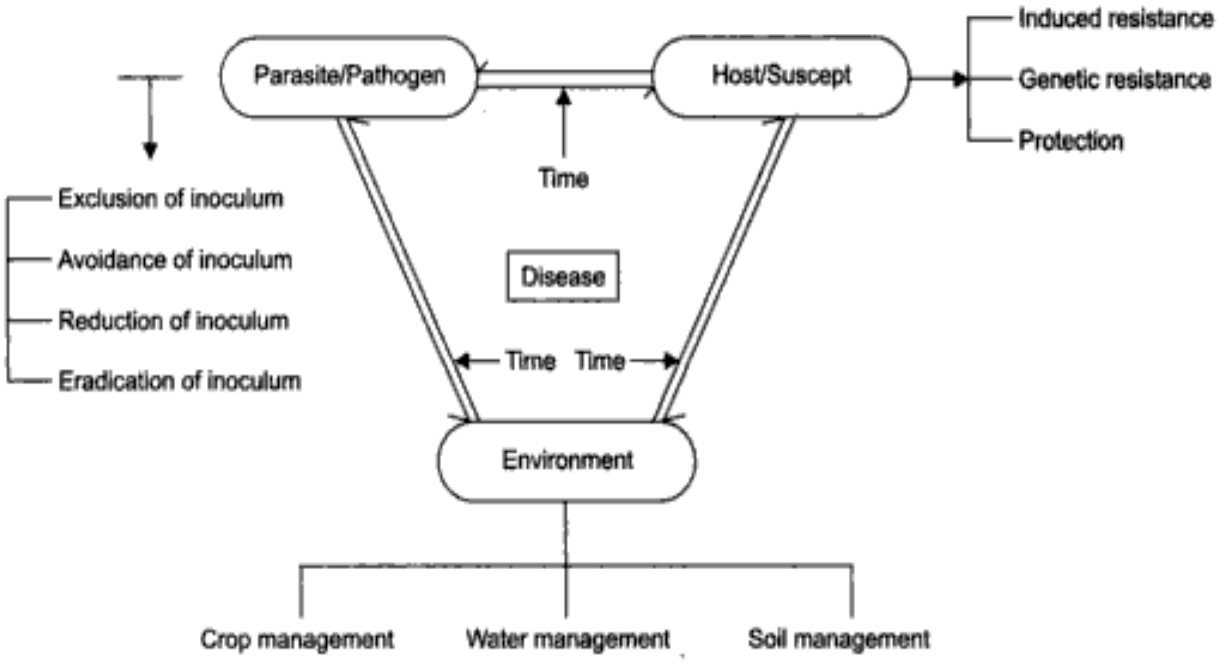
These interactions are originally proposed by Baker (1968) and Roberts and Boothroyd (1972) and subsequently modified for the readers are illustrated as below:



Integrated disease management

The term Integrated pest management was originally designed for management of insect pest but it is equally applicable to plant diseases also. IPM is an ecosystem- based strategy that focuses on long term prevention of pests or their damage through a combination of techniques such as biological control, habitat manipulation, and modification of cultural practices and use of resistant varieties.

Management of pathogen involves the practices directed to exclude, reduce or eradicate inoculums. Management of the host involves the practices directed to improve plant vigor and induce resistance through nutrition, introduction of genetic resistance through breeding and providing need based protection by chemical means. Management of environment involves the practices that modify the environment which is not favorable to pathogen or disease development and does not predispose host to attack.



Lecture 23

Regulatory methods – Plant Quarantine and Inspection – Quarantine Rules and Regulations

Plant Quarantine

The term 'Quarantine' means simply forty i.e., 40 days period. This was more commonly referred to the period of detention for ships arriving from countries subject to epidemic diseases such as the Bubonic plague, cholera and yellow fever. The crew and the passengers used to be compelled to remain isolated on board for sufficient period to permit the diseases to develop and be detected. The purpose of the health authorities was to establish adequate detention period. Later on, the term 'Quarantine' came to be only used for the detention and the practices connected with it. The term got associated from the human disease field to the animal disease field and later on adopted to cover protective methods for the exclusion of pests and diseases of agricultural and horticultural crops.

In strict sense 'Plant Quarantine' refers to the holding of plants in isolation until they are believed to be healthy. Now, broader meaning of the plant quarantine covers all aspects of the regulation of the movement of living plants, living plant parts/plant products between politically defined territories or ecologically distinct parts of them. Intermediate quarantine and post entry quarantine are used respectively to denote the detention of plants in isolation for inspection during or after arrival at their final destination.

Importance

The entry of a single exotic insect or disease and its establishment in the new environment continues to cause great, national loss (table) till such time it is brought under effective control. In certain cases a country has to spend a few million rupees before success in controlling the introduced insect pest or disease is achieved.

Losses caused by introduced plant diseases

Disease	Host	Country	Introduced from	Losses caused
Canker	Citrus	U.S.A	Japan	$ 13 million; 19.5 million trees destroyed
Dutch elm	Elm	U.S.A.	Holland	$ 25 million -$ 50,000 disease million

Blight	Chestnut	U.S.A.	Eastern Asia	$ 100-1000 million
Powdery mildew	Grapevine	France	U.S.A	80% in wine production
Downy mildew	Grapevine	France	U.S.A	$ 50,000 million
Bunchy top	Banana	India	Sri Lanka	Rs.4 crores
Wart	Potato	India	Netherlands	2500acres infected
South American leaf blight	Rubber	Dutch – Brazil	Guiana	40,000 trees destroyed
do	-do-	North Columbia	Brazil	78% trees destroyed
Blue mould	Tobacco	Europe	U.K	.$ 50 million
–do	--do-	Sweden	U.K.	1.2 million Kroner

History

The first plant quarantine law was promulgated in Rollen, France in 1860 to suppress and prevent the spread of common barberry, the alternate host for wheat stem rust. Among other countries, the first few to establish plant quarantine services were Germany, France, Australia and the U.S.A. In India, legislative measures against crop pests and diseases was initiated under the Destructive Insects and pests Act of 1914 (DIP act) and it was passed by Governor General of India on 3 rd February, 1914. Under this Act, rules governing the import and movement of plants and plant materials, insects and fungi are framed. The Act provides

- It authorizes the Central Government to prohibit or regulate the import into India or any part there of any specific place therein, of any article of class of articles.
- It authorizes the officers of the Customs at every port to operate, as if the rules under the D.I.P. Act is made under the Sea Customs Act.

1. It authorizes the Central Government to prohibit or regulate the export from a State of the transport from one State to another State in India of any plants and plant materials, diseases or insects likely to cause or infestation. It also authorizes the control of transport and carriage and

gives power to prescribe the nature of documents to accompany such plants and plant materials and articles.

2. It authorizes the State Governments to make rules for the detention, inspection, disinfection or destruction of any insect or class of insects or of any article or class of articles, in respect of which the Central Government have issued notifications. It also authorizes the State governments for regulating the powers and duties of the officers whom it may appoint on this behalf.

3. It provides penalty for persons who knowingly contravene the rules and regulations issued under the Act.

4. It also protects the persons from any suit or prosecution or other legal proceedings for anything done in good faith or intended to be done under the Act. Consequent to Bengal famine 1943, a Central Plant Protection organization was established in 1946 under the then Ministry of Food and Agriculture. Often a new pest, disease or weed has accidentally entered a country where it did not exist before and has multiplied, spread and caused enormous damage to the crops of that country.

For instance powdery mildew of grapevine (*Plasmopara viticola*), introduced into France from America, was responsible for the destruction of the vine industry of that country until hybridization with resistant American stock offered a solution. The blight disease of chestnut (*Endothia parasitica*) which was introduced into U.S.A. from Asia in 1904, completely wiped out chestnut trees. Coffee rust (*Hemileia vastarix*) which came into India in 1879 from Sri Lanka is now widespread in all coffee growing areas. Fire blight (*Erwinia amylovora*) of pear and other pomes which was introduced from England in 1940 is well established in Uttar Pradesh. Late blight (*Phytophthora infestans* of potato introduced into India in 1889 from Europe is now present in many parts of the country. Flag smut (*Urocystis tritici*) of wheat introduced from Australia is now well spread in Madhya Pradesh, Punjab, Rajasthan and Uttar Pradesh. Rubber powdery mildew (*Oidium heavea*), which was introduced from Malaysia in 1938, is also causing great concern in Kerala. Black rot of crucifers (*Xanthomonas campestris* pv.*campestris)* believed to have been introduced to India with seeds imported from Holland, and other European countries after World War II, prevailed for some years on the hills and then spread to the plains and became established in Indian seed stocks, especially in West Bengal. Among the more important plant disease introductions, mention may be made of bunchy top virus of banana introduced from Sri Lanka in 1940 which has since spread widely in Kerala, Orissa, West Bengal

and Assam. The wart disease (*Synchytrium endobioticum*) of potato was first noticed in Darjeeling district of West Bengal having been introduced with seed potatoes from Holland. By 1962, the disease spread over nearly 1000 ha and has recently been reported from Nepal also. The mosaic disease of banana is another introduced disease which is only confined to Gujarat and Maharashtra states. Recently the apple scab (*Venturia inaequalis* which was only confined to small area in Jammu and Kashmir has now appeared in severe form in many locations in Himachal Pradesh, and is posing a problem to apple industry. The establishment of a plant quarantine regulation should rest on the following fundamental pre-requisites.

i. The pest/disease under consideration must be one that will offer actual or expected threats to substantial interests (Agricultural and / or commercial)

ii. The quarantine regulation or degree must represent a measure for which no substitute action involving less interference with normal activities is available.

Diseases believed to have been introduced into India from foreign countries

Disease	**Host**	**Date of first record**	**Introduction from**
Leaf rust(*Hemileia vastarix*)	Coffee	1879	Sri Lanka
Late blight (*Phytophthora infestans*)	Potato	Tomato 1883	Europe
Rust (*Puccinia carthami*)	Chrysanthemum	1904	Japan or Europe
Flag smut(*Urocystis tritici*)	Wheat	1906	Australia
Downy mildew(*Plasmopara viticola)*	Grapevine	1910	Europe
Downy	Cucurbits	1910	Sri Lanka

mildew(*Pseudoperonospora cubensis)*			
Downy mildew(*Sclerospora philippinensis*)	Maize	1912	Java
Foot rot (*Fusarium moniliforme* var. *majus*)	Rice	1930	South East Asia
Leaf spot(*Phyllachora sorghi*)	Sorghum	1934	South Africa
Powdery mildew(*Oidium heveae*)	Rubber	1938	Malaya
Black shank (*Phytophthora parasitica* var. *nicotianae*)	Tobacco	1938	Dutch East Insides
Fire blight Pear and other(*Erwinia amylovora*	pomes	1940	England
Crown-gall and hairy root (*Agrobacterium tumefaciens A. rhizogenes)*	Apple, Pear	1940	England

1. Bunchy top Banana 1940 Sri Lanka
2. Canker Apple 1943 Australia(*Sphaeropsis malorum*)
3. Wart Potato 1953 Netherlands(*Synchytrium endobioticum)*

Despite every precaution of inspection, certification and treatment, it is not always possible to guarantee that a consignment is completely free from pathogens. In doubtful cases it is advisable to subject plants to a period of growth in isolation under strict supervision in the importing country (post-entry quarantine). The plants are grown at a quarantine station. When direct importation of plants to a country's own quarantine station is considered very dangerous, quarantine during transit from the country of origin (intermediate quarantine) may be required.

The requirements of an intermediate station are similar to those for a post-entry station. Intermediate quarantine inspection must always be followed by post-entry quarantine after arrival of the consignment at its final destination. During post-entry or intermediate quarantine plants must be kept under close supervision, so that any pest or disease which appears may be immediately detected and grown under optimum conditions, so that symptoms are not marked by physiological disturbances.

International plant protection convention the first effort towards international agreement on Plant Protection was made in 1914 under the auspices of the International Institute of Agriculture in Rome. This was followed by an International Convention of Plant Protection by over 50 member countries of the Institute in 1919 and certain Agreements regarding the issue and acceptance of phytosanitary certificates were finalized. The project received a set back due to Second World War and was later on revived by the FAO. In post-war period International action in Plant Protection and particularly in plant quarantine was encouraged by FAO with the establishment in 1951 of the International Plant Protection Convention. This agreement was constituted with the purpose of securing common and effective action to prevent the introduction and spread of pests and diseases of plants and plant products as to encourage Governments to take all steps necessary to implement its prevention (Ling, 1953).

The following regional Plant Protection Organizations are now in operation.

1. The European and Mediterranean Plant Protection Organization (EPPO)
2. The Inter-African Phytosanitary Council (IAPSC)
3. Organismo International Regional de Sanidad Agropecnario (OIRSA)
4. The Plant Protection Committee for, the South East Asia and Pacific region.
5. Comit'e Interamericano de Protection Agricola. (CIPA)
6. The Caribbean Plant Protection Commission (CPPC)
7. The North American Plant Protection Organization (NAPPO).

Under article 3 of that International Plant Protection Convention, the Plant Protection Agreement for South East Asia and Pacific Region was sponsored by F.A.O in 1956, and India became in party to this Agreement in the same year the along with Australia, Sri Lanka, the U.K., Laos, Netherlands, Indonesia, Portugal and Vietnam. Our Government agreed to adopt

legislative measures specified in the Convention for the purpose of securing common and effective action to prevent the introduction and spread of pests and diseases of plants and plant products and to promote measures for their control and also agreed to assume all responsibilities for the fulfillment within its territories of all requirements under the Convention. It was agreed that the Government shall make provision for:

a. An official plant protection organization, with the following main functions:

1. The inspection of growing plants, of areas under cultivation and of plants and plant products in storage and in transportation with the object of reporting the existence, outbreak and spread of plant diseases and pests and of controlling those pests and diseases.

2. The inspection of consignments of plants and plant products moving in international traffic, the inspection of consignments of other articles or commodities moving in international traffic under conditions where they may act incidentally as carriers of pests and diseases of plants and plant products and the inspection and supervision of storage and transportation facilities of all kinds involved in international traffic whether of plants and plant products or other commodities, with the object of preventing the dissemination across national boundaries of pests and diseases of plants and plant products.

3. The disinfestation or disinfection of consignments of plants and plant products moving in international traffic, and their containers, storage places, or transportation facilities of all kinds employed.

4. The issue of certificates relating to phytosanitary condition and origin of consignments of plants and plant products (Phytosanitary certificates).

b. The distribution of information within the country regarding the pests and diseases of plants and plant products and the means of their prevention and control

c. Research and investigation in the field of plant protection. A revised text of convention was approved in 1979. As of December 1980, the number of states party to the convention is 81. Besides this world-wide convention, other regional agreements and organizations have been created to safeguard the interests of groups of neighbouring countries with similar plant protection problems.

Regional action is needed to prevent a pathogen or pest absent from a whole area from being introduced into any part of the area, as its entry into one territory will endanger neighbouring countries.

Plant quarantine methods

There are number of plant quarantine methods which are used separately or collectively to prevent or retard the introduction and establishment of exotic pests and pathogens. The components of plant quarantine activities are:

1. Complete embargoes

It involves absolute prohibition or exclusion of specified plants and plant products from a country infected or infested with highly destructive pests or diseases that could be transmitted by the plant or plant products under consideration and against which no effective plant quarantine treatment can be applied or is not available for application.

2. Partial embargoes

Partial embargoes, applying when a pest or disease of quarantine importance to an importing country is known to occur only in well defined area of the exporting country and an effectively operating internal plant quarantine service exists that is able to contain the pest or disease within this area.

3. Inspection and treatment at point of origin

It involves the inspection and treatment of a given commodity when it originates from a country where pest/disease of quarantine importance to importing country is known to occur.

4. Inspection and certification at point of origin

It involves pre-shipment inspection by the importing country in cooperation with exporting country and certification in accordance with quarantine requirements of importing country.

5. Inspection at the point of entry

It involves inspection of plant material immediately upon arrival at the prescribed port of entry and if necessary subject to treatment before the same related.

6. Utilization of post entry plant quarantine facilities

It involves growing of introduced plant propagating material under isolated or confined conditions.

Plant quarantine organizations in India

The first recorded plant quarantine measure in India dates back to 1906 when perceiving the danger of introducing the Mexican boll weevil, the Government of India directed that all cotton imported from the New World should only be admitted to India after fumigation with

carbon disulphide at the port of entry. In India two categories of regulatory measures are in operation for controlling pests, diseases and weeds. In the first category regulatory measures are aimed to prevent the introduction of exotic pests and diseases into the country or their spread from one State or Union Territory to another (Plant Quarantine).

The second pertains to suppression or prevention of spread of pests and diseases in localized areas within a State or Union Territory. The former derives its authority from the Destructive Insects and Pests (DIP) Act 1914 of the Central Government and the latter from Agricultural Pests and Diseases Acts of the various States. The legislative measures against crop pests and diseases were initiated under the DIP Act of 1914 which was passed by the then Governor General of India in Council on 3 February 1914. Prior to the establishment of the Directorate of Plant Protection, Quarantine and Storage in 1946, under the Ministry of Food and Agriculture, the various rules and regulations of the DIP Act were enforced by the customs department. The quarantine regulations are operative through The Destructive Insects and Pests Act, 1914 (which has been revised 8 times from 1930 to 1956 and amended in 1967 and 1992.

The provisions of the DIP Act are

1. It authorizes the Central Government to prohibit or regulate the import into India or any part thereof or any specific place therein of any article or class of articles.
2. It authorizes the officers of the Customs at every port to operate, as if the rules under DIP Act are made under the Sea Customs Act.
3. It authorizes the Central Government to prohibit or regulate the export from a State or the transport from one State to another State in India of any plants and plant material, diseases or insects, likely to cause infection or infestation. It also authorizes the control of transport and carriage and gives power to prescribe the nature of documents to accompany such plants and plant materials and articles.
4. It authorizes the State Governments to make rules for the detention, inspection, disinfection or destruction of any insect or class of insects or any article or class of articles, in respect of which the Central Government has issued notification. It also authorizes the State Governments for regulating the powers and duties of the officers whom it may appoint on its behalf.
5. It provides penalty for persons who knowingly contravene the rules and regulations issued under the Act.

6. It also protects the personnel from any suit or prosecution or other legal proceedings for anything done in good faith as intended to be done under this Act.

The quarantine regulations are operative through "The Destructive Insects and Pests Act, 1914 (which has been revised and time from 1930 to 1956 and amended in 1967 and 1992. The Act also empowers the State Governments to frame suitable rules and issue notifications for inter-state movement of plant and plant material. Those rules are known as plant quarantine rules. Under the Act, Central Government frames rules prescribing the seaports, airports and land frontiers through which plants and specified plant material can enter India, and the manner in which these can be imported. The DIP Act operates under the National Sea Customs Act and the points of entry are located within the jurisdiction of State on the advice of Central Government, the State frames rules for detention, inspection, disinfection and destruction (as against entry) of material, if required, and delegates powers in this regard to concerned authorities with the enforcement of rules.

The plant quarantine service is centrally organized and administered through the Directorate of Plant Protection, Quarantine and Storage established under the Ministry of Agriculture (Department of Agriculture and Co-operation) which is headed by the Plant Protection Adviser to the Government of India and having its headquarters at N.H. IV, Faridabad, Haryana State. Import regulations When plants are imported the following principles should be followed. Some plant pathogens and pests are generally distributed in most parts of the world but others are more or less restricted in their occurrence.

In some cases this limitation is due to such factors as unsuitable environmental conditions or lack of the required host plant, but in many other cases the absence of a pathogen. Most countries are aware of the desirability of delaying for as long as possible the arrival of exotic pathogens and take action to prevent their spread by introducing legislation and setting up organizations to prevent their entry. Plant quarantine legislation varies from country to country but in most cases it restricts or prohibits the importation of the pests or pathogens themselves, plants on which they might be living, soil which might be infested, foodstuffs which might carry them, and packing materials, particularly those of plant origin. Good legislation is as brief and clear as possible, at the same time being easy to interpret, gives adequate protection without interfering more than is essential with trade, and contains only restrictions which are

scientifically justifiable. When plants are imported there are certain principles which, if followed ensure that as few risks as possible are taken.

1. Import from a country where, for the crop in question, pathogens which are particularly to be guarded against are absent.

2. Import from a country with an efficient plant quarantine service, so that inspection and treatment of planting material before despatch will be thorough, thus reducing the likelihood of contaminated plants being received.

3. Obtain planting material from the safest known source within the selected country.

4. Obtain an official certificate of freedom from pests and diseases from the exporting country. Treatment of the material in the country of origin may be done; this should be noted on the certificate.

5. The smaller the amount the less the chance of its carrying infection, and inspection as well as post-entry quarantine.

6. Inspect material carefully on arrival and treat (dust, spray, fumigate, heat treat) as necessary.

7. Import the safest type of planting material, e.g. seeds are usually safer than vegetative material, unrooted cuttings than rooted. The use of axenic cultures of meristem tip tissues (micropropagation) for the international exchange of germplasm material has outstanding advantages, as such tissues can be expected to be free from latent infections by viruses, phytoplasmas etc., as well as other pathogens which are more readily detectable by visual means.

8. If other precautions are not thought to be adequate, the consignment for import should be subject to intermediate or post-entry quarantine. Such quarantine must be carried out at a properly equipped station with suitably trained staff.

Seed was not originally included in the DIP Act, but because of the changing situation and to meet the current requirements, the Government of India passed the Plants, Fruits, Seeds (Regulation of Import into India) Order 1984 which came into effect in June 1985. The conditions for the import of 17 crops are stipulated in this order. The main features of the order are:

1. Seed has been brought under the purview of the DIP Act.

2. No consignment can be imported into the country without valid import permit issued by the Plant Protection Adviser to the Government of India.

3. No consignment can be imported without an official phytosanitary certificate issued by the plant quarantine agency of the exporting country.

4. Post-entry growth of the specified crops at approved locations.

A. Conditions for import

In India, there are general and specific conditions for the import of plants (including bulbs, tubers, rhizomes, corms, cuttings, buddings, grafts, layers, suckers, roots and flowers) and plant materials (including plant products such as ginned cotton, unmanufactured tobacco etc.).

General conditions

1. Import permits are essential for :

a. Seeds and fruits for consumption,

b. Seeds and plants for sowing or planting,

c. Soil, earth clay for microbiological, soilmechanics or mineralogical investigations

d. Peat for horticultural purposes

e. Live insects and f. Living fungi in pure culture, including *Rhizobium cultures.*

2. All plants should be accompanied by Phytosanitary certificate from the country of origin.

3. All plants on arrival at port, shall be inspected and if necessary fumigated, disinfested or disinfected by Plant Protection Adviser to the Government of India or any other officer authorized by him on his behalf.

4. Plants and seeds which require post-entry quarantine inspection shall be grown in post-entry quarantine facilities approved by the Plant Protection Adviser to the Government of India.

5. Import of hay or straw or any material of plant origin used for packing is prohibited.

6. Import of soil, earth, compost, sand, plant debris along with plants, fruits and seeds is prohibited.

Note: Cut flowers, garlands, bouquets, fruits and vegetables weighing less than 2 kg for personal use may be imported without a permit or phytosanitary certificate, but are subject to inspection.

Special conditions In addition to the general conditions, there are special conditions for certain notified plants as follows.

1. Prohibition from certain areas

Name of the plant	Countries from where prohibited
Cocoa and all species of Sterculiaceae	Africa, Sri Lanka, West Indies and Bombaceae
Coffee beans	Africa, South America, Sri Lanka
Rubber	South America, West Indies
Sugarcane	Australia, Fiji, Papua New Guinea
Sunflower	Argentina, Peru

1. Prohibited for general public: Coconut plants and seeds, coffee plants and seeds, cotton seeds and unginned cotton, forest tree seed (*Castanea*, *Pinus*, *Ulmus*), groundnut seeds and cuttings, potato, sugarcane, tobacco seeds and wheat seeds.

2. Plants/seeds which require post entry quarantine: Cocoa, citrus, coconut, groundnut, potato, sugarcane, sunflower, tobacco and wheat.

3. Additional declarations required for notified plants (see Table below)

Plant/seed Additional declarations for freedom of pests

All species of *Allium* (onion, garlic, leek, chive, shallot, etc.) .	Smut (*Urocystis cepulae*)
Cocoa and all species of the family Sterculiaceae and Bombaceae	Pod rot (*Monilia rorei*), Mealy pod (*Trachysphaeria* and *fructigena*), Witches' broom (*Crinipellia perniciosus*) Swollen shoot virus
All species of *Citrus* (lemon, lime, orange etc.,)	Mal Secco (*Deuterophoma tracheiphila*)
Coconut seeds and all species of C*ocos*	Lethal yellowing, Cadang, Bronze leaf wilt, Guam ,Coconut disease, Leaf scorch
Coffee – plants, seeds	American leaf spot (*Omphali flavida*), virus diseases

Cotton seeds	Bacterial blight (*Xanthomonas axonopodis* pv. *malvacearum* and *Glomerella gossypii*)
Forest tree seeds (all species *Cronartium ribicola, Endothea* of *Pinus, Ulmus, Castanea*)	*parasitica, Ceratocystis ulmi, Dothiostroma pini*.
Groundnut seeds (all species of *Arachis*)	i. production of seeds in areas free of *Puccinia arachidis* and *Sphaceloma arachidis*. ii. Inspection of parent crops in active growing seasons and certification for freedom from peanut mottle, peanut stunt, marginal chlorosis and peanut stripe viruses
Lucerne (all species of *Medicago*)	Bacterial wilt (*Corynebacterium incidiosum*)
Potato (all species of *Solanum*)	Wart (*Synchytrium endobioticum*) and freedom of parent crop from virus diseases
Rubber (all species of *Hevea*)	South American leaf blight (*Microcyclus ulei, Sphaerostilbe repens*)
Sugarcane (all species of *Saccharum*)	Leaf scald (*Xanthomonas albineans*), Gummosis (*Xanthomonas vasculorum*), Sereh, downy mildew, chlorotic streak and Fiji disease.

Agencies involved in plant quarantine

The authority to implement the quarantine rules and regulations framed under DIP Act rests basically with the Directorate of plant Protection, Quarantine & Storage, under the Ministry of Agriculture. This organization handles bulk import and export of seed and planting material for commerical purpose. Under this organization 9 seaports, 10 airports and 7 land frontiers are functioning. These are the recognized ports for entries for import of plant and plant material. The names and places of the ports and stations are as follows.

A. Seaports - Place State / Union territory

1. Bhavnagar - Gujarat
2. Calcutta - West Bengal
3. Chennai - Tamil Nadu
4. Cochin - Kerala
5. Mumbai - Maharashtra
6. Nagapattinam - Tamil Nadu
7. Rameswaram - Tamil Nadu
8. Tuticorin - Tamil Nadu
9. Visakhapatnam - Andhra Pradesh

B. Airports

1. Amritsar - Punjab
2. Calcutta - West Bengal
3. Chennai - Tamil Nadu
4. Hyderabad - Andhra Pradesh
5. Mumbai - Maharashtra
6. New Delhi - New Delhi
7. Patna - Bihar
8. Tiruchirappalli - Tamil Nadu
9. Trivandrum - Kerala
10. Varanasi - Uttar Pradesh

C. Land frontiers

1. Amritsar Railway Station - Punjab
2. Attari Railway Station - Punjab
3. Attari-Wagah Border- Punjab
4. Bangaon Benapol Border - West Bengal
5. Gede Road Railway Station - West Bengal
6. Kalimpong - West Bengal
7. Sukhia Pokhri - West Bengal

The Government of India has also approved three other national institutions to act as official quarantine agencies, especially for research material.

1. National Bureau of Plant Genetic Resources (NBPGR)

The NBPGR in New Delhi and its regional station at Hyderabad in the agency involved in processing of germplasm, seed, plant material of agricultural, horticultural, and silvicultural crops of all the institutions of Indian Council of Agricultural Research (ICAR) functioning in the country. It is also responsible for quarantine clearance of seed and plant material received from International Agricultural Research Centers *viz*., ICRISAT, ICARDA, CIMMYT, etc. ICRISAT was established in 1972 at Patancheru (near Hyderabad) to work on improvement of sorghum, pearlmillet, chickpea, pigeonpea and groundnut. The quarantine clearance of all its exchanges was handled by Central Plant Protection Training Institute of Directorate of Plant Protection, Quarantine & Storage, until July 1986. This authority was later passed on to NBPGR in August 1986.

2. Forest Research Institute (FRI), Dehra Dun, for forestry plants and

3. Botanical Survey of India (BSI) for other plants.

Quarantine inspection, treatment and certification procedures Inspection: Inspection of plant material is an important part of plant quarantine procedure, and may be done both in the exporting country, before issue of a health certificate and after arrival to detect any pest or disease which may have become evident during transit. Publications like manuals, hand books on individual organisms of quarantine importance are prepared with illustration by each country / region to help inspectors. The following series published by Commonwealth Mycological Institute ill be useful for all countries.

1. CMI descriptions of pathogenic fungi and bacteria
2. CMI/AAB descriptions of plant viruses and
3. CMI distribution maps of plant diseases.

The various steps involved in import quarantine clearance of seed and propagating plant material is outlined below

i. Securitization of import application filed along with attached documents such as phytosanitary certificate (original), permit (importer's copy), shipping bill, invoice, packing list and customs bill of entry etc., to ensure the import is in order and that no prohibited plant material is imported.

ii. Assessment of inspection fees and registration of application.

iii. Inspection and sampling of the consignment at port warehouses or container terminal. Sampling of seed usually carried out as per the provisions of ISTA Rules and Regulations. Whereas in case of bulk import of vegetative planting material such as cuttings/saplings/ bud woods/bulbs/tubers etc., at least a minimum of 0.1% of propagules are sampled variety and examined to ensure free from exotic pests or pathogens. In case of quarantine pests suspected, 100 per cent inspection is carried out for critical assessment of the risk.

iv. Detailed laboratory testing

a. Visual inspection: The samples of seed/ propagating plant material is examined with the help of illuminated magnifier to record live insect infestation, contamination by soil and weed seeds, nematode galls, sclerotia, smut/bunt balls etc. Sometimes inspections are carried out under U.V. lamp to facilitate detection of specific seed-borne inspection by characteristic fluorescence.

b. X-Ray test for detecting hidden insect infestation such as bruchids and weevils that bore into seed.

c. Washing test to detect surface-borne oospores of downy mildew/smut spores/ bunt spores etc. and nematode cysts. Seed samples of onion, clover and lucerne are soaked for 24 to detect stem and bulb nematode and also root washings are examined for ectoparasitic nematodes.

d. Incubation tests such as blotter test or agar plate test carried out for detecting seed-borne pathogens such as fungi. Fluorescent pseudomonas agar used for selective detection of seed-borne bacteria.

e. Grow-out test coupled with indicator inoculation tests for detecting seedborne viruses and bacteria. Besides this, special diagnostic tests such as Electron Microscopy (dip method), Enzyme Linked Immunosorbent Assay (ELISA) are used for detection of specific viruses in the imported seed / planting material pencillnase based DAC-ELISA is widely used for the detection of virus in imported seed/plant material. The detailed testing procedures for the detection of seed-borne pathogens are outlined in the seed health testing chapter.

v. Fumigation and treatment techniques

Fumigation is the versatile technique used for eliminating insect infestation. Methyl bromide is the most commonly employed for controlling insect infestation and readily adopted in quarantine programmes as the exposure time involved is short and affect all stages of insect pests and high penetrating power. Two types of fumigation *viz*., i. atmospheric fumigation under gas-proof sheets or chambers and ii. vacuum fumigation in vacuum chamber is widely employed. The other

chemical treatments include insecticidal/fungicidal drippings or spraying or seed dressings are invariably associated with growing under post-entry quarantine conditions. The temperature treatments such as hot water treatment/ hot air treatment or vapour heat treatment are carried out to control internally borne infection/infestation and the latter particularly employed to control fruit fly infestation.

Cold treatments such as refrigeration to control insect infestation in fresh fruits and vegetables. Of late, irradiation is used to control insect infestation and spoilage of food products during storage and as well as application of high intensity electronic beams through an accelerator is under experimentation.

Certification

Phytosanitary or health certificate is a certificate which should accompany a plant or plant material or seed which is to be moved from one place to another place. This certificate indicates or certifies that the material under transit is free from pests or diseases. A model phytosanitary certificate proposed at the Government consultation on the International Plant Protection convention at Rome in 1976 (Chock, 1977) and approved by
F.A.O. in 1979 is given below.

MODEL PHYTOSANITARY CERTIFICATE

(to be typed or printed in block letters)

Plant Protection OrganizationNo. _____ of _____

To: Plant Protection Organization(s) of

_____

DESCRIPTION OF CONSIGNMENT

Name and address of exporter _____Declared name and address of consignee _____Number and description of packages _____Distinguishing marks _____Place of origin

_____Declared means of conveyance _____Declared point of entry _____Name of produce and quantity declared _____Botanical name of plants

_____

This is to certify that the plants or plant products described above have been inspected according to appropriate procedures and are considered to be free from quarantine pests and practically free from injurious pests; and that they are considered to conform to the current phytosanitary regulations of the importing country.

DISINFESTATION AND/OR DISINFECTION TREATMENT

Date _____ Treatment

_____ Chemical (active ingredient) ____

Duration and temperature _____ Concentration

_____ Additional information _____

Additional declaration:

(Signature)

Note:No financial liability with respect to this certificate shall attach to..... (name of plant protection organization)... or to any of its officers or representatives.

Domestic Quarantine

Under the DIP Act, the Directorate of Plant Protection, Quarantine and storage has the responsibility to take the necessary steps and regulate the inter-state movement of plants and plant material in order to prevent the further spread of destructive insects and diseases that have already entered the country. The sole object of enforcing domestic quarantine is to prevent the spread of these diseases from infected to non-infected areas. Currently, domestic plant quarantine exists in four diseases, wart (*Synchytrium endobioticum*) of potato from 1959, bunchy top (virus) of banana from 1959, mosaic (virus) of banana from 1961 and apple scab (*Venturia inaequalis*) from 1979. Most of the states in India have plant quarantine laws to avoid entry of plant pests and diseases

1. Bunchy top of banana: The export and the transport from the States of Assam, Kerala, Orissa, West Bengal, Tamil Nadu to any other State of Banana plant or any other plant of the genus *Musa*, including sucker, stem, leaf, flower, and any other part thereof which may be used for propagation, or the materials of banana plant or any other plant of the genus *Musa*, which are used for packing and wrapping, excluding the banana fruit is prohibited.

2. Banana mosaic : The export and transport from the States of Maharashtra andGujarat of any plant of Banana or any other plant of genus *Musa* including the sucker, stem,flower and any

other part thereof, but excluding leaf and fruit thereof is prohibited; videGovernment of India notification No.F. 6-10-PPS dated the 11thApril, 1961.

3. Potato wart: The export to potato tubers from the State of West Bengal to any other State or territory of India is prohibited.

4. Apple scab: The Directorate of Horticulture, Himachal Pradesh worked out a detailed scheme for the eradication of scab, and also issued a notification No.NIC.20/76 dated 28 December 1978, prohibiting the export of planting material of apple outside the State.

In Tamil Nadu as per Madras pests and Diseases Act of 1919, quarantine regulations are periodically enforced. e.g., cardamom mosaic prevalent in Anamalai area of Coimbatore District and is free from Nelliampatti area. Hence the movement of diseased plant material from Anamalai to Nelliampatti area is prevented.

Limitations

There are many limitations to implementing domestic plant quarantine in India due to the vastness of the country and the unrestricted movement of plant material from one state to another. As a result the diseases like bunchy top and mosaic of banana have spread to several other states. However, the wart disease, golden nematode of potato, and scab of apple are restricted in the states where they were initially noticed.

Export regulations

In India the plant quarantine measures for exporting plants and material including seeds have been streamlined and rigid inspections are enforced before the material is allowed to be landed into the country. At present plant quarantine regulations differ with different countries for major agricultural commodities that are being exported out of India. The Central Government has authorized officers of the Directorate of Plant Protection, Quarantine & Storage, ICAR Research Institutes, National Institutes like Forest Research Institute, Botanical Survey of India, and the Directorates of Agriculture of all States.

The quarantine authorities have also framed terms and conditions pertaining to inspection, fumigation or disinfection of the exportable plants and plant material in India including the following schedule/or fee for inspection and issue of phytosanitary certificate, and/or fumigation or disinfection in respect of plants, plant material, seeds, and plant products to issue phytosanitary certificate. All the plants and plant material are subjected to inspection by

officials issuing certificate. Infested materials are given necessary treatment with chemicals and fumigated if necessary.

The list of plant quarantine and fumigation stations in India is given below.

Punjab

1. Plant Quarantine and Fumigation Station, Hussainiwala, Ferozepur District.
2. Plant Quarantine and Fumigation Station, Attari – Wagah Border, near Attari Bus Stand, Attari, Ferozepur District.
3. Plant Quarantine and Fumigation Station, Civil Aerodrome, Rajasansi, Amritsar.

New Delhi

1. Plant Quarantine and Fumigation Station, Palam Airport, New Delhi – 10.
2. Plant Quarantine and Fumigation Station, Garden Reach Road, Calcutta–24.
3. Plant Quarantine and Fumigation Station Sukhiapokri, Darjeeling District.

Gujarat

1. Plant Quarantine and Fumigation Station, Haryana Plot No.75, Behind Yusuf Bagh. Bhavnagar.

Maharashtra

1. Plant Quarantine and Fumigation Station, Haji Bunder Road, Sewri, Mumbai

Andhra Pradesh

1. Plant Quarantine and Fumigation Station, The Harbour, Visakhapatnam – 1.

Tamil Nadu

1. Plant Quarantine and Fumigation Station, 6, Clive Battery, Chennai – 1.
2. Plant Quarantine and Fumigation Station, 335, Beach Road, Tuticorin – 1.
3. Plant Quarantine and Fumigation Station, Tiruchirappalli Airport, Tiruchirappalli.
4. Plant Quarantine and Fumigation Station, 110, Railway Feeder Road, Rameswaram.

Kerala

1. Plant Quarantine and Fumigation Station, Willingdon Island, Cochin – 3

Lecture 24

Cultural methods – Rouging, eradication of alternate and collateral hosts, crop rotation, manure and fertilizer management, mixed cropping, sanitation, hot weather ploughing, soil amendments, time of sowing, seed rate and plant density, irrigation and drainage

Eradication

Eradication is the elimination of pathogen after it has become established in the area where host is growing. The following are the important methods followed to prevent the spread of the disease:

i. eradication of alternate hosts,
ii. eradication of collateral and self sown overwintering hosts
iii. eradication of the affected plants or trees,
iv. eradication of pathogens from infected plant parts by surgery and
v. eradication of culled out plant materials, debris, etc., through different cultural practices

i. Eradication of alternate hosts

Removal of alternate hosts helps to prevent and check the spread of the disease caused by heteroecious rust pathogens in the primary hosts. Barberry bush is the alternate host for black stem rust pathogen *Puccinia graminis tritici* on wheat where the pathogen survives in the off-season. Barberry was eradicated in Canada, Denmark, France, Hungary, Norway and in the U.S.A. by passing stringent laws in each country. The eradication of barberry had two benefits i.e., it elimination of early spring primary inoculum and prevention of the formation of new physiologic races of the pathogens. In the U.S.A. white pine blister rust *(Cronartium ribicola)* was controlled by eradication of alternate host, *Ribes*. In Australia, Europe and the U.S.A. the apple rust (*Gymnosporangium juniperi-virginianae*) is controlled by eradication of alternate host, cedar.

ii. Eradication of collateral and self sown overwintering hosts

There are many weed hosts or wild species of cultivated plants act as collateral hosts or volunteer plants of an economic crop which act as reservoirs of pathogens of annual crop. Reservoir hosts help the pathogen to continue the infection chain. The primary inoculum is produced on and dispersed from these hosts to the cultivated crop hosts. If these wild or uneconomic host plants of the pathogen are destroyed, the sources of primary inoculum are

eliminated and chances of initiation of the disease in the crop hosts are reduced. Destruction of these hosts breaks the life cycle of the pathogen and the infection chain. Reservoir hosts or indigenous plant species which are not actually involved with the life cycle of the pathogen but provide additional sites for its persistence and multiplication. In some cases such plant species act as symptomless carriers, especially for viruses and root pathogens. Regional elimination of such hosts requires careful attention to roadside areas and other non-agricultural land also.

Crop	**Disease**	**Pathogen**	**Collateral hosts**
a. Fungi 1. Rice	**Blast**	***Pyricularia oryzae***	*Brachiaria mutica* *Dinebra retroflexa,* *Leersia hexandra,* *Panicum repens.*
2. Sorghum	Ergot	*Sphacelia sorghi*	*Panicum* spp.
b. Bacteria 1. Rice	Bacterial leaf blight	*Xanthomonas oryzae* pv. *oryzae*	*Cyanodon dactylon, Cyperus rotundus, Leersia hexandra, Leersia oryzoides, Panicum repens, Paspalum dictum.*
2. Apple and pear	Fire blight	*Erwinia amylovora*	*Hauthom* bushes *Crataegus* sp.
3. Cotton	Bacterial blight	X. *axonopodis* pv.*malvacearum*	*Eriodendron anfructuosum, Jatropha curcas, Thurbaria thespesoides*
c. Viruses 1. Potato	Rugose mosaic	Rugose mosaic virus	*Physalis* spp.

2. Bean	Yellow mosaic	Bean yellow mosaic virus	Sweet clover
3. Bhendi	Yellow vein mosaic	Bhendi yellow vein mosaic virus	*Hibiscus tetraphyllus*
d.Phytoplasma **1. Brinjal**	Little leaf	Phytoplasma	*Catharanthus roseus, Datura* sp.

Self sown crops / volunteer plants help the pathogen to overwinter / oversummer in the absence of economic hosts. In Sudan it was enforced through legislation to pull out the cotton plants to prevent regrowth which facilitate the carryover of the cotton leaf curl virus. Wheat streak mosaic virus has been effectively controlled by eliminating the volunteer wheat plants that served as reservoirs for the virus.

iii. Eradication of affected plants or trees

In some threatening plant diseases, it is essential to eradicate the host and the pathogen from an area. Citrus, canker (*Xanthomonas axonopodis* pv. *citri)* is an example of success of an eradication programme. This disease was first noticed in Florida citrus trees in 1913. An eradication campaign was started in 1915. All the citrus nurseries and orchards were inspected and the infected trees were cut and burnt. The eradication programme continued till 1927 and no citrus canker was present in that area. Peach yellows and peach rosette were also controlled by removal and destruction of diseased trees. In Tamil Nadu also there were some eradication campaigns launched under Destructive Pests and Diseases Act. Eradication programme was set up to control bud rot of palms and completed with success. At Sathyamangalam eradication of sandal wood tree affected by spike disease was also made to contain this disease.

iv. Eradication of pathogens from infected plant parts by surgery

Eradication of affected plant parts (tree surgery) are also practiced in certain cases which reduces the source of primary inoculum. Lesions caused by fire blight bacterium *(Erwinia amylovora)* on pear and apple trees are removed during winter months. This not only prevents further spread in the affected trees but also reduces the amount of inoculum that can spread to other branches and trees. The cankered areas in the branch or trunk of almond and pear trees caused by *Ceratocystis fimbriata* are surgically removed and the trees are saved. Tree surgery is

also practiced in coconut trees affected by stem bleeding disease *(Ceratocystis paradoxa)*, citrus gummosis (*Phytophthora citrophthora*), *Dendrophthoe* spp. on citrus, bud rot of palms (*Phytophthora palmivora*) and koleroga of arecanut (*P.arecae*)

v. Eradication of culled out plant materials, debris etc. through different cultural practices

2. Crop rotation

Crop rotation is essentially a preventive measure and has its effect mainly on the succeeding crop. Crop rotation is the oldest and cheapest method adopted in agriculture for eradication of certain types of pathogens from infested soil. Continuous cropping or monoculturing provides opportunity for perpetuation of pathogenic organisms in the soil when the same crop is raised year after year in the same field.

The soil-borne pathogens of that crop easily perennate in the soil and increase in their population. After sometime, the soil becomes so heavily infested that it becomes unfit for cultivation of the particular crop. Virus diseases of crop plants and their vectors are found to increase after every crop if a crop is cultivated continuously in a field. On the other hand, when immune, resistant or non-host crops are grown for a definite duration after a susceptible crop in the field it is expected that in the absence of nutrition, the pathogen will be starved off and the population of such pathogens consequently decreases.

It is also possible that different crops release some biochemical substances in their root exudates which either directly kill the pathogen or encourage development of antagonistic microorganisms in the soil. In this way, crop rotation is one of the most effective methods of root disease control. Organisms which are soil inhabitant types remain in soil for a very long time, even more than five years in the absence of the host. Long-lived spores or the organisms by themselves, subsist as saprophytes and therefore their presence in soil is long term. Onion smut (*Urocystis cepulae*)and club root (*Plasmodiophora brassicae*)organisms are producing resistant type of spores while *Rhizoctonia, Fusarium* and some species of *Pythium* are those which could remain in soil as saprophytes for a very long time.

Eradication of such organisms becomes fairly difficult. Soil also harbours soil invaders. These organisms are not persistent and they can live as long as the host residues serve as substrate. They perish when they are forced to exist in the soil in competition with soil inhabitants and disappear gradually in due course. Bean anthracnose fungus *Colletotrichum lindemuthianum*, cabbage black rot bacterium, *Xanthomonas campestris* pv. *campestris* are

some examples, which live in soil for 1 to 2 years. They can be eliminated from soil by adopting 3 or 4 year rotation with non-host crops. Crop rotation is effective in the control of brown stem rot of soybean (*Cephalosporium gregatum*). The disease incidence can be reduced to a great extent by rotating with corn for 4 to 5 years between two soybean crops.

Crop rotation with sugarcane or paddy is effective in the control of 'Panama wilt' of banana (*Fusarium oxysporum* f.sp. *cubense*) and crop rotation with paddy or green manures is effective in the control of red rot of sugarcane (*Colletotrichum falcatum*). Rotation of cereal crops like pearlmillet, finger millet or fox-tail millet is recommended for the control of *Macrophomina* root rot of pulse crops. Two year crop rotation with lucerne is recommended in the control of *Verticillium* wilt of cotton. Many diseases such as *Fusarium* wilt of pigeonpea (*F. udum*), foot rot of betelvine (*Phytophthora capsici*), bacterial leaf blight of rice (*Xanthomonas oryzae* pv. *oryzae*), bacterial blight of cotton (*X.campestris* pv. m*alvacearum*) etc., are controlled by this method. Soybean seed infection by *Phomopsis* sp. can be reduced by rotating soybean with maize. Pathogens are reduced or eliminated by following the crop rotations given in the table.

Table. Effect of crop rotation in reduction / elimination of plant pathogens

Beneficial crop	Pathogen reduced or eliminated	Preceding crop
1.Rice	*Verticillium dahliae*	Cotton
2.Pea	*Gaeiimannomyces graminis*	Wheat
3.Sudan grass	*Pseudomonas solanacearum*	Tomato

3. Fallowing

Fallowing starves the pathogen and helps in reduction of the inoculum by elimination of the host. Diseases like *Macrophomina* root rot on different crop plants is controlled by following this method. Flood fallowing is to a depth of 0.6 to 1.5 m for 4 to 6 months markedly reduced the Panama wilt pathogen *Fusarium oxysporum* f.sp.*cubense* inoculum in banana. Soil inoculum of *Phytophthora parasitica* var. n*icotianae*, the causal organism of black shank of tobacco was destroyed by flooding the field for 3 to 4 months and by raising swamp rice in a 2 year rotation with tobacco-rice crop in Java. Flooding the soil strewn with debris infected by *Xanthomonas axonopodis* pv. m*alvacearum* for 4 days reduced the inoculum level and thus the incidence of disease was only 2.1% as against 69.5% in unflooded fields. Wet fallowing makes

the pathogenic propagule in or on the soil to germinate, spent them, is become susceptible attack of saprophytes. Example, *Sclerotium rolfsii* and *Verticillium dahliae*. The sclerotia or microsclerotia of these fungi are activated in the absence of root exudates of this host. They germinate quickly when there is alternate wetting and drying of the soil. When the population of *Pythium myriotylum* is not high wet fallowing is successful in reducing the population. Wet fallowing reduces saprophytic survival of *Alternaria solani* on crop debris.

4. Application of organic manures

Addition of organic manures like farm yard manure or green manures or oil cakes to the soil increases the antagonistic microorganisms in the soil. Build up of antagonistic microorganisms reduces the population of soil borne plant pathogens and the diseases caused by them. Application of farm yard manure at the rate of 12.5 tonnes/ha reduced the incidence of *Macrophomina* root rot of cotton. Application of 5 kg of neem cake/tree three times in a year reduces the basal stem rot (*Ganoderma lucidum)* of coconut. In the control of sesame root rot *(Macrophomina phaseolina)* application of neem cake at the rate of 150 kg/ha is recommended. Application of neem cake at the rate of 2 tonnes/ha in two split doses and covering with mud reduced foot rot disease in betelvine garden.

Soil amendment

It has been proved that the organic amendments rich in carbon and deficient in nitrogen control the take-all disease (O*phiobolus graminis*) of wheat. There is considerable liberation of CO_2 by soil saprophytes which suppresses the pathogenic activity of this fungus .In the process of survival also, low nitrogen content in the soil reduces the longevity of the fungus. *Phytophthora* root rot of avocado is controlled by amending the soils with alfalfa meal- a material of low C/N ratio. The other diseases are pea root rot *Aphanomyces euteichus* when cruciferous plant residues were incorporated into the soil. Alfalfa meal and barley straw application in the soil reduced the root rot of cotton and sorghum caused by *Macrophomina phaseolina.* Black scurf of potato (*Rhizoctonia solani*) is less in the field where wheat straw was incorporated.

5. Summer ploughing

Deep ploughing during summer periods buries the inocula of fungi of soil borne nature. Fungal propagules, sclerotia and different types of spores conidia on plant refuses die when exposed to sunlight due to the higher temperature prevailing during the summer. Further

infected self sown plants, volunteer hosts plants, weed hosts, regrowths from the plant roots, alternate hosts and alternative hosts are also destroyed. Here, the spread of the disease is avoided. Groundnut blight (*Corticium rolfsii*) is controlled by ploughing the soil to a depth of 20 cm. The inverted plough sole soil buries the sclerotia of the fungi, *Claviceps, Sclerotium* and *Sclerotinia* in association with plant or alone, impedes the discharge of ascospores from perithecia. Bunt and smut spores of wheat, smut spores of sugarcane and sorghum and microsclerotia of *Verticillium* in cotton are buried deep in to the soil by deep ploughing.

6. Crop growing seasons

Rice blast becomes serious when the rice crop is raised from August to September in Tamil Nadu. Ragi blast becomes serious when sowing is made between June and August. Similarly yellow mosaic of blackgram/green gram and phyllody of sesame are serious during kharif season in South India. Incidence of powdery mildews of different crops is found to be high during rabi when compared to kharif and summer seasons. In bhendi, yellow vein mosaic incidence is very high during summer. The seasons with high incidence of diseases should be avoided in the epidemic areas.

a. Adjustment of sowing time

In many diseases the incidence is more severe when the susceptible stage of the plant growth and favourable conditions for the pathogens coincides. While choosing the time of sowing it should be taken into consideration that susceptible stage of the crop growth and soil conditions and other environments favourable for maximum activity of the pathogen does not fall at the same time. Properly adjusting the sowing dates can give good dividends. Late planted wheat crops contract less infection than wheat planted on normal dates. Early and late sown crops have been found to be free from Oodhubathi disease of rice.

Avoiding cool and cloudy days for planting will help to reduce red rot of sugarcane. Late sowing of winter wheat and barley is considered to be the most effective measures in reducing take all disease of wheat. Rapeseed sown in mid to late August is more liable to attack by leaf spot (*Alternaria brassicae*) than late-sown crops. Pea and gram planted soon after rains when soil temperature and moisture are at a high level, show high incidence of root rot and blight. As the soil temperature falls and moisture becomes less (Nov-Dec) these diseases are also reduced. In areas where these diseases are serious, late sowing helps in saving the crop. Stem rust of wheat damages the late sown crop more than the early sown crop. Because, time of onset of

disease and ear formation coincides. Sowing from January to April or October to December is advocated to escape from the attack of neck blast of finger millet. Peas and chickpea sown in October usually suffer heavily from root rot and wilt (a complex of *Fusarium*, *Rhizoctonia* and *Sclerotium*). When these crops are sown late, the diseases are not so severe or almost absent. The groundnut rosette is transmitted by *Aphis craccivora.*

In Nigeria the population of this vector is low in crops sown in June than in July. The sowing time is adjusted in cumbu and sorghum in such a way that the flowering stage does not coincide with the rainy season to avoid the sugary diseases. Early sown crops show decreased incidence of curly top and yellows on sugarbeet, rosette on groundnut and barley yellow dwarf on cereals. Delayed sowing on the other hand is beneficial to maize rough dwarf disease.

b. Adjustment of harvesting time

Harvesting of groundnut should not coincide with the rainy days and it helps to avoid infection by *Aspergillus flavus*. Freedom of onions and roses grown in rainless seasons from downy mildew diseases and freedom of beans, chilli and cucurbits from bacterial diseases in such seasons are the best examples for sowing of crops at correct season to avoid disease outbreaks. In the case of deciduous fruit trees and grapevines, the season of sprouting, flowering and fruit set can be advanced or delayed by pruning practices or by treatments to break dormancy. Advantage can sometimes be taken of this fact to avoid coincidence of all or one of these phases of host growth with weather periods particularly favourable to specific pathogens that attack trees in the phases.

7. Growing of seed crops

Coffee can be grown in the western Hemisphere usually free from coffee rust which causes heavy losses in Eastern Hemisphere. In the case of virus diseases this will be more useful. By growing seed materials in isolated places where the population of vectors is very low and the condition is uncongenial for the vectors. Virus free potato tubers to be used as seeds are grown in cool and windy places in many parts of the world. Under tropical and subtropical countries, such conditions prevail in the hills at high altitudes. Obtaining seed from disease-free localities has been very successfully resorted to the elimination of many seed –borne diseases. In the U.S.A. seed-potatoes are invariably grown in northern snow-clad sections, where viruses are practically absent and then exported to various other sectors in the south. Similar practice has been in vogue in India, where seed-potatoes are annually imported in southern states from Simla

hills for control of virus diseases and bacterial ring. In the U.S.A, the seed growing areas have been shifted to arid pacific regions for crops like cabbage, turnip, beans and peas for obtaining disease-free seed and indirectly controlling such diseases like black leg and black rot of cabbage and turnip and anthracnose of beans and peas. Similar practice is obtained in parts of Bombay, where the foot rot of ginger (*Pythium myriotylum*) prevalent in the southern parts, is controlled through the importation of seed-rhizomes from disease-free arid regions of the north, where the disease is practically non-existent on account of the dry climate, lighter soils and moderate rainfall.

8. Selection of seeds and seed materials

Seeds and seed materials carry many fungi, bacteria, viruses and phytoplasmas and may introduce these pathogens into the field, i.e., seeds and seed materials form the primary source of infection. Seed and seed materials like cuttings, tubers, grafts, setts etc., should be well matured, disease free, uninjured and have a high germinating capacity. The absence of an initial inoculum in seeds is definitely helpful in delaying or suppressing the incidence of the disease. It is a preventive method.

The diseases like foot rot, brown spot, short smut of sorghum, loose smut of wheat, bacterial blight of rice, bacterial blight of cotton, leaf crinkle of blackgram etc., are transmitted through seeds. Virus diseases and black ring of potatoes, foot rot of ginger, foot rot of betelvine, Panama disease of banana, red rot of sugarcane cassava mosaic, bunchy top and virus diseases of fruit trees are transmitted through tubers, setts, rhizomes, corns, grafts and budwoods. 'Tuber indexing' is a special method to obtain disease free seed materials in potato. It is commonly practiced by nurseries and seed merchants selling potato seed tubers. Use of seeds in the place of rhizome/sucker is recommended in the control of 'katte' disease of cardamom.

9. Leveling of the field and provision of drainage facilities

Water stagnation in different patches of field favours the fungi like *Pythium, Phytophthora, Rhizoctonia solani*, etc., for which proper leveling of the field before sowing or planting is very essential. Further improving the drainage is necessary in the control of sheath blight of rice. Provision of drainage channels in orchard crops like citrus, jack, mango etc., in the garden is necessary before planting. In the control of damping-off diseases of vegetable and other crops, raising seedling in the raised beds method is followed. Foot rot of ginger (*Pythium myriotylum*) is also controlled by following the raised bed system of nursery.

10. Seed rate

Use of higher seed rate in the nursery creates favourable microclimate for the pathogens causing damping-off in vegetables, tobacco, chillies and forest nurseries. Hence, use of optimum seed rate should be adhered in such crops.

11. Burning of stubbles and crop residues

Burning of plant wastes, crop residues, stubbles, *etc.,* in the areas selected for raising nurseries for vegetable crops, tobacco, chillies and forest trees etc. heats the soil and kills the inoculum of the pathogens present in the top layer of the soil. When nurseries are raised in these areas incidence of damping off disease is highly reduced. This practice is also followed in pits made for planting coconut, banana, fruit trees etc., Burning of wheat plant every second or third year is suggested for eradication of pathogen in the field when *Cephalosporium gramineum* infects wheat. Otherwise, debris in the field helps the perpetuation of the pathogen and the disease. Burning of rice crop residues avoid carryover of sheath blight (*Rhizoctonia solani*); stem rot (*Sclerotium oryzae*) of rice and bacterial blight of cotton.

12. Depth of sowing

Depth of sowing greatly influences seed transmission of smuts. Shallow planting in wet soils protects wheat plants from U*rocystis tritici* (flag smut) of wheat. Deep planting may cause delay in the emergence of seedlings, which may be vulnerable to pre-emergence damping off. Early emergence results in early lignification of tissues which become resistant to attack of soil-borne pathogens.

13. Spacing

Closer spacing invariably alters the microclimate underneath the canopy of the crop which may provide favourable environment for development of diseases. Boll rot in cotton is quite common in crowded crop. Defoliation of plants or skip cropping gives better control against the boll rot disease. In certain virus diseases like groundnut rosette the incidence is observed to be less when wider spacing is adopted. Closer spacing favours many air borne diseases because of high humidity in the crop canopy. Early and late blight of groundnut and blister blight of tea are more in dense canopy. Early spread of black rot of cabbage takes place in closer spacing. Crowded stands may reduce some systemic diseases. Cotton wilt caused by *Verticillium albo-atrum* will be less in closely planted crop if the fungal inoculum is less in the soil. Similarly closer spacing of rice reduces rice tungro virus infection particularly when vector

population is less. Avoiding shade and providing wider spacing reduces the incidence of powdery mildew of tobacco. Late blight of potato and downy mildew of grapevine spread fast in closer spaced crops. In the case of bud necrosis of groundnut caused by tomato spotted wilt virus, seeds are sown adopting closer spacing of 15x15cm to compensate the rogued out plants with regard to plant population and yield. These are examples where dense sowing helps in disease reduction.

The virus of tomato leaf curl, transmitted by *Bemisia tabaci*, is less severe in a crowded planting than in spaced planting. Same is true for cucumber mosaic, transmitted by *Aphis gossypii* and groundnut rosette transmitted by *Aphis craccivora*. The fungal diseases for which the phenomenon of lower incidence at closer spacing of the crop has been studied most profitably is the wilt caused by *Verticillium albo atrum* and V.*dahliae* in cotton. This is ascribed to the reduction of effective inoculum per plant in proportion to the increase in the number of plants per unit area in the densely sown field. The incidence of brown rot (*Cephalosporium gragatum*) of soybean is also higher in widely spaced planting than in closer rows.

14. Method of sowing/planting

In places where water accumulation is a problem to the crop growth sowing of seeds on the sides or ridges is found effective in reducing the incidence of *Sclerotium rolfsii* on groundnut and vegetable crops and *Sclerotinia sclerotiorum* and *Rhizoctonia solani* on vegetable crops and *Phytophthora* blight of pigeonpea. High ridging prevents infection of potato tubers, by zoospores from leaf lesions in late blight diseases. Ridging is disadvantageous in water deficit areas where it encourages pathogens like *Macrophomina phaseolina.*

15. High budding

High budding is a practice to avoid infection by gummosis fungus of citrus trees. In low budded plants the bud point is close proximity to infection centre (the soil), become readily diseased. High budding is a simple device for lengthening this distance between the bud point and infected soil. In this method the soil borne pathogens (*Phytophthora palmivora* and *P.citrophthora*) have no chance of reaching the bud point, through which they enter the bark. Staking of lower most branches arising close to the soil, increases the distance between the fruits and soil inoculum and removes the chances of brown rot (*Phytophthora sp*) infection and buck-eye rot of tomato (*P. nicotianae* var. p*arasitica*).

16. Avoiding injury

Injury of plant parts should be avoided in order to check the entry of pathogens. Clipping of tips of tall rice seedlings favours the entry of bacterial blight pathogen and incidence of the disease. Hence clipping should be avoided at the time of transplanting of rice. While harvesting the pods in groundnut, fruits in tree crops and vegetable crops injuries to the fruits pave the way for the pathogen and causing pod/fruit rot. It also reduces the storage life of fruits and vegetables. Hence much care should be given to avoid wounds during the harvest time.

17. Altering the soil pH

In certain soil borne diseases adjustment of soil reaction helps in the reduction of inoculum level of the pathogens. The altered pH of the environment forms a barrier against the pathogen. A very low pH less than 5.2 is unfavourable to common scab bacterium on potato (*Streptomyces scabies*). Thus, use of acid forming fertilizers (like sulphur) and avoiding lime and calcium ammonium nitrate application are effective in controlling the common scab disease.

On the other hand the club root pathogen of cabbage (*Plasmodiophora brassicae*) cannot live and infect when the soil pH is 7.0 or more. Hence liming which increases the soil pH gives satisfactory control of club root disease. In Punjab, root rot of tobacco (*Macrophomina phaseolina*) has been overcome by application of 2.5 to 5.0 tons of lime /ha to the soil.

18. Mixed cropping

Mixed cropping materially helps in checking certain diseases. Blight of pulse crop (*Phyllosticta phaseolina)* has been successfully overcome by growing pulses as a mixed crop with cereals like sorghum and pearlmillet.

19. Intercropping

Intercropping is also a device in the control of some soil borne diseases. Intercrops should be properly chosen so that they should not have any common pathogen for e.g., *Macrophomina phaseolina* has got wide host range and hence common host should not be grown as intercrops. Intercropping with moth bean (*Phaseolus aconitifolius*) in a cotton field reduced the root rot (*M.phaseolina*) incidence.

Due to reduction in the number of host plants there is sufficient spacing between them and chances of contact between foliage of roots of diseased and healthy plant are greatly reduced. Therefore, root pathogens are unable to spread from diseased to healthy roots and spread of foliar pathogens is also reduced to a great extent. Intercropping of sorghum in

pigeonpea field reduced the wilt (F. *udum*) incidence. The roots of non-host plants may act as a barrier obstructing the movement of pathogens in soil. They may release toxic substances from their roots which may suppress the growth of the pathogens attacking the main crop. Hydrocyanic acid (HCN) in root exudates of sorghum is toxic to *F. udum*, the pigeonpea wilt fungus. Intercropping of sorghum or mothbean in a crop of clusterbean reduced the incidence of root rot (*R.solani*) and wilt (*F.coeruleum*) from 50 to 60% in single crop to 8 to 15% in the mixed crop.

Intercropping of pigeonpea with gingelly at 1:6 ratio reduced the incidence of phyllody disease. In Jordan, intercropping tomatoes with cucumber is found to be effective and cheaper in controlling the whiteflies and lowering the incidence of tomato yellow leaf curl virus. (TYLCV) Cucumber is planted one month before tomato. Cucumber is known to be a preferred host for whiteflies and immune to TYLCV. Insecticides are applied when adult whitefly populations are at high levels, usually two weeks after planting of cucumber and the second one before tomato planting. Growing of an intercrop of cereals such as corn or sorghum between rows of peach trees is an effective method in combating Texas root rot (*Phymatotrichum omnivorum*) infection in the U.S.A.

20. Barrier cropping

Taller crops can be grown to protect a crop of lesser height from virus vectors. The insects may land at the taller crops (barrier crops) and the dwarf crop may escape from virus diseases by those insects. Barrier cropping with 3 rows of maize or sorghum or pearlmillet around the main crop namely blackgram or greengram is effective in reducing the vector population and incidence of yellow mosaic. Another best example is growing of 3 rows of kale or barley as barrier crops in cauliflower seed beds and undersown beet steckling against cauliflower mosaic and beet yellows diseases respectively. The incoming aphids are thought to land on the barley or kale and probe briefly, causing them to lose the non-persistently transmitted virus they are carrying. Maize or sunflower are the other barrier crops considered for these crops.

21. Decoy crop and trap crop

Decoy crops (hostile crops) are non-host crops sown with the purpose of making soil-borne pathogens waste their infection potential. This is effected by activating dormant

propagules of fungi, seeds of parasitic plants, etc. in absence of the host. A list of pathogens that can be decoyed is given in table.

Table. **Decoy crops for the reduction of pathogen populations**

Host	Pathogen	Decoy crops
1. Sorghum	*Striga asiatica*	Sudan grass
2. Cabbage	*Plasmodiophora brassicae*	Rye grass, *Papaver rhoeas*, *Reseda odorata*
3. Potato	*Spongospora subterranea*	*Datura stramonium*
4.Tomato, tobacco	*Orobanche* spp.	Sunflower, safflower, lucerne, chickpea etc.

Trap crops are host crops of the pathogen, sown to attract pathogens but destined to be harvested or destroyed before they complete their life cycle. Fodder sorghum can be raised as a trap crop to reduce downy mildew of sorghum.

22. Trenching

Trenching between rows of trees in orchards has been effectively utilized in arresting the growth and spread of the pathogen in the soil to the neighbouring trees. *Ganoderma lucidum* root rot infected citrus trees should be isolated by digging a trench of 30 cm wide and 60 cm to 90 cm deep around the tree at a distance of 2.5 to 3.0 m from the base to prevent the contact of diseased roots with healthy roots. Thereby the spread of the pathogen to neighbouring tree is prevented. Similar method is also followed in the control of basal stem rot (*Ganoderma lucidum*) of coconut in India.

23. Isolation distances

The distance between seed production and commercial plots has been worked out for reducing seed borne loose smut of barley and wheat. Barley and wheat crops should be isolated by at least 50 m from any source of loose smut infection for production of certified seeds in the U.K.

The number of viruliferous insects reaching a healthy crop from a diseased one decreases with distance between them so that cultivation of susceptible crops at a distance from each other delays or reduces the severity of virus diseases. Incidence of lettuce and cucumber mosaic viruses is about 3% if the new lettuce crop is sown 0.8 km away from an old lettuce field Much

greater incidence of mosaic in sugarbeet fields occurs within 90 metres of a seed crop than in the fields at a greater distance. Beet mosaic and beet yellows are markedly reduced by isolating beet fields by 19 to 24 km and 24 to 32 km mites respectively from a large source of infected beets.

24. Yellow sticky traps

Sticky, yellow polythene sheets erected vertically on the windward side of red pepper fields have been sown to reduce the incidence of potato virus Y (PVY) and cucumber mosaic virus (CMV) in the crop. The aphids are attracted to the yellow colour and are caught on the sticky polythene. The control obtained was so successful that the method has become a standard control procedure in red pepper crops in Israel. Similar traps have also been used to protect 'seed' potato crops, against potato leaf roll virus. Yellow sticky traps are in use to attract and kill the whitefly vectors which spread yellow mosaic of blackgram and greengram and bhendi yellow vein mosaic.

25. Mulching

Mulching or covering of top soil with organic residues often helps in reducing plant diseases. Mulches of non-host origin should be used in the field. These mulches are known to release inhibitory substances in the underlying soil and also promote development of parasites and predators of nematodes. Reflective surfaces (mulches) laid on the soil around the crop plant, have been found to be highly effective in controlling aphid vectors. Aluminium strips or grey or white plastic sheets are used as mulch and it has successfully protected red peppers against CMV and PVY in Israel and summer squash against watermelon mosaic virus in the Imperial valley of California. Straw mulches have been successfully used to control the white fly – transmitted tomato yellow leaf curl virus in tomato crops in Israel. It is believed that the colour of the straw attracts the whiteflies and they are subsequently killed by the reflective heat. The disadvantage with straw mulches is that they eventually lose their yellow colour, but prolonged control may be obtained if straw is replaced by yellow polythene sheets.

26. Irrigation water management

Irrigation to the crop in the field is to wet the soil to the extent that roots easily get water and nutrients. If excess water is added to soil, it may directly affect activity of pathogens and/or it may affect disease incidence through the effect on the host. Scab attack on potato tubers is prevented by maintaining soil moisture near field capacity during tuber formation. Bacterial flora antagonistic to *Streptomyces scabies* increases under high moisture conditions. The

charcoal rot pathogen, *Macrophomina phaseolina* attacks potatoes and cotton when the soil temperature rises and there is water stress. By irrigating the field, soil temperature is brought down, stress is removed and the disease is suppressed. When excess irrigation is made the juvenile stage of plants is lengthened making it susceptible to attack of fungi like *Pythium*. Supply of frequent but low quantity of irrigation water is, therefore, recommended for reducing chances of damping off in nurseries.

Under conditions of excess water, respiration of roots is inhibited and many soluble salts accumulate in toxic amounts around the roots and base of the stem. This increases disease proneness of the roots. Irrigation increases guttation. Guttation drops on leaves serve as media for multiplication and penetration of many pathogens, such as *Helminthosporium* spp. on cereals and *Xanthomonas campestris* on *Brassica* spp. Cereal rusts usually are more severe when the crop is grown in wet soil than in relatively drier soils. Vascular wilts appear aggravated soon after irrigation. These effects are through the host.

Pathogens directly taking advantage of excess water are those that need wet soil for (i) activation of their resting structures and (ii) for movement of these propagules. Thus, in presence of excess free water bacterial cells and zoospores of Pythiaceous fungi are dispersed easily. Therefore, at the plant stage when these pathogens can attack the crop irrigation should be avoided. Generally, sprinkler irrigation increases diseases by increasing leaf wetness and by dispersing propagules of the pathogens by water splashes just like rain water. At the same time, it has some advantages also such as washing off of inoculum from the leaf surface.

Irrigation especially at seed-development stage, may favour seed infection. Irrigation time and amount of water should be controlled so that the relative humidity is not raised to such an extent that it becomes conducive for seed infection. Control of seed-borne diseases favoured by wet climate can be achieved by raising the seed crop in dry areas. Some examples are anthracnose of bean and cucurbits (*Colletotrichum* spp.), *Ascochyta* blight of pea (*Ascochyta* spp.) and bacterial blight of legumes. Such crops can be grown in dry areas with the help of irrigation so that these aerial parts remain dry and do not contact infection. Virus-free potato seed tubers can be produced more successfully in areas where temperature and moisture conditions do not favour buildup of populations of the insect vectors.

Sclerotia, smut spores, chlamydospores, oospores and mycelium found in the soil are carried from one field to another through irrigation and drainage water. Stem rot, sheath blight and bacterial blight diseases of rice, damping off of vegetables and *Macrophomina* root rots of many crops spread mainly through irrigation and drainage water. Hence care should be taken not to irrigate a healthy field using drainage/irrigation water from a diseased field.

27. Field and plant sanitation

Field and plant sanitation is an important method of disease control through cultural practices. The inoculum present on field plants in the field may multiply on the plant or in the soil and in due course of time may be sufficient to nullify or reduce the effect of control practices. Many pathogens overwinter or oversummer on plant debris during the off-seasons and become active when the crop is again grown in the field. Hence plants bearing pathogens or plant debris introducing inoculum into the soil should be removed as early as possible. In most of the soil borne diseases like wilt and root rot, it has been reported that as long as the dead roots and other roots and other affected parts are present in the soil, the fungus continue its growth. When such diseased plant materials are removed, there is quick decline in the population of pathogens in the soil.

In this manner *Fusarium* wilt of cotton, pigeonpea and banana, *Verticillium* wilt of cotton, root rot of beans, downy mildew of pearlmillet, sorghum, maize and peas, foot rot of betelvine, bacterial blight of cotton, white rust of crucifers, black spot of rose, powdery mildew of pea and cereals are reduced. In certain areas the linseed rust fungus (*Melampsora lini*), the rice blast and brown spot fungi and the fungus causing early blight of potato also perennate through dormant stages in diseased crop debris. Destruction of crop debris by burning immediately after harvest reduces the amount of inocula which survive through debris.

It has been observed that leaf blight disease or rice particularly one caused by *Helminthosporium oryzae* is carried over in the stubbles and primary infection is evident in the self-sown tillers arising from these stubbles. Infection of *Sclerotium rolfsii* on jute is carried over in the foot and root regions in the stubbles left over after harvest of the jute plants. Sugarcane stubbles left over in the field help to carry over red rot fungus *Glomerella tucumanensis, Xanthomonas oryzae* pv. *oryzae* causing bacterial leaf blight disease on rice is capable of surviving for some time in rice stubbles. In many cases, diseased planting materials left in the field after discarding them, serve as sources of infection as in the case of late blight of potato

where piles or refuses of rejected tubers later become an important source of infection. Left over plant parts of maize infected with the smut *Ustilago zeae* constitute an important source of infection later.

Avoidance of the transfer of inoculum from one field to another by man, machine or water is one of the ground rules of cultural control. Where soil-borne diseases are concerned, anything that carries soil is suspect, this includes wheels, boots and water flowing either from adjacent fields, or through drainage ditches from distant fields. As regards sap-borne viruses, attention must be paid to disinfection of wheels and of the hands of labourers, as they pass from one field to another. Where such virus can also be carried on clothing. The work should be planned so that the labourers do not go from older to younger fields on the same day.

Many pathogens are capable of surviving on implements and materials used in sequential seasons. Tobacco mosaic virus has been shown to survive on iron stakes used for tomato trellises and disinfection of such stakes has been recommended. Soil adhering to plastic sheeting may carry sclerotia and other overseasoning bodies.

28. Roguing

Roguing consists of completely removing or uprooting the diseased plants to prevent further spread of the disease. This method is widely adopted in the control of virus diseases spread by insects (cassava mosaic, yellow mosaic of blackgram and greengram, citrus tristeza, katte disease of cardamom, bunchy top of banana) and basal stem rot of coconut, green ear of pearlmillet and broomrape (*Orobanche*) in tobacco. The whip smut of sugarcane (*Ustilago scitaminea*) in the canal areas of Bombay in Co.475 variety has been greatly checked by roguing carried out over wide areas and long period. In Jamaica, a country-wide campaign of destroying infected plants has succeeded in the control of Panama wilt of banana. Root rot and wilt attached plants after their death should be as and when noticed in the field uprooted and burnt to check the inoculum build up in the soil.

29. Management of plant nutrients

The plant nutrients in general when applied in excess may increase or reduce the resistance in plants to diseases. Increased application of nitrogenous fertilizers increases the incidence of many diseases. Crops fed with heavy doses of nitrogenous was fertilizers grow robust with foliage and succulent tissue but become highly susceptible to the attack of diseases like rust powdery mildew, blast, tobacco mosaic and some bacterial diseases .In the case of blast

of rice optimum dose of nitrogenous fertilizers are recommended and it is applied in 3 split doses viz. 50% as based at transplanting, 25% at tillering and 25% at panicle initiation stage. Late application of nitrogenous fertilizers increases wheat leaf blotch (*Septoria nodorum*) and powdery mildew (*Erysiphe graminis tritici*).

Some diseases are favoured by ammoniacal form of nitrogen while others are favoured by nitrate form of nitrogen. In general wilts (*Fusarium* sp.) and root rots (*Rhizoctonia* spp.) are favoured by ammoniacal nitrogen while *Verticillium* wilts and root rots due to *Pythium* spp. are favoured by nitrate nitrogen. In rice, blast disease is favoured by ammoniacal nitrogen while brown spot (*Helminthosporium oryzae*) is favoured by nitrate nitrogen. In maize Northern corn leaf blight caused by *H. turcicum* is favoured by ammoniacal nitrogen while stalk rot (*Diplodia maydis*) is favoured by nitrate nitrogen.

In wheat, sharp eye spot (*Rhizoctonia solani*) is favoured by ammoniacal nitrogen while stem rust (*Puccinia graminis tritici*) is favoured by nitrate nitrogen. In potato, wilt (*Verticillium albo-atrum)* and scab (S*treptomyces scabies)* are favoured by nitrate nitrogen while ammoniacal nitrogen increases black scurf (*R. olani*) .

Effects of nitrogenous fertilizers on major soil borne diseases have been studied. Their effect on the disease i.e., whether increased or decreased incidence by nitrogen in different forms are given in the following table.

Table. Effects of different forms of nitrogen on soil-borne diseases

Pathogen	Host	Amendment
Diseases increased		
Fusarium oxysporum f.sp. *lycopersici*	Tomato	NO_3
	Sorghum	$NaNO_3$ - NH_4NO_3
F.moniliforme	Carnation	NO_3
F. roseum	Bean	NH_4
F.solani f.sp. *phaseoli*	Wheat	$(NH_4)_2SO_4$
Gaeumannomyces graminis	Tabacco	NO_3
Phytophthora nicotianae	Cotton	$(NH_4)_2SO_4.Ca(NO_3)_2.KNO_3$
var. *nicotianae*	Potato	$NH_4\ NO_3$+$CaCO_3$
Verticillium albo-atrum		
Streptomyces scabies		

Disease decreased		
F. oxysporum f.sp.*cubense*	Banana	Urea(nitrite)
F.solani f.sp. *phaseoli*	Bean	KNO_3
Gaeumannomyces graminis	Wheat	$(NH_4)_2SO_4$
Phytophthora cinnamomi	Avocado	KNO_3
Sclerotium rolfsii	Tomato	$Ca(NO_3)_2$
S.rolfsii	Sugarbeet	$NH_3.(NH_4)_2SO_4.Ca\ (NO_3)_2$

Repeated application of phosphatic fertilizers delays the onset and lessens the severity of take-all disease of barley (*Gaeiimannomyces graminis*). Potassium application reduces the disease incidence in many crop diseases probably by increasing phenolics synthesis in plants. Application of potash induces resistance in groundnut against root rot caused by *Macrophomina phaseolina*. Calcium application suppresses the lesions due to the *R.solani* on bean roots. It is due to formation of calcium pectate, which is less available to action by polygalacturanase (PG) enzyme than is pectic acid.

Calcium has also been shown to affect *Sclerotium rolfsii* by neutralizing the oxalic acid produced by the fungus. Application of molybdenum reduces infection of potato tubers by *Phytophthora infestans* and also diminishes incidence of *Ascochyta* blight on beans and peas. Manganese reduces late blight of potato, ferric chloride controls rice brown spot and silicon application reduced rice blast.

30. Time of harvesting

Time of harvesting affects the cleanliness of the seeds. Delayed harvesting of grain crops in temperate climatic conditions enables the pathogen more time to contaminate the seeds. The best example is grain mould of sorghum where contamination by species of *Fusarium, Curvularia, Alternaria, Aspergillus, Phoma* is seen. Potato tubers harvested when the tops are green get easily contaminated by the late blight pathogen present on the leaves. Removal of tops and making them to dry before digging the tubers kills the sporangia and avoids contamination of tubers harvested later.

31. Avoiding ratoons

Ratooning is a general practice in sugarcane when the incidence of grassy shoot disease and red rot are very high. Hence ratooning should be avoided.

32. Solar heating

When the soil is covered with white polythene sheets during hot seasons, soil temperature increases. Increased soil temperature eliminates wilt pathogens like *Fusarium oxysporum* f.sp. *lycopersici* and V*erticillium dahliae* from tomato field. High soil temperature also favours antagonistic fungi.

Lecture 25

Biological control and PGPR – Scope and importance – Role and mechanisms of biological control and PGPR with examples. Plant growth promoting rhizobacteria

Biological control is defined as the reduction of inoculum density or disease producing activities of a pathogen or parasite in its active or dormant stage by one or more organisms accomplished naturally or through manipulation of the environment, host or by introduction of one or more antagonists or by mass introduction of one or more antagonists.

Biological control is but control of plant diseases using living microorganisms. Root rot disease *(Macrophomina phaseolina)* is a major disease in pulses, oilseeds, cofton, etc., and the most common method of control is using fungicides. But the chemical methods are uneconomical and law effective, as seed treatment with chemical may give protection only in the early stages of crop growth 2 weeks.

In addition, it is harmful to the beneficial microorganisms in soil and creates residual problems. So, the biological control can be very efficasy used for the root rot disease management as the biological agent multiply in soil and offer protection throughout the crop growth. The four main mechanisms involved in the biocontrol are (i) the biological agent (antagonist), may parasite the other organism, (ii) antagonist may secrete metabolites (antibiotics) harmful to the pathogens (Antibiosis) (iii) antagonist may compete with the pathogens for nutrients or space (Competition) and (iv) may cause death of the parasite by producing enzymes (Lysis).

Parasitism and Lysis

The biocontrol against parasitizes the pathogen by coiling around the hyphae, e.g., *Trichoderma* viride; various bacteria and fungi secrete hydrolytic about the degradation of cell wall of pathogens.

e.g. (i) *Bacillus* sp. causes hyphal lysis of *Gaeumanornyces* graminis

(ii) The chitnolytic enzymes of *Serratia marcescens* caused cell wall lysis of *Scierotium rolfsii.* (iii) *Trichoderma* sp. produces chitinases and β-1,3 glucanases which lyses the cell wall of *Rhizoctonia solani.*

Antibiosis

The antibiotic compounds secreted by the biocontrol agent suppress the growth of the pathogen. e.g. Phenazine-l-carboxylic acid produced by *P fluorescens* plays an important role in suppressing the take all disease of wheat.

Competition

The biocontrol bacteria and fungi compete for food and essential elements with the pathogen thereby displacing and suppressing the growth of pathogen.

e.g. (i) the competition for nutrients between *Pythium aphanidermatum, P ultimum* and bacteria suppress the damping off disease in cucumbers.

(ii) Fluorescent siderophores (iron chelaters) such as pseudobactinis & *pyoverdins* produced by P *fluorescons* chelates iron available in the soil, thereby depriving the pathogen of Its Fe requirements.

A. TRICHODERMA VIRIDE

The fungus, *Tfichoderma vitide* is one such biocontrol agent, mainly used for the control of root rot diseases of pulses and oil seeds in Tamil Nadu. A mass production technology for *T.viride* has been developed by Tamil Nadu Agricultural University, Coimbatore.

Systematic Position

Asexual **(conidial) Sexual (sscospore)**

Sub division : Deuteromycotina Ascomycotina

Class : Hypomycetes Pyremomycetes

Order : Moniliales Sphaeriales

Family : Moniliaceae Hypocreaceae

Genus : Trichoderma Hypocrea

Isolation of *Trichoderms* from soil

Trichoderma is isolated from the soil by using *Trichoderma* selective medium developed by Elad and Chet (I 983). Collect soil samples from the field, mix well and make it into fine particles. Soil samples should be collected in root zone at 5-1 5 cm depth and from rhizosphere wherever possible. Ten gram of soil sample is taken, and suspended in 100 ml of sterile distilled water and stirred well to get I : IO dilution. Transfer one ml from this to 9 ml of sterile water in a test tube to get 1: 100 dilution. Make serial dilutions by transferring one ml of suspension to subsequent tubes to get dilution of 1: 1 0,000. Transfer one ml of the desired soil suspension to

sterile petriplates. Pour 15 ml of melted and cooled *Trichoderma* selective medium in the same petriplates. Rotate the plate gently and allow to solidify, incubate at room temperature for 5-7 days and observe for the development of fungal colonies. Trichoderma colonies will be white initially and turn to green. Count the number of colonies developing in individual plates. Transfer the individual colonies to potato de)drose agar slants.

Testing Method

Dual Culture Technique

It consists of growing the test organism and the pathogenic organism on the same plate. This ran be done by the following procedure. Transfer 15-20 ml of melted and cooled PDA to sterilised petridishes. Allow it to solidify. Transfer 8 mm disc of test organism to one end of the petriplate. In the opposite end, 8 mm disc of the pathogenic culture is transferred in the same petriplate (if the antagonistic micro-organism is slow growing it should be plated in the previous day itself). Incubate the plate at room temperature. Observe the development of inhibition zone. Observe under microscope where both the test organism and the pathogen come in contact.

Mass Production

Molasses yeast medium (Molasses 30g + yeast 5g + water 1000ml) is prepared in conical flasks and sterilized at 1.1 kg/CM 2 for 20 minutes. *T.viride* culture is inoculated by taking a fungal disc from 10 day old culture and incubated for 10 days. This serves as mother culture. Molasses yeast medium is prepared in a fermenter and sterilized. Then, the mother culture is added to the fermenter @ 1.5 litre/50 litres of medium and incubated at room temperature for 10 days. The fungal biomass and broth are mixed with talc powder at 1:2 ratio. The mixture is air dried and mixed with carboxy methyl cellulose (CMC) @ 5g / kg of the product. It is packed in Polythene covers and used within 4 months.

Quality Control Specifications

1. Fresh product should contain not less than 28 X 10 6 CfU / g
2. After 120 days of storage at room temperature, the population should be 10 x IO 6 cfu / g.
3. Maximum storage period using talc as carrier is 120 days.
4. Size of the carrier (talc) should be 500 microns.
5. Product should be packed in white Polythene bags.
6. Moisture content of the final product should not be more than 20%.

B. *Bacillus subtilis*

This bacterium is widely used for the control of soil-bome plant pathogens like *Macrophomina phaseolina, Rhizoctonia solani, Fusarium* spp. etc. This treatment also considerably improves the plant growth and yield. *Bacillus subtilis* is a rod shaped, thermophilic gram positive, aerobic bacterium. Roots may be formed in chains. It is 5-6 mm in length and 2-3 mm in width. It forms endospores during adverse conditions.

Isolation

One gram of soil sample is mixed with 9 ml sterilized nutrient broth in a test tube. This has to be kept on a boiling waterbath at 800C for 10 minutes. Then it is kept for incubation at root temperature for 24-48 hrs. From this serial dilution is prepared upto 10-6 dilution. Dilution 10-5 and 10 -6 are plated In Nutrient Agar and incubated for 24- 48 hrs. *B. subtilis* colonies will be rough, opaque with irregular margins.

Staining for Identification

Bacterial smear is prepared with 24 hours old culture, air dried and heat fixed. The slide is flooeded with crystal violet for 60 seconds and then washed with tap water. Then, the slide is flooded with Grams iodine mordant for 60 seconds and washed with tap water. It is then the smear is counterstrained with safranin for seconds, washed with tap water, blot dried and observed under microscope. *Bacillus subtilis* appeared violet since it,is gram positive.

Biochemical tests for Identification

The following biochemical tests are carried out for identification.

1. Starch hydrolysis
2. Catalase test
3. Nitrate reduction test
4. Acid and gas production test

Bacillus subtilis is amylase positive catalase positive, nitrate positive, acid positive and gas negative.

Mass multiplication

Nutrient broth (Peptone 5g, beef extract 3g, sodium chloride 3g in 1 litre of distilled water, pH7) is prepared and sterilized at 1.1 kg/ CM 2 pressure for 20 minutes. One loopful of *B. subtilis* is inoculated and incubated for 24 hours. This serves as mother culture. One litre of mother culture is transferred to 100 litres of sterilized nutrient broth in a fermenter and the

bacterial growth is harvested after 72 hrs. Then it is mixed with 250 kg of sterilized peat soil amended with 37 kg Calcium carbonate, dried in shade and packed in Polythene bags. This product can be stored upto 6 months.

C. *Pseudomonas fluorescens*

This is another bacterium effectively used in controlling sheath blight and blast of paddy, wilt diseases of redgram, and banana. *Pseudomonas fluorescens* is a gram negative, rod shaped nonspore forming bacteria which may be mono or lopotrichous or non motile. It produces greenish, fluorescent and water soluble pigment, pyoverdin. The direct influence of pseudomonas on plant growth is mediated either by release of auxin-like substances or through improved uptake of nutrients in the environment. The indirect promotion of plant growth is achieved when fluorescent *Pseudomonas* decreases or prevents the deleterious influence of phytopathogens.

lsolation

One gram of rhizosphere soil sample is mixed in 100 ml of sterilewaterto give 1:100dilution. From this serial dilutions upto 10 -7 level are made by repeatedly transferring 1 ml of 1:I00 dilution to 9 ml sterile water stants 10 -5 , 10 -6 and 10 -7 dilutions are plated in kings B Agar medium and incubated for 24-48 hours. P *ftuorescens* appears as smooth, slimy, circular translucent colonies.

Mass production

P. fluorescens is multiplied in sterilized Kings 'B' broth for 48 hours. The pH of the substrate (Peat soil or talc powder) is adjusted to 7 by adding calcium carbonate @150 g / kg. The substrate is then sterilized at 1.1 kg/cm 2 pressure for 30 minutes for two successive days. Four hundred ml of *P. fluorescens* suspension is added to 1 kg of substrate containing 5 g of carboxy methyl cellulose and mixed well.The formulation is packed in Polythene covers and can be stored for one month.

Quality Control

1. Fresh product should contain 2.5 x I 0" cfu / g
2. After 3 months of storage at room temperature, the population should be 8-9 x 10 7 CfU / g.
3. Storage period is 3-4 months
4. Minimum population load for use is 1.0 x I0 8 cfu / g.
5. Product should be packed in white Polythene bags.

6. Moisture content of the product should not be more than 20% in the final product.

7. Population per ml of the broth is 9 ± 2 x 1 0 8 cfu / g.

Methods of Application

Crop: Paddy -blast, sheath blight

1. Seed Treatment

Mix paddy seeds with the formulation at the rate of 10 g per kg of seeds and soak the seeds in water for ovemight. Decant the excess water and allow to sprout the seeds for 24 hrs and then sow.

2. Seedling root dipping

Apply 2.5 kg of the formulation to the water stagnated in an area of 25 sq.m. The seedlings, after pulling out from the nursery can be left in the stagnating water containing the bacteria. A minimum period of 30 minutes is necessary for soaking the roots and prolonged soaking will enhance the efficacy.

3. Soil application

Apply the product @ 2.5 kg / ha after 30 days of transplanting (This product should be mixed with 50 kg of well decomposed FYM / sand and then applied).

4. Foilar application

Spray the product at 0.2% concentration (1 kg/ha) commencing from 45 days after transplanting at 10 days interval for 3 times depending on disease intensity. If there is no disease incidence, a single spray is sufficient. Crop: Groundnut, Gingelly, Sunflower, Redgram, Greengram, Blackgram - root rot and wilt

Seed treatment : 10 g /kg of seeds

Soil application : Apply 2.5 kg/ha. mixed with 50 kg of well decomposed FYM / sand at 30 days after sowing.

Crop : Banana - Fusarium wilt

Sucker treatment: 10 g/sucker

Capsule application: 50 mg / capsule / sucker.

Apply once in 3 months from 3 months after planting

Soil application: 2.5 kg / ha + 50 kg FYM / sand

Apply once at the time of planting and repeat it once In 3 months.

Plant Products and Antiviral principles in plant disease management

Plant products play an important role in evolving an ecologically sound and environmentally acceptable disease management system. Plant products have been found to have fungicidal, bactericidal and antiviral properties. It is well established that about 346 plant products have fungicidal properties, 92 have bactericidal and 90 have antiviral properties. This clearly indicates that the plant kingdom is a vast storehouse of chemicals that can check several plant pathogens. As many of them have more than one type of activity there is a less chance for development of resistance and moreover, the plant products are saferto non-target organisms.

Neem Products

Among the plant products, the neem derivatives are reported to be effective in controlling several diseases. The neem tree *(Azadirachta indica),* popularly called as china berry, crackjack, Nim, Indian lilac, margosa and paradise tree, contains several active principles in various parts. The important active principles are Azadirachtin, Nimbin, Nimbidin, Nimbinene, Nimbridic acid and Azadirone which have anitifungal and insecticidal properties.

(i) Neem Seed Kernel Extract (NSKE)

It is prepared by soaking 5 kg of powdered neem seed kernel (in a gunny bag) in 100 litres of water for 8 hours. The gunny bag is then removed afterthorough shaking. Then, 100 ml of teepol is mixed thoroughly, before spraying. The quantity of extract required for a liectare is 500 litres,

(ii) Neem oil solution

One hundred nil of teepol is mixed first with 100 litres of waterThen, 3 litres of neem oil is slowly added to this solution with constant shaking. The milky solution formed is ready for spray. The spray volume is 500 litres/ha.

(iii) Neem cake extract

Ten kg of powdered neem cake in a gunny bag is soaked in 100 litres of water for 8 hours. The gunny bagis removed after thorough shaking. Then, 100 ml of sticker is added and mixed well. The quantity of spray fluid required is 500 litres / ha.

(iv) Neem cake

Powdered neem cake is directly applied to the field at the time of last ploughing. The quantity applied is 150 kg/ha.

Diseases controlled by neem products

(a) Paddy: Tungro (virus) (Vector: *Nophotettix virescens)*

Neem cake is applied at 150 kg/ha as basal dose. In addition, 3% neem oil or 5% NSKE @) 500 l/ ha can be sprayed. If one jassid is noticed in a plant. Three sprays have to be given at 15 days interval.

(b) Paddy : Sheath rot *(Acrocyfindrium oryzae)*

Five per cent NSKE or 3% neem oil can be sprayed @ 500 lit/ ha at the time of grain emergence.

(c) Paddy: Blast *(Pyricularia oryzae)* Spraying 5% neem oil is effective

(d) Paddy: Sheath blight *(Rhizoctonia solani)*

Application of 150 Kg of neem cake/ha

(e) Groundnut : Rust *(Puccinia arachidis)*

Application of 3% neem oil @ 500 lit/ha. The first spray should be given immediately on noticing the symptom and second 15 days later.

(f) Groundnut : Foot rot *(Sclerotium rolfsii)* Application of 1 % neem oil is effective.

(g) Coconut: Wilt *(Ganoderma lucidum)*

Application of 5 kg of neem cake/ tree/ year during the rainy season.

(h) Black gram: Powdery mildew *(Erysiphe polygoni)*

Two sprays with 3% neem oil or 5% NSKE, starting first spray at the initiation of the disease and second 15 days later are effective.

(i) Black gram: Root rot *(Macrophomina phaseolina)* Application of neem cake @ 150 kg/ha

(j) Black gram: Yeliow mosaic (Virus) Application of 3% neem oil is effective.

(k) **Soybean:** Root rot *(M. phaseolina)* Application of neem cake @ 150 kg/ha.

Other Plant Products

In addition to the neem products, products from several other plant species are also found to be effective in disease management. The leaf extract of tuisi *(Ocimum sanctum)* is found effective against *Helminthosporium oryzae* (paddy brown spot). The leaf and pollen extracts of vilvam *(Aegle marmolos)* effectively reduced early blight of tomato *(Altenaria solani)* and blight of onion *(A. porri). A. solani* is also effectively checked by flower extract of periwinkle *(Catheranthus roseus)* and bulb extract of garlic *(Allium sativum).*

Rice discolouration caused by *Drechslera oryzae* is effectively reduced by leaf extract of mint *(Mentha piperita).* The bulb extract of garlic is also effective in reducing leaf blight of finger millet *(H. nodulosum)* and blast of paddy *(Pyricularia oryzae).* The root exudates of kolinji and rhizome extract of banana are effectively used against *Ganoderma lucidum, the* pathogen of Thanjavur wilt of coconut. The seed oil of pinnai *(Calophyllum inophyllum)* is effective against *Puccinia arachidis* causing groundnut rust. Leaf extract of nochi *(Vitex negundo)* effectively reduced, Rice Tungro viruses by checking the vector, Nephotettix *virescens.*

Anti Viral Principle (AVP)

Plants are also known to contain some compounds which are inhibitory to virus. They are called Anti-Viral Principles (AVP) or AntiViral Factors (AVF). The leaf extracts of sorghum, coconut, bougainvillea, *Prosopis juliflora and Cyanodon dactylon* are known to contain virus inhibiting principles.

Preparation of AVP extract

Dried coconut or sorghum leaves are cut and powdered. Twenty kg of leaf powder is mixed with 50 litres of water and heated at 60 0 C for one hour. It is filtered and volume is made upto 200 litres. This gives 10 per cent extract. Five hundred litres of extract is required to cover one hectare. The 10 per cent AVP extract is very effective in controlling groundnut ring mosaic virus (bud necrosis).

Two sprays are to be given at ten and twenty days after sowing. Similarly of percent leaf extracts of *P. juliflora* and C. *dactylon* effectively reduced the tomato spotted wilt virus in tomato. The leaf extracts are known to contain some proteinaceous substances which induce virus inhibition in the plants.

PGPR

Plant growth promoting rhizobacteria are bacteria that colonize plant roots, and in doing so, they promote plant growth and/or reduce disease or insect damage. There has been much research interest in PGPR and there is now an increasing number of PGPR being commercialized for crops. Organic growers may have been promoting these bacteria without knowing it. The addition of compost and compost teas promote existing PGPR and may introduce additional helpful bacteria to the field. The absence of pesticides and the more complex organic rotations likely promote existing populations of these beneficial bacteria. However, it is also possible to

inoculate seeds with bacteria that increase the availability of nutrients, including solubilizing phosphate, potassium , oxidizing sulphur, fixing nitrogen, chelating iron and copper. Phosphorus (P) frequently limits crop growth in organic production. Nitrogen fixing bacteria are miniature of urea factories, turning N2 gas from the atmosphere into plant available amines and ammonium via a specific and unique enzyme they possess called nitrogenase. Although there are many bacteria in the soil that ‘cycle' nitrogen from organic material, it is only this small group of specialized nitrogen fixing bacteria that can ‘fix' atmospheric nitrogen in the soil. Arbuscular mycorrhizal fungi (AMF) are root symbiotic fungi improving plant stress resistance to abiotic factors such as phosphorus deficiency or deshydratation.

The fourth major plant nutrient after N, P and K is sulphur (S). Although elemental sulphur, gypsum and other sulphur bearing mined minerals are approved for organic production, the sulphur must be transformed (or oxidized) by bacteria into sulphate before it is available for plants. Special groups of microorganisms can make sulphur more available, and do occur naturally in most soils.

One of the most common ways that PGPR improve nutrient uptake for plants is by altering plant hormone levels. This changes root growth and shape by increasing root branching, root mass, root length, and/or the amount of root hairs. This leads to greater root surface area, which in turn, helps it to absorb more nutrients.

Disease control

PGPR have attracted much attention in their role in reducing plant diseases. Although the full potential has not been reached yet, the work to date is very promising and may offer organic growers some of their first effective control of serious plant diseases. Some PGPR, especially if they are inoculated on the seed before planting, are able to establish themselves on the crop roots. They use scarce resources, and thereby prevent or limit the growth of pathogenic microorganisms. Even if nutrients are not limiting, the establishment of benign or beneficial organisms on the roots limits the chance that a pathogenic organism that arrives later will find space to become established. Numerous rhizosphere organisms are capable of producing compounds that are toxic to pathogens like HCN

Challenges with PGPR

One of the challenges of using PGPR is natural variation. It is difficult to predict how an organism may respond when placed in the field (compared to the controlled environment of a

laboratory. Another challenge is that PGPR are living organisms. They must be able to be propagated artificially and produced in a manner to optimize their viability and biological activity until field application. Like Rhizobia, PGPR bacteria will not live forever in a soil, and over time growers will need to re-inoculate seeds to bring back populations.

PGPR in Research

Over the years the PGPR (plant growth promoting rhizobacteria) have gained worldwide importance and acceptance for agricultural benefits. These microorganisms are the potential tools for sustainable agriculture and the trend for the future. Scientific researchers involve multidisciplinary approaches to understand adaptation of PGPR to the rhizosphere, mechanisms of root colonization, effects of plant physiology and growth, biofertilization, induced systemic resistance, biocontrol of plant pathogens, production of determinants etc. Biodiversity of PGPR and mechanisms of action for the different groups: diazotrophs, bacilli, pseudomonads, Trichoderma, AMF, rhizobia, Phosphate solubilising bacteria and fungi, Lignin degrading , chitin degrading , cellulose degrading bacteria and fungi are shown. Effects of physical, chemical and biological factors on root colonization and the proteomics perspective on biocontrol and plant defense have also shown positive results. Visualization of interactions of pathogens and biocontrol agents on plant roots using autofluorescent protein makers has provided more understanding of biocontrol processes with overall positive consequences.

Ways that PGPR promote plant growth

- Increasing nitrogen fixation in legumes
- Promoting free-living nitrogen-fixing bacteria
- Increasing supply of other nutrients, such as phosphorus, sulphur, iron and copper
- Producing plant hormones
- Enhancing other beneficial bacteria or fungi
- Controlling fungal diseases
- Controlling bacterial diseases
- Controlling insect pests

Lecture 26

Physical Methods – Heat treatments, soil solarization, hot water treatment, hot air treatment, control by refrigeration and radiation

As early as 1832, Sinclair suggested that hot air treatment in an oven might control smuts of oats and barley. Gardeners in Scotland while treating the bulbs of different ornamental plants first employed hot water therapy.

The scientific principle involved in heat therapy is that the pathogen present in seed material is selectively inactivated or eliminated at temperatures that are non lethal to the host tissues.

Following physical methods are employed for reduction or elimination of primary inoculums that may be present in seed, soil or planting material.

i. Hot water treatment (HWT)

The seeds are soaked in cold water at 20-300C for 5 hrs to induce the dormant mycelium to grow. Then the seeds are immersed in hot water at 50-540C for 10 minutes to kill the mycelium. It is very effectively used to eliminate loose smut of wheat. The setts of sugarcane can be treated at 500C for 2 hrs to eliminate grassy shoot pathogen. The main drawback in the hot water treatment is that the seeds may be killed or loose its germinability, if the period of treatment exceeds the specified time. So this method is replaced by other physical methods like Hot air and Aerated steam treatment wherein the seeds are exposed only to hot air/aerated steam.

ii. Hot air treatment (HAT)

Sugarcane setts are treated with hot air at 500C for 2 hrs to eliminate mosaic virus.

iii. Aerated steam therapy (AST)

Sugarcane setts are also exposed to aerated steam at 500C for 3 hrs to eliminate mosaic virus.

iv. Moist hot air treatment (MHAT)

This method is effectively used in sugarcane to eliminate grassy shoot disease. Initially the setts are exposed to hot air at 540C for 8 hrs, then exposed to aerated steam at 500C for 1 hr and finally to moist hot air at 540C for 2 hours.

v. Solar heat treatment (SHT)

A simplest treatment has been devised in India to eliminate the pathogen of loose smut of wheat. Previously the hot water treatment was followed to eliminate loose smut. As the termal

death point of the fungus and the embry are very close. The extensive care should be taken to avoid killing of the embryo. Luthra in 1953 devised a method to eliminate the deep seated infection of *ustilago nuda.* The method is popularly known as solar heat or solar energy treatment.

Luthras solar energy treatment: The seeds are soaked in cold water for 4 hours in the forenoon on a bright summer day followed by spreading and drying the seeds in hot sun for four hours in the afternoon. Then, the seeds are again treated with carboxin or carbendazin at 2g/kg and stored. This method is highly useful for treating large quantities of the seed lots.

vi. Soil Solarization

Soil solarization is generally used for controlling soil-borne pathogens like *Pythium, Verticillium, Rhizoctonia, Fusarium* etc. and nematodes in small areas like nurseries. Irrigate the nursery bed to moisten the soil to a depth of 10cm. Cover the bed after 2 days with thin transparent polythylene sheets for 4-6 weeks and then irrigate the beds once in a week. The purpose of irrigation is to increase the thermal sensitivity of resting structures of fungi and to improve heat conduction.

vii. Steam Sterilization

Steam is passed through perforated pipes at a depth of 15 cm to sterilize the upper layers of soil. It is mostly practiced under glass house and green house conditions.

viii. Hot air Sterilization

Hot air is also passed through pipelines to sterilize the soils in the nursery areas.

ix. Hot water treatment

It is mainly done in pot culture studies to kill the fungi and nematodes. The pots containing soil are immersed in boiling water at 980C for 5 minutes or drenching boiling water @ 20 litres/ Sq.m.

Refrigeration

It is an accepted fact that the low temperature at or slightly above the freezing point checks the growth and activities of all such pathogens that cause a variety of post harvest diseases of vegetables and fruits. Therefore most perishable fruits and vegetables should be transported and stored in refrigerated vehicles and stores. Cool chains refrigerated space from field to consumer table is becoming very popular. Regular refrigeration is sometimes preceded

by a quick hydro cooling or air cooling to remove the excess heat carried in them from the field to prevent development of new or latent infections.

Radiation

Electromagnetic radiations such as ultraviolet (UV) light, x rays and y rays as well as particulate radiations have been studied in relation to management of post harvest diseases of horticultural crops. Y rays controlled post harvest fungal infections in peaches, straw berries and tomatoes but doses of radiation required to kill pathogens, were found injurious to host tissues. Some plant pathogenic fungi sporulate only when they receive light in the ultraviolet range. It has been possible to control diseases on green house vegetables caused by species of these fungi by covering or constructing the green house with a special UV absorbing vinyl film that blocks transmission of light wavelengths below 390 nm.

Lecture 27

Chemical methods – study of different groups of fungicides.

Methods of application of fungicides

Fungicides – definition

The word 'fungicide' originated from two latin words, viz., 'fungus' and 'caedo'. The word 'caedo' means 'to kill.' Thus the fungicide is any agency/chemical which has the ability to kill the fungus. According to this meaning, physical agents like ultra violet light and heat should also be considered as fungicides. However, in common usage, the meaning is restricted to chemicals only. Hence, fungicide is a chemical which is capable of killing fungi.

Fungistat

Some chemicals do not kill the fungal pathogens. But they simply arrest the growth of the fungus temporarily. These chemicals are called fungistat and the phenomenon of temporarily inhibiting the fungal growth is termed as fungistatis.

Antisporulant

Some other chemicals may inhibit the spore production without affecting the growth of vegetative hyphas and are called as 'Antisporulant'. Eventhough, the antisporulant and fungistatic compounds do not kill the fungi, they are included under the broad term fungicide because by common usgage, the fungicide has been defined as a chemical agent which has the ability to reduce or prevent the damage caused to plants and their products. So, some of the plant pathologists prefer the term 'Fungitoxicant' instead of fungicide.

Characters of an ideal fungicide

1. It should have low phytotoxicity
2. It should have lonf shelf life
3. Stability during dilution
4. It should be less toxic to human being, cattle, earth worms , microorganisms etc.
5. It should be a broad spectrum in its action
6. Fungicide preparation should be ready for use
7. It should have compatibility with other agrochemicals
8. It must be cheaper one
9. It should be available in different formulations
10. It should be easily transportable

Classification of Fungicides

Fungicides can be broadly grouped based on their (i) mode of action (ii) general use and (iii) chemical composition.

I. Based on mode of action

Protectant

As the name suggests, protectant fungicides are prophylactic in their behaviour.Fungicide which is effective only if applied prior to fungal infection is called a protectant, eg., Zineb, Sulphur.

Therapeutant

Fungicide which is capable of eradicating a fungus after it has caused infection and there by curing the plant is called chemotherapeutant. eg. Carboxin, Oxycarboxin antibiotics like Aureofungin. Usually chemo therapeutant are systemic in their action and affect the deep-seated infection.

Eradicant

Eradicant are those which remove pathogenic fungi from an infection court (area of the host around a propagating unit of a fungus in which infection could possibly occur). eg. Organic mercurials, lime sulphur, dodine etc. These chemicals eradicate the dormant or active pathogen from the host. They can remain effective on or in the host for some time.

II. Based on general uses

The fungicides can also be classified based on the nature of their use in managing the diseases.

1. Seed protectants : Eg. Captan, thiram, organomercuries carbendazim, carboxin etc.
2. Soil fungicides (preplant) : Eg. Bordeaux mixture, copper oxy chloride, Chloropicrin, Formaldehyde Vapam, etc.,
3. Soil fungicides : Eg. Bordeaux mixture, copper oxy (for growing plants) chloride, Capton, PCNB, thiram etc.
4. Foliage and blossom : Eg. Capton, ferbam, zineb, protectants mancozeb, chlorothalonil etc.
5. Fruit protectants : Eg. Captan, maneb, carbendazim, mancozeb etc.
6. Eradicants : Eg. Organomercurials, lime sulphur, etc.
7. Tree wound dressers : Eg. Boreaux paste, chaubattia paste, etc.

8. Antibiotics : Eg. Actidione, Griseofulvin, Streptomycin, Streptocycline, etc.,

9. General purpose spray and dust formulations.

III. Based on Chemical Composition

The chemical available for plant disease control runs into hundreds, however, all are not equally safe, effective and popular.Major group of fungicides used include salts of toxic metals and organic acids, organic compounds of sulphur and mercury, quinines and heterocyclic nitrogenous compounds. Copper, mercury, zinc, tin and nickel are some of the metals used as base for inorganic and organic fungicides. The non metal substances include, sulphur, chlorine, phosphorous etc. The fungicides can be broudly grouped as follows and discussed in detail.

Groups of Fungicides – Copper Fungicides, Sulphur Fungicides and Mercury Fungicides

Copper Fungicides

The fungicidal action of copper was mentioned as early as 1807 by Prevost against wheat bunt disease *(Tilletia caries),* but its large scale use as a fungicide started in 1885 after the discovery of Bordeaux mixture by Millardet in France. The mixture of copper sulphate and lime was effective in controlling downy mildew of grapevine caused by *Plasmopara viticola* and later, late blight of potato *(Phytophthora infestans).*

Some other copper sulphate preparations later developed were Borduaux paste, Burgandy mixture and Cheshnut compound which are all very effectively used in the control of several plant diseases. In addition some preparations of copper oxy chloride preparations arev also mused. These are all insoluble copper compounds very successfully used in managing several leaf diseases and seeding diseases in nursery. Some of the important diseases controlled by copper fungicides are listed below.

I. Copper sulphate preparations

Boreaux Mixture

In 1882, Millardet in France (Bordeaux University) accidently observed the efficacy of the copper sulphate against the downy mildew of grapes caused by *Plasmopara viticola.* When copper sulphate was mixed with lime suspension, it effectively checked the disease incidence. The mixture of copper sulphate and lime was named as “Bouillie Bordelaise” (Bordeaux Mixture). The original formula developed by Millardet contains 5 lbs of CuSO4 + 5lbs of lime + 50 gallons of water. The chemistry of Bordeaux mixture is complex and the suggested reaction is:

$CuSO_4 + Ca(OH)_2 \rightarrow Cu(OH)_2 + CaSO_4$

The ultimate mixture contains a gelatinous precipitate of copper hydroxide and calcium sulphate, which is usually sky blue in colour. Cupric hrdroxide is the active principle and is toxic to fungal spores. In metric system, to prepare one percent Bordeaux mixture the following procedure is adopted:

One kg of copper sulphate is powdered and dissolved in 50 litres of water. Similarly, 1 kg of lime is powdered and dissolved in another 50 litres of water. Then copper sulphate solution is slowly added to lime solution with constant stirring or alternatively, both the solutions may be poured simultaneously to a third contained and mixed well.

The ratio of copper sulphate to lime solution determines the pH of the mixture. The mixture prepared in the above said ratio gives neutral or alkaline mixture. If the quality of the used is inferior, the mixture may become acidic. If the mixture is acidic, it contains free copper which is highly phytotoxic resulting in scorching of the plants. Therefore, it is highly essential to test the presence of free copper in the mixture before applied. There are several methods to test the neutrality of the mixture, which are indicated below:

(i) Field Test: Dip a well polished knife or a sickle in the mixture for few minutes. If reddish deposit appears on the knife/sickle, it indicates the acidic nature of the mixture.

(ii) Litmus paper test: The colour of blue litmus paper must not change when dipped in the mixture.

(iii) pH paper test : If the paper is dipped in the mixture, it should show neutral pH.

(iv) Chemical test: Acid a few drops of the mixture into a test tube containing 5 ml of 10% potassium ferrocyanide. If red precipitate appears, it indicates the acidic nature of the mixture.

If the prepared mixture is in the acidic range, it can be brought to neutral or near alkaline condition by adding some more lime solution into the mixture. Bordeaux mixture preparation is cumbersome and the following precautions are needed during preparation and application.

(i) The solution should be prepared in earthen or wooden or plastic vessels. Avoid using metal containers for the preparation, as it is corrosive to metallic vessels.

(ii) Always copper sulphate solution should be added to the lime solution, reverse the addition leads to precipitation of copper and resulted suspension is least toxic.

(iii) Bordeaux mixture should be prepared fresh every time before spraying. In case, the mixture has to be stored for a short time or a day, jaggery can be added at the rate of 100kg/100 litres of the mixture.

(iv) Bordeaux mixture is sometimes phytotoxic to apples, peaches, rice varieties like IR8 and maize varieties like Ganga Hybrid 3.

Bordeaux paste

Bordeaux Paste consists of same constituents as that of Bordeaux mixture, but it is in the form of a paste as the quantity of water used is too little. It is nothing but 10 percent Bordeaux mixture and is prepared by mixing 1 kg of copper sulphate and 1 kg of lime in 10 litres of water. The method of mixing solution is similar to that of Bordeaux mixture. It is a wound dresser and used to protect the wounded portions, cut ends of trees etc., against the infection by fungal pathogens.

Burgundy mixture

It is prepared in the same way as Bordeaux mixture, except the lime is substituted by sodium carbonate. So it is called as 'Soda Bordeaux'. It was developed Burgundy (France) in 1887 by Mason. The usual formula contains 1 kg of copper sulphate and 1 kg of sodium carbonate in 100 litres of water. It is a good substitute for Bordeaux mixture and used in copper-sensitive crops.

Cheshunt compound

It is compound usually prepared by mixing 2 parts of copper sulphate and 11 parts of ammonium carbonate. This formula was suggested by Bewley in the year 1921. The two salts are well powdered, mixed thoroughly and stored in a air tight container for 24 hours before being used. The ripened mixture is used by dissolving it in water at the rate of 3 g/litre. The mixture is dissolved initially in a little hot water and volume is made up with cold water and used for spraying.

II. Copper carbonate preparation

Chaubattia Paste

Chaubattia paste is another wound dressing fungicide developed by Singh in 1942 at Government Fruit Research Station, Chaubattia in the Almora district of Uttar Pradesh. It is usually prepared in glass containers or chinaware pot, by mixing 800g of copper carbonate and 800g of red lead in litre of raw linseed oil or lanolin. This paste is usually applied to pruned parts

of apple, pear and peaches to control several diseases. The paste has the added advantage that it is not easily washed away by rain water.

III. Copper carbonate preparation

III. Cuprous oxide Preparation	Fungimar, Perenox, Copper Sandoz, Copper 4% dust, Perecot, Cuproxd, Kirt i copper.	Cuprous oxide is a protective fungicide, used mainly for seed treatment and for foilage application against blight, downy mildew and rusts.
IV. Copper oxychloride Preparation.	Blitox, Cupramar 50% WP, Fytolan, Bilmix 4%, Micop D-06, Micop w-50, Blue copper 50, Cupravit, Cobox, Cuprax, Mycop.	It is a protective fungicide, controls *Phytophthora infestans* on potatoes and several leaf spot and leaf blight pathogens in field.

Sulphur fungicides

Use of sulphur in plant disease control is probably the oldest one and can be classified as inorganic sulphur and organic sulphur. Inorganic sulphur is used in the form of elemental sulphur or as lime sulphur. Elemental sulphur can be either used as dust or wettable sulphur, later being more widely used in plant disease control. Sulphur is best known for its effectiveness against powdery mildew of many plants, but also effective against certain rusts, leaf blights and fruit diseases.

Sulphur fungicides emit sufficient vapour to prevent the growth of the fungal spores at a distance from the area of deposition. This is an added advantage in sulphur fungicides as compared to other fungitoxicants.

Organic compounds of sulphur are now widely used in these days. All these compounds, called as 'carbamate fungicides', are derivatives of Dithiocarbamic acid, Dithiocarbamates are broadly grouped into two, based on the mechanism of action.

Dithiocarbamates

Monoalkyl Dithiocarbamates Eg. Zineb, Maneb, Eg. Thiram, Ziram, Mancozeb, Nabam, Vapam Ferbam	Dialkyl Dithiocarbamates

List of sulphur fungicides and the important diseases controlled by them are tabulated below:

Trade Name	**Diseases Controlled**	
Inorganic Sulphur 1. Elemental Sulphur (i) Sulphur dust	Sulphur dust Cosan, Wetsulf, Microsul	Sulphur is a contact and protective fingicide, normally applied as sprays or as dust. It is generally used to control powdery mildews of fruits, vegetables, flowers and tobacco. This is also effective against apple scab (Venturia inaequallis) and rusts of field crops.
2. Lime Sulphur (Calcium poly sulphide)	It can be prepared by boiling 9 Kg or rock lime and 6.75Kg of sulphur in 225 litres of water.	Lime Sulphur is effective against powdery mildews as a protective fungicide.
Organic Sulphur	Hexathane 75% WP,	It is used to protect

(Dithiocarbamates) a. Monoalkyl	Dithane Z-78, Funjeb, Lonocol, Parzate C,	foliage and fruits of a wide range of crops
dithiocarbamate 1. Zineb (Zinc ethylene bisdithiocarbamate)	Du Pant Fungicide A, Polyram.	against diseases such as early and late blight of potato and tomato, downy mildews and rusts of cereals, blast of rice, fruitrot of chilly etc.
2. Maneb (Manganese ethylene bisdithiocarbamate)	Dithane M22, Manzate WP, MEB	These two are protective fungicide used to control many fungal diseases of field crops, fruits, nuts, ornamentals and vegetables, especially blights of potatoes and tomatoes, downy mildews of vines, anthracnose of vegetables and rusts of pulses.
3.Mancozeb (Maneb + Zinc ion)	Dithane M45, Indofil M45, Manzeb.	
4. Nabam (DSE) (Di Sodium ethylene bisdithiocarbamate)	Chembam, Dithane A-40, Dithane D-14, Parzate Liquid	Nabam is primarily used for foilar application against leaf spot pathogens of fruits and vegetables. Soil

		applications were also reported to have a systemic action on *Pythium, Flusarium* and *Phytophthora.* It is also used to control algae in paddy fields.
5. Vapam (SMDC) (Sodium methyl dithiocarbamate)	Vapam, VPM, Chemvape, 4-S Karbation, Vita Fume.	It is a soil fungicide and nematicide with fumigant action. It is also reported to have insecticidal and herbicidal properties. It is effective against damping off disease of papaya and vegetables and wilt of cotton. It is also effective against nematode infestation in citrus, potato and root knot nematodes in vegetables.
b. Dialkyl Dithiocarbamate 1. Ziram (Zinc dimethyl dithiocarbamate)	Cuman L. Ziram, Ziride 80 WDP, Hexaazir 80% WP, Corozate, Fukiazsin, Karbam white, Milbam, Vancide 51Z, Zerlate, Ziram, Ziberk, Zitox 80% WDP.	Ziram is a protective fungicide for use on fruit and vegetables crops against fungal pathogens including apple scab. It is non phytotoxic except to zinc sencitive plants. It is highly effective against anthracnose of

		beans, pulses, tobacco & tomato, and also against rusts of beans etc.
2. Ferbam (Ferric dimethyl dithiocarbamate)	Coromat, Febam, Ferberk, Femate, Fermate D, Fermicide, Hexaferb 75% WP, Karbam Black, Ferradow.	Ferbam is mainly used for the protection of foliage against fungal pathogens of fruits and vegetables including *Taphrina deformans* of peaches, anthracnose of citrus, downy mildew of tobacco and apple scab.
3. Thiram (Tetra methyl thiram disulphide)	Thiride 75 WDP, Thiride 750, Thiram 75% WDP, Hexathir, Normerson, Panoram 75, Thiram, TMTD, Arasan, Tersan 75, Thylate, Pomarsol, Thiuram.	It is used for seed treatment both as dry powder or as a slurry. It is a protective fungicide also suitable for application to foilage to control *Botrytis spp.* on lettuces, ornamental, soft fruits and vegetables, rust on ornamentals and *Venturia pirina* on pears. It is also effective against soilborne pathogens like *Pythium, Rhizoctonia* and *Fusarium.*

Mercury Fungicides

Mercury fungicides can be grouped as inorganic and organic mercury compounds. Both the groups are highly fungitoxic and were extensively used as seed treatment chemicals against seed borne diseases. Ignorance compounds show bactericidal property also. However, due to their residual toxicity in soil and plants and their extreme toxicity nature to animal and human beings, the use of mercury fungicides is beings discouraged. In most of the countries, the use of mercury fungicides is banned and in countries like India, the use of mercury fungicides is restricted only in seed treatment for certain crops. The list of diseases against which mercury fungicides used are listed below

Common Name	Trade Name	Diseases Controlled
I. Inorganic Mercury		It is used for treating potato tubers and propagative materials of other root crops
1. Mercuric chloride	Merfusan, Mersil	
2. Mercurous chloride	Cyclosan, M-C Turf fungicide.	Mercurous chloride is limited to soil application in crop protection use because of its phytotoxicity.
II. Organomercurials	Agallol, Aretan, Emisan, Ceresan wet (India)	These are used mainly for treatment of seeds and planting materials. These fungicides are used for seed treatment by dry, wet or slurry method. For seed treatment 1% metallic mercury is applied at 0.25% concentration
Methoxy ethyl mercury Chloride		
Phenyl mercury chloride	Ceresan Dry (India), Ceresol, Leytosan.	

Ethyl Mercury Chloride Tolyl mercury acetate	Ceresan (USA) Agrosan GN.	

Heterocyclic Nitrogen Compounds, Quinones and Miscellaneous Fungicides

Heterocyclic Nitrogen Compounds

Heterocyclic nitrogen compounds are mostly used as foliage and fruits protectants. Some compounds are very effectively used as seed dressers. Some of the commonly used fungicides are listed below.

Common Name	**Trade Name**	**Diseases Controlled**
1.Captan (Kittleson's Killer) (N-trichloromethyl thio-4- cyclohexence-1,2-dicarboximide)	Captan 50W, Captan 75 W, Esso Fungicide 406, Orthocide 406, Vancide 89, Deltan, Merpan, Hexacap.	It is a seed dressing fungicide used to control diseases of many fruits, ornamental and vegetable crops against rots and damping off.
2. Captafol (Cis-N-1,1,2,2-tetra chloro hexane 1,2- dicarboximide)	Foltaf, Difolaton, Difosan, Captaspor, Foleid, Sanspor.	It is a protective fungicide, widly used to control foliage and fruit diseases of tomatoes, coffee potato.
3. Glyodin	Glyoxaliadine, Glyoxide,	It has a narrow specrum of

	Glyodin, Glyoxide Dry, Glyodex 30% liquid and 70% WP.	activity. As a spray, it controls apple scab and cherry leaf spot.
4.Folpet (Folpet) [N-(trichloromethyl-thi)] phthalimide	Phartan, Acryptan, Phaltan, Folpan, Orthophaltan.	It is also a protective fungicide used mainly for foliage application against leaf spots, downy and powdery mildews of many crops.

Benzene compounds

Many aromatic compounds have important anti-microbial properties and have been developed as fungicides. Some important benzene compounds commonly used in plant disease control are listed below.

Common Name	**Trade Name**	**Diseases Controlled**
1. Quintozene (PCNB)	Brassicol, Terraclor, Tritisan 10%, 20%, 40% D and 75% WP, PCNB 75% WP.	It is used for seed and soil treatment. It is effective against *Botrytis, Sclerotium, Rhizoctonia* and *Sclerotinia spp.*
2. Dichloran	Botran 50% WP and 75% WP, Allisan.	It is a protective fungicide and very effective against *Botrytis, Rhizopus and Sclerotinia* spp.
3. Fenaminsosuplh (Sodiumpdimethylamino benzenediazosulphonate	Dexon 5% G and 70% WP	It is very specific in protecting germinating seeds and growing plants from seeds as well as soil-borne infection of

		Phythium, Aphanomyces and *Phytophthora* spp.
4.Dinocap (2,4-dinitro-6-octyl phenylcrotonate)	Karathane, Arathane, DNOPC, Mildex, Crotothane, Crotothane 25% WP, Crotothane 48% Liq.	It is a non-systemic acaricide and control fungicide recommended to control powdery mildews on various fruits and ornamentals. It is also used for seed treatment.

Quinone Fungicides

Quinone areresent naturally in plants and animals and they exhibit anti-microbial activity and some compounds are successfully developed and used in the plant disease control. Quinones are very effectively used for seed treatment and two commonly used fungicides are listed below:

Common Name	**Trade Name**	**Diseases Controlled**
1. Chloranil (2,3,5,6-tetrachlora-1,4-benzoquinone)	Spergon	Chloronil is mainly used as a seed protectant against smuts of barely and sorghum and bunt of wheat.
2. Dichlone (2,3-dichloro-1,4- napthoquinone)	Phygon, Phygon XL WP.	Dichlone has been used widely as seed protectant. This is also used as a foliage fungicide, particularly against apple scab and peach leaf curl.
Organo – Phosphorous		It has a specific action

fungicide Ediphenphos (Edifenphos) (O-ethyl-SS-diphenyldithiophosphate)	Hinosan 50% EC and 2% D.	against *Pyricularia oryzae* (Rice blast). It is also effective against *Corticium sesakii* and *Cochliobolus miyabeanus* in rice.

Organo Tin compounds

Several other organic compounds containing tin, lead, etc. have been developed and successfully used in plant disease control. Among them, organo tin compounds are more popular and effective against many fungal diseases. These compounds also show anti bactericidal properties. Some of the organo tin compounds commonly used are listed below.

Common Name	**Trade Name**	**Diseases Controlled**
1. Fentin hydroxide (TPTHTiphenyl tin hydroxide)	Du-Ter WP 20% or 50% WP. Du-Ter Extra-WP, Farmatin 50 WP, Du-Terforte WP, Tubotin.	It is a non-systemic fungicide recommended for the control of early and late blight of potato, leaf spot of sugar beet, blast of rice and tikka leaf spot of ground nut.
2. Fentin acetate (TPTATriphenyl tin acetate)	Brestan WP 40% and 60% WP.	It is a non systemic fungicide recommended to control *Ramularia* spp.on celery and sugar beet anthracnose and downy mildew It is effective against Cercospora leaf spot of

3. Fentin Chloride (TPTC- Triphenyl tin chloride)	Brestanol 45% WP, Tinmate.	sugarbeet and paddy blast

Systemic Fungicides and Antibiotics

Systemic Fungicides

Since the late 1960s there has been substantial development in systemic fungicides. Any compound capable of being freely translocated after penetrating the plant is called systemic. A systemic fungicide is defined as fungitoxic compound that controls a fungal pathogen remote from the point of application, and that can be detected and identified. Thus, a systemic fungicide could eradicate established infection and protect the new parts of the plant.

Several systemic fungicides have been used as seed dressing to eliminate seed infection. These chemicals, however, have not been very successful in the cases of trees and shrubs. On the basis of chemical structure, systemic fungicides can be classified as Benzimidazoles, Thiophanates, Oxathilins and related compounds, pyrimidines, morpholines, organo-phosphorus compounds and miscellaneous group.

I. Oxathilin and related compounds

Oxathalins were the earliest developed compounds. This group of systemic fungicide is also called as carboxamides, carboxyluc acid anillides, carboxaanillides or simply as anillides which are effective only against the fungi belong to *Basidiomycotina* and *Rhizoctonia solani*. Some of the chemicals developed are (i) Carboxin (DMOC: 5,6 - dithydra-2-methyl-1, 4-oxathin-3-carboxanillide) and (ii) Oxycarboxin (DCMOD- 2,3-dihydro-5-carboxanillido-6-methyl-1, 4 oxathilin-4, 4, dioxide). The diseases controlled by these chemicals are listed below.

Common Name	**Trade Name**	**Diseases Controlled**
1. Carboxin (5,6-dinydro- 2-methyl-1-4-oxanthin-3-carboxanlido)	Vitavax 10% D, Vitavax 75% WP, Vitavax 34% liq. Vitaflow.	It is systemic fungicide used for seed treatment of cereals against bunts and smuts, especially loose smut of wheat

2. Oxycarboxin (5,6-dihydro-2-methyl- 1,4-oxathin-3-carboxianilid-4,4- dioxide)	Plantvax 5G, Plantvax 5% liq. Plantvax 1.5 EC, 10% dust, 75 WP.	It is a systemic fungicide used for the treatment of rust diseases of cereals, pulses, ornamentals, vegetables and coffee
3.Pyracarbolid (2-methyl-5,6-dihydro- 4H-Pyran-3-carboxylic acid anilide).	Sicarol.	It controls rusts, smuts of many crops and *Rhizoctonia solani*, but is slightly more effective than carboxin

II. Benzimidazoles

The chemicals of this group show a very broad spectrum activity against a variety of fungi. However, they are not effective against bacteria as well as fungi belongs to *Mastigomycotina*. Two types of fungicidal derivates of benzimidazoles are known. The first type of derivates includes fungicides such as thiabendazole and fuberidazole. The fungicidal moiety of the second type is methyl-2-benzimidazole carbamate (MBC). The fungicides of this group may be simple MBC such as carbendazim or a complex from such as benomyl, which transforms into MBC in plant system. Some of the important diseases controlled by these compounds are shown below:

Common Name	**Trade Name**	**Diseases Controlled**
1.Benomyl (Methyl - 10 (butly carbomyl)-2 benzimidazole carbamate)	Benlate 50 WP, Benomyl. Bavistin 50 WP, MBC, Dersol, B.Sten 50, Zoom, Tagstin, Agrozim,	It is a protective and eradicative fungicide with systemic activity, effective against a wide range of fungi

2. Carbendazim (MBC) (Methyl -2-benzimidazole carbamate)	Jkenstin.	affecting field crops, fruits and ornamentals.It is very effective against rice blast, apple scab, powdery mildew of cereals, rose, curcurbits and apple and Diseases caused by *Verticillium and Rhizoctonia.* It is also used as pre-and postharvest sprays of dips for the control of storage rots of fruits and vegetables. Carbendazim is a systemic fungicide controlling a wide range of fungal pathogens of field crops, fruits, ornamentals and vegetables. It is used as spray, seedling dip, seed treatment, soil drench and as post harvest treatment of fruits. It is very effective against wilt diseases especially, banana wilt. It controls effectively the sigatoka leaf spot of banana, turmeric leaf spot and rust diseases in many crops.
3. Thiabendazole (TBZ) (2,4-thiazoyl benzimidazole)	Thiabendazole, Mertect, Tecto, Storite.	It is a broad spectrum systemic fungicide effectivel against many major fungal diseases. Pathogenic fungal control

		includes species of *Botrytis, Ceratocystis, Cercospora, Colletotrichum, Fusarium, Rhizoctonia, Sclerotinia, Septoria and Verticillium.* It is also effective for the post harvest treatment of fruits and vegetables to control storage diseases.
4.Fuberidazole (2, (2-buryl) - benzimidazole).	Voronit.	It is used for the treatment of seeds against diseases caused by *Fusarium*, Particularly *F.nivale* on rye and *F.culmorum* of peas

III. Thiophanates

These compounds represent a new group of systemic fungicides based on thiourea. They are the derivatives of thioallophanic acid. These fungicides contain aromatic nucleus which is converted into benzimidazole ring for their activity. Hence, thiophanates are often classified under benzimidazole group and the biological activity of thiophanates resembles of benomyl. Two compounds are developed under this group are discussed.

Common Name	**Trade Name**	**Diseases Controlled**
1. Thiophanate(1,2 - bis (ethyl carbonyl-2-thioureido) benzene)	Topsin 50 WP, Cercobin 50 WP, Enovit.	It is a systemic fungicide with a broad range of action, effective against

2. Thiophanate - methyl (1,2 bis (3 methoxycarbonyl-2-thioureido) benzene.)	Topsin-M70 WP, Cercobin-M 70 WP, Envovit-methyl, Mildothane.	*Venturia* spp., on apple and pear crops, powdery mildews, *Botrytis* and *Sclerotinia* spp. On various crops. It is effective against a wide range of fungal pathogens, including *Venturia spp.* on apples and pears, *Mycosphaerella musicola* on bananas, powdery mildews on apples, cucurbits, pears and vines, *Pyricularia oryzae* on rice, *Botrytis and Cerospora* on various crops.

IV.Morpholines

Common Name	**Trade Name**	**Diseases Controlled**
Tridemorph (2-6 - dimethyl-4-cyclo - tridecyl morpholine)	Calixin 75 EC, Bardew, Beacon	It is an eradicant fungicide with systemic action, being absorbed through foilage and roots to give some protective action. It controls powdery mildew diseases of

		cereals, vegetables and ornamentals. It is highly effective against *Mycosphaerella, Exobasidium*

V. Pyrimidines, Pyridines, Piperidines and Imidazole

Common Name	**Trade Name**	**Diseases Controlled**
1. Triadimefon (1-(4-chlorophenoxy)-3, 3-dimethyl-1-(1-2-triazol-1yl) butan-2-one)	Bayleton, Amiral	It is very effective against powdery mildews and rusts of several crops.
2. Triadimenol (1-(4-Chlorophenoxyl-3, 3-dimethyl-1(1,2,4-triazol-1-yl) butan-2-ol)	Baytan	It is also very effective against powdery mildews and rusts of several crops.
3. Bitertanal (B-(1-1-biphenyl-4-yloxy-a-(1-1-dimethyl-ethyl-1-H-1,2-4- triazole-1-ethanol)	Baycor Terrazole 30% WP, Terrazole 95% WP,	It is highly effective against rusts and powdery mildew of a variety of crops. It is also used against *Venturia* and *Monilinia* on fruits and *Cereospora* leafspots of groundnut and banana.

4. Etridiazole (5-ethaoxy-3-trichloromethyl, 1,2-4-thiadiazole)	Terrazole 25% EC, Koban, Pansol EG, Pansol 4% DP, Turban WP, Terracoat Aaterra.	It is very effective against *Phytophthora* and *Pythium* spp. and seeding diseases of cotton, groundnut, vegetables, fruits and ornamentals

VI. Hydroxy Pyrinidines

Common Name	**Trade Name**	**Diseases Controlled**
1. Ethirimol (5-butyl 2-ethyl amino-4-hydrop-6-methyl pyrimidine)	Milliatem 80 WDP, Milcurb Super, Milgo	It is effective against powdery mildew of cereals and other field crops. It is also effective against powdery mildews of cucumber and ornamentals.
2. Dimethirimol (5-butyl 2-dimethylamino-4-hydroxy-6-methy pyrimidine)	Milcurb	It is very effective against powdery mildews of chrysanthemum and cucurbits.
VII. Furan derivatives 1. Furcarbanil (2-5-dimethyl-3-furanilide)		It is used as seed or soil application, It systemically controlled bean rust and is being used as a seed

2. Cyclafuramid (N-cyclohexyl-2,5-dimethyl firamide)		dressing fungicide against loose smut of wheat and barley. It is effective against bunts, smuts and rusts of cereals, coffee rust, blister blight of tea, smut and red rot of sugarcane, *Fusarium wilt* of tomato, *Rhizoctonia* on tomato, potato, groundnut, rice as well as *Armillaria* sp. On rubber.
VIII.Benzanilide derivative 1. Mebenil (2-methyl benzanilide)		It is effective against yellow rust on wheat and barley *(P. striiformis)* and brown rust on barley *(P. hordei).* It is also having direct fungitoxic activity against *Sclerotium rolfsli* and *Rhizoctonia.*

IX. Organo phosphorous compounds

Common Name	**Trade Name**	**Diseases Controlled**
1. Pyrazophos (2-0-0-	Afugan, Curamil, WP,	It is used to control

Diethylthionophosphoryl) -5- methyl-6-carbethoxy pyrazolo-(1- 5a)pyrimidine)	Missile EC.	powdery mildews of cereals, vegetables, fruits and ornamentals.
2. Iprobenphos (IBP) (S-benyzl-0-0-bisisopropylphosphorothiate)	Kitazin 48% EC, Kitazin 17G, Kitazin 2% D.	It is used to control *Pyricularia oryzae* and sheath blight of rice.
X. Piperazine 1.Triforine(N,N-bis-(1-foramido-2,2,2-trichloroethyl- piperazine)	Saprol-EG, Fungitex.	It is effective against powdery mildew, scab and other diseases of fruits and rust on ornamentals and cereals.
XI. Phenol derivative 1. Choloroneb (1-4-dichloro-2,5-dimethoxy benzene)	Demonsan 65 WP, Tersan SP, Turf fungicide	It is also active against storage diseases of fruits. It is highly fungistatic to *Rhizoctonia* spp., moderately so to *Pythium* spp. and poorly to *Fusarium* spp. It is used as a supplemental seed treatment for beans and soyabeans to control seedling disease

XIII. Other systemic fungicides

Common Name	Trade Name	Diseases Controlled
1. Metalaxyl (methyl-DLN-(2,6-dimethylphenyl-N-)2-methoxyacetyl	Apron 35 SD, Ridomil Ridomil MZ 72 WP (8% Metalaxyl + 64% Mancozeb) Beam, Bim Alliette 80 WP	It is a systemic fungicide and highly effective for specific use as seed dressing against fungal pathogens of the order Peronosporales.
2. Metalaxyl + Mancozeb		It is a fungicide with systemic and contact action and effective against damping-off, root rots, stem rots, and downy mildew of grapes and millets.
3. Tricyclazole (5-methyl-1,2,4 triazole(3,4b)-benzothiazole)		It is a specific fungicide used against paddy blast fungus, *P. oryzae*
4. FosetylAI. (Aluminium - Trisaluminium		It is a very specific Fungicide for Oomycetous fungi, especially against *Pythium* and *Phytophthora*

Antibiotics

Antibiotic is defined as a chemical substance produced by one micro-organism which is low concentration can inhibit or even kill other micro-organism. Because of their specificity of

action against plant pathogens, relatively low phytotoxicity, absorption through foliage and systemic translocation and activity in low concentration, the use of antibiotic is becoming very popular and very effectively used in managing several plant diseases. They can be grouped as antibacterial antibiotics and antifungal antibiotics. Most antibiotics are products of several actinomycetes and a few are from fungi and bacteria.

I. Antibacterial antibiotics

1. Streptomycin sulphate

Streptomycin is an antibacterial, antibiotic produced by streptomyces griseus. Streptomycin are streptomycin sulphate is sold as Agrimycin,-100, Streptomycin sulphate, Plantomycin, Streptocycline, Paushamycin, Phytostrip, Agristrep and Embamycin, Agrimycin -100 contains 15 per cent streptomycin sulphate + 1.5 percent terramycin (Oxy tetracycline). Agristerp contains 37 percent streptomycin sulphate. Phytomycin contains 20 percent streptomycin. Streptocycline and paushamycin contains 9 parts f streptomycin and 1 part of tetracycline hydrochloride.

This group of antibiotics act against a broad range of bacterial pathogens causing blights, wilt, rots etc. This antibiotic is used at concentrations of 100-500 ppm. Some important diseases controlled are blight of apple and pear *(Erwinia amylovora)*, Citrus canker *(Xanthomonas campestris p.v. citri)*, Cotton black arm *(X.c*. p.v. *malvacearum)*, bacterial leaf spot of tomato *(Pseudomonas solanacearum)*, wild fire of tobacco *(Pseudomonas tabaci)* and soft rot of vegetables *(Erwinia carotovora)*.

In addition, it is used as a dip for potato seed pieces against various bacterial rots and as an disinfectant in bacterial pathogens of beans, cotton, crucifers, cereals and vegetables. Although it is an antibacterial antibiotic, it is also effective against some diseases caused by Oomycetous fungi, especially foot-rot and leaf rot of betelvine caused by *Phytophthora parasitica var. piperina.*

2. Tetracyclines

Antibiotics belonging to this group are produced by many species of Streptomyces. This group includes Terramycin or Oxymicin (Oxytetracycline). All these antibiotics are bacteriostatic, bactericidal and mycoplasmastatic. These are very effective against seed-borne bacteria. This group of antibiotic is very effective in managing MLO diseases of a wide range of crops. These are mostly used as combination products with Streptomycin sulphate in controlling

a wide range of bacterial diseases. Oxytetracyclines are effectively used as soil drench or as root dip controlling crown gall diseases in rosaceous plants caused by Agrobacterium tumefaciens.

II Antifungal antibiotics

1. Aureofungin

It is a hepataene antibiotic produced in sub-merged culture of Streptoverticillium cinnamomeum var. terricola. It is absorbed and translocated to other parts of the plants when applied as spray or given to roots as drench. It is sold as Aurefungin-Sol. Containing 33.3% Aureofungin and normally sprays at 50-100 ppm. The diseases controlled are citrus gummosis caused by several species of Phytophthora, powdery mildew of apple caused by *Podosphaera leucotricha* and apple scab (Venturia inaequalis), groundnut tikka leaf spot, downy mildew, powdery mildew and anthracnose of grapes, potato early and late blight. As seed treatment it effectively checked are *Diplodia* rot of mango, *Alternaria* rot of tomato, *Pythium* rot of cucurbits and *Penicillium* rot of apples and citrus. As a truck application/root feeding, 2 g of aureofungin-sol+1g of copper sulphate in 100 ml of water effectively reduce. Thanjavur wilt of coconut.

2. Griseofulvin

This antifungal antibiotic was first discovered to be produced by *Penicillium griseofulvum* and now by several species of *Penicillium,* viz., *P.patulum, P.nigricans, P.urticae, and P.raciborskii.* It is commercially available as Griseofulvin, Fulvicin and Grisovin. It is highly toxic to powdery mildew of beans and roses, downy mildew of cucumber. It is also used to control *Alternaria solani* in tomato *Sclerotinia fructigena* in apple and *Botrytis cinerea* in lettuce.

3. Cycloheximide

It is obtained as a by-product in streptomycin manufacture. It is produced by different species of *Streptomyces,* including *S.griseus* and S. *nouresi.* It is commercially available as Actidione, Actidione PM, Actidione RZ and Actispray. It is active against a wide range of fungi and yeast. Its use is limited because it is extremely phytotoxic. It is effective against powdery mildew of beans *(Erysiphe polygoni),* Bunt of wheat *(Tilletia spp.)* brownnot of peach *(Sclerotinia fructicola)* and post harvest rots of fruits caused by *Rhizopus* and *Botrytis* spp.

4. Blasticdin

It is a product of *Streptomyces griseochromogenes* and specifically used against blast disease of rice caused by *Pyricularia oryzae.* It is commercially sold as Bla-s.

5. Antimycin

It is produced by several species of *Streptomyces,* especially *S. griseus* and *S. Kitasawensis.* It is effectively used against early blight of tomato, rice blast and seedling blight of oats. It is commercially sold as Antimycin.

6. Kasugamycin

It is obtained from *Streptomyces kasugaensis.* It is also very specific antibiotic against rice blast disease. It is commercially available as Kasumin.

7. Thiolution

It is produced by *Streptomyces albus* and effectively used to control late blight of potato and downy mildew of cruciferous vegetables.

8. Endomycin

It is a product of *Streptomyces endus* and effectively used against leaf rust of wheat and fruit rot of strawberry *(Botrytis cinerea).*

9. Bulbiformin

It is produced by a bacterium, *Bacillus subtills* and is very effectively used against wilt diseases, particularaly redgram wilt.

10. Nystatin

It is also produced by *Streptomyces noursei.* It is successfully used against anthracnose disease of banana and beans. It also checks downy mildew of cucuribits. As a post harvest dip, it effectively reduces brown rot of peach and anthracnose of banana in stroage rooms. It is commercially marketed as Mycostain and Fungicidin.

11. Eurocidin

It is a pentaene antibiotic produced by *Streptomyces anandii* and called as pentaene G-8. It is effectively used against diseases caused by several species of
Colletotrichum and *Helminthosporium.*

Methods of allocation of fungicides – Precautions and safety measures while handling fungicides

Proper selection of a fungicide and its application at the correct dose and the proper time are highly essential for the management of plant diseases. The basic requirement of an application method is that it delivers the fungicide to the site where the active compound will

prevent the fungus damaging the plant. This is mostly achieved by spray, fog, smoke, aerosol, mist, dust, or granules applied to the growing plant or by seed or soil treatment.

In addition, some trees and shrubs can be protected by injection of fungicide liquid into the trunk or by brushing wounds with fungicide paints or slurries. In the case of sprays, mists, aerosols and fogs, the fungicide is in of droplets of water of another fluid. In the case of smokers, the solid particles of the fungicide are carried by the air. In the case of dusts and granules, the fungicide is straightly mixed with an inert carrier, impregnated into it coated on the particles, which are applied mechanically.

The object of spraying or dusting is to cover the entire susceptible surface of hostwith a thin covering of a suitable concentration of the fungicide before the pathogen has come into contact with the host. However, these practices may not effectively eradicate the inoculum present on the surface of the seeds or deep-seated in the seed. So, the application of chemicals as seed dressing is highly essential.

In addition, soil harbours several pathogens which cause root diseases in several crop plants. So treatment of soil with chemicals is also highly useful in reducing the inoculum load present in the soil. The fungicidal application varies according to the nature of the host part diseased and nature of survival and spread of the pathogen. The method which are commonly adopted in the application of the fungicides are discussed.

1. Seed treatment

The seed treatment with fungicides is highly essential because a large number of fungal pathogens are carried on or in the seed. In addition, when the seed is sown, it is also vulnerable to attack by many common soil-borne pathogens, leading to either seed rot, seeding mortality or produce diseases at a later stage. Seed treatment is probably the effective and economic method of disease control and is being advocated as a regular practice in crop protection against soil and seed-borne pathogens. Seed treatment is therapeutic when it kills pathogens that infect embroys, cotyledons or endosperms under the seed coat, eradicative when it kills pathogens that contaminate seed surfaces and protective when it prevents penetration of soilborne pathogens into the seedling. There are various types of seed treatment and broadly they may be divided into three categories (a) Mechanical, (b) Chemical and (c) Physical.

A. Mechanical method

Some pathogen when attack the seeds, there may be alteration in size, shape and weight of seeds by which it is possible to detect the infected seeds and separate them from the healthy ones. In the case of ergot diseases of cumbu, rye and sorghum, the fungal sclerotia are usually larger in size and lighter than healthy grains. So by sieving or flotation, the infected grains may be easily separated. Such mechanical separation eleminates the infected grains may be easily separated. Such mechanical separation eliminates the infected materials to a larger extent. This method is also highly useful to separate infected grains in the case of 'tundu' disease of wheat. Eg. Removal of ergot in cumbu seeds.

Dissolve 2kg of common salt in 10 litres of water (20% solution). Drop the seeds into the salt solution and stir well. Remove the ergot affected seeds and sclerotia which float on the surface. Wash the seeds in fresh water 2 or 3 times to remove the salts on the seeds. Dry the seeds in shade and use for sowing.

B. Chemical methods

Using fungicides on seed is one of the most efficient and economical methods of chemical disease control. On the basis of their tenacity and action, the seed dressing chemicals may be grouped as (i) Seed disinfectant, which disinfect the seed but may not remain active for a long period after the seed has been sown and (ii) Seed protectants, which disinfect the seed surface and stick to the seed surface for sometime after the seed has been sown, thus giving temporary protection to the young seedlings against soil borne fungi. Now, the systemic fungicides are impregnated into the seeds to eliminate the deep seated infection in the seeds. The seed dressing chemicals may be applied by (i) Dry treatment (ii) Wet treatment and (iii) Slurry.

(i) Dry Seed Treatment

In this method, the fungicide adheres in a fine from on the surface of the seeds. A calculated quantity of fungicide is applied and mixed with seed using machinery specially designed for the purpose. The fungicides may be treated with the seeds of small lots using simple Rotary seed Dresser (Seed treating drum) or of large seed lots at seed processing plants using Grain treating machines. Normally in field level, dry seed treatment is carried out in dry rotary seed treating drums which ensure proper coating of the chemical on the surface of seeds. In addition, the dry dressing method is also used in pulses, cotton and oil seeds with the

antagonistic fungus like *Trichoderma vitide* by mixing the formulation at the rate of 4g/kg of the seed.

Eg. Dry seed treatment in paddy.

Mix a required amount of fungicide with required quantity of seeds in a seed treating drum or polythene lined gunny bags, so as to provide uniform coating of the fungicide over the seeds. Treat the seeds atleast 24 hours prior to soaking for sprouting. Any one of the following chemical may be used for treatment at the rate of 2g/kg : Thiram or Captan or Carboxin or Tricyclazole.

(ii) Wet seed treatment

This method involves preparing fungicide suspension in water, often at field rates and then dipping the seeds or seedlings or propagative materials for a specified time. The seeds cannot be stored and the treatment has to be done before sowing. This treatment is usually applied for treating vegetatively propagative materials like cuttings, tubers, corms, setts rhizomes, bulbs etc., which are not amenable to dry or slurry treatment.

a. Seed dip / Seed soaking

For certain crops, seed soaking is essential. Seeds treated by these methods have to be properly dried after treatment. The fungicide adheres as a thin film over the seed surface which gives protection against invasion by soil-borne pathogens.

Eg. Seed dip treatment in paddy.

Prepare the fungicidal solution by mixing any of the fungicides viz., carbendazim or pyroquilon or tricyclazole at the rate of 2g/litre of water and soak the seeds in the solution for 2 hrs. Drain the solution and keep the seeds for sprouting.

Eg. Seed dip treatment in Wheat.

Prepare 0.2% of carboxin (2g/litre of water) and soak the seeds for 6 hours. Drain the solution and dry the seeds properly before sowing. This effectively eliminates the loose smut pathogen, *Ustilago nuda tritici.*

b. Seedling dip / root dip

The seedlings of vegetables and fruits are normally dipped in 0.25% copper oxychloride or 0.1% carbendazin solution for 5 minutes to protect against seedling blight and rots.

c. Rhizome dip

The rhizomes of cardamom, ginger and turmeric are treated with 0.1% emisan solution for 20 minutes to eliminate rot causing pathogen present in the soil.

d. Sett dip / Sucker dip

The sets of sugarcane and tapioca are dipped in 0.1% emisan solution for 30 minutes. The suckers of pine apple may also be treated by this method to protect from soilborne diseases.

(iii) Slurry treatment (Seed pelleting)

In this method, chemical is applied in the form of a thin paste (active material is dissolved in small quantity of water). The required quantity of the fungicide slurry is mixed with the specified quantity of the seed so that during the process of treatment slurry gets deposited on the surface of seeds in the form of a thin paste which later dries up.

Almost all the seed processing units have slurry treaters. In these, slurry treaters, the requisite quantity of fungicides slurry is mixed with specified quantity of seed before the seed lot is bagged. The slurry treatment is more efficient than the rotary seed dressers.

Eg. Seed pelleting in ragi.

Mix 2.5g of carbendazim in 40 ml of water and add 0.5g of gum to the fungicidal solution. Add 2 kg of seeds to this solution and mix thoroughly to ensure a uniform coating of the fungicide over the seed. Dry the seeds under the shade. Treat the seeds 24 hrs prior to sowing.

(iv) Special method of seed treatment

Eg. Acid - delinting in cotton

This is follows in cotton to kill the seed-borne fungi and bacteria. The seeds are treated with concentrated sulphuric acid @ 100 ml/kg of seed for 2-3 minutes. The seeds are then washed 2 or 3 times thoroughly with cold water and shade dried. After drying, they are again treated with captan or thiram @ 4g/kg before sowing.

II. Soil treatment

It is well known that soil harbours a large number of plant pathogens and the primary sources of many plant pathogens happens to be in soil where dead organic matter supports active or dormant stages of pathogens. In addition, seed treatment does not afford sufficient protection against seedling diseases and a treatment of soil around the seed is necessary to protect them.

Soil treatment is largely curativ in nature as it mainly aims at killing the pathogens in soil and making the soil 'safe' for the growth of the plant.

Chemical treatments of the soil is comparatively simple, especially when the soil is fallow as the chemical is volatile and disappears quickly either by volatilization or decomposition. Soil treating chemicals should be non-injurious to the plants in the soil adjacent to the area where treatment has been carried out because there may be standing crop in adjacent fields. The soil treatment methods involving the use of chemicals are

(i) Soil drenching, (ii) broadcasting, (iii) furrow application, (iv) fumigation and (v) chemigation.

(i) Soil drenching

This method is followed for followed for controlling damping off and root rot infections at the ground level. Requisite quantity of fungicide suspension is applied per unit area so that the fungicide reaches to a depth of atleast 10-15 cm.

Eg. Emisan, PCNB, Carbendazim, Copper fungicides, etc.

(ii) Broadcasting

It is followed in granular fungicides wherein the pellets are broadcasted near the plant.

(iii) Furrow application

It is done specifically in the control of some diseases where the direct application of the fungicides on the plant surface results in phytotoxic. It is specifically practiced in the control of powdery mildew of tobacco where the sulphur dust is applied in the furrows.

(iv)Fumigation

Volatile toxicants (fumigants) such as methyl bromide, chloropicrin, formaldehyde and vapam are the best chemical sterilants for soil to kill fungi and nematodes as they penetrate the soil efficiently. Fumigations are normally done in nursery areas and in glass houses. The fumigant is applied to the soil and covered by thin polythene sheets for 5-7 days and removed. For example, Formaldehyde is applied at 400 ml/100 Sq.m. The treated soil was irrigated and used 1 or 2 weeks later. Vapam is normally sprinkled on the soil surface and covered. Volatile liquid fumigants are also injected to a depth of 15-20 cm, using sub-soil injectors.

(v) Chemigation

In this method, the fungicides are directly mixed in the irrigation water. It is normally adopted using sprinkler or drip irrigation system.

III. Foliar application

A. Spraying

This is the most commonly followed method. Spraying of fungicides is done on leaves, stems and fruits. Wettable powders are most commonly used for preparing spray solutions. The most common diluent or carrier is water. The dispersion of the spray is usually achieved by its passage under pressure through nozzle of the sprayer.

The amount of spray solution required for a hectare will depend on the nature of crops to be treated. For trees and shrubs more amount of spray solution is required than in the case of ground crops. Depending on the volume of fluid used for coverage, the sprays are categorised into high volume, medium volume, low volume, very high volume and ultra low volume.

The different equipments used for spray application are: Foot-operated sprayer, rocking sprayer, knapsack sprayer, motorised knapsack sprayer (Power sprayer), tractor mounted sprayer, mist blower and aircraft or helicopter (aerial spray).

B. Dusting

Dusts are applied to all aerial parts of a plant as an alternative to spraying. Dry powders are used for covering host surface. Generally, dusting is practicable in calm weather and a better protective action is obtained if the dust is applied when the plant surface is wet with dew or rain drops. The equipments employed for the dusting operation are: Bellow duster, rotary duster, motorised knapsack duster and aircraft (aerial application).

IV. Post – harvest application

Fruits and vegetables are largely damaged after harvest by fungi and bacteria. Many chemicals have been used as spray or dip or fumigation. Post harvest fungicides are most frequently applied as aqueous suspensions or solutions. Dip application has the advantage of totally submerging the commodity so that maximum opportunity for penetration to the infection sites.

Systemic fungicides, particularly thiabendazole, benomyl, carbendazim, metalaxyl, fosety-AI have been found to be very effective against storage diseases. In addition, dithiocarbamates and antibiotics are also applied to control the post-harvest diseases. Wrapping the harvested products with fungicide impregnated wax paper is the latest method available.

VI. Special method of applications

1. Trunk Application / Trunk Injection

It is normally adopted in coconut gardens to control Thanjavur wilt caused by *Ganoderma lucidum*. In the infected plant, a downward hole is made to a depth of 3-4" at an angle of 450C at the height of 3' from the ground level with the help of an auger. The solution containing 2g of Aureofungin soil and 1 g of copper sulphate in 100 ml of water is taken in a saline bottle and the bottle is tied with the tree. The hose is inserted into the hole and the stopper is adjusted to allow the solution in drops. After the treatment, the hole is covered with clay.

2. Root Feeding

Root feeding is also adopted for the control of Thanjavur wilt of coconut instead of trunk application. The root region is exposed; actively growing young root is selected and given a slanting cut at the tip. The root is inserted into a polythene bag containing 100 ml of the fungicidal solution. The mouth of the bag is tied tightly with the root.

3. Pseudostem Injection

This method is very effective in controlling the aphid vector *(Pentalonia nigronervosa)* of bunchy top of bannana. The banana injector is used for injecting the insecticide.Banana injector is nothing but an Aspee baby sprayer of 500 ml capacity. In which, the nozzle is replaced by leurlock system and aspirator needle No. 16. The tip of the needle is closed and two small holes are made in opposite direction.

It is for free flow of fluid and the lock system prevents the needle from dropping from the sprayer. One ml of monocrotophos mixed with water at 1:4 ratio is injected into the pseudostem of 3 months old crop and repeated twice at monthly intervals. The same injector can also be used to kill the bunchy top infected plants by injecting 2 ml of 2, 4-D (Femoxone) mixed in water at 1:8 ratio.

4. Corn Injection

It is an effective method used to control Panama will of banana caused by *Fusarium oxysporum* f. sp. *cubense.* Capsule applicator is used for this purpose. It is nothing but an iron rod of 7 mm thickness to which a handle is attached at one end. The length of the rod is 45 cm and an iron plate is fixed at a distance of 7 cm from the tip.

The corm is exposed by removing the soil and a hole is made at 45) angle to a depth of 5 cm. One or two gelatin capsules containing 50-60 mg of carbendazim is pushed in slowly and covered with soil. Instead of capsule, 3 ml of 2% carbendazim solution can also be injected into the hole.

5. Paring and Pralinage

It is used to control *Fusarium* wilt and burrowing nematode (*Radopholus similis)* of banana. The roots as well as a small portion of corm is removed or chopped off with a sharp knife and the sucker is dipped in 0.1% carbendazim solution for 5 minutes.

Then, the sucker is dipped in clay slurry and furadan granules are sprinkled over the corm @ 40 g/corm.

Lecture 28

Host plant resistance – Importance – disease resistance, tolerance, susceptibility and disease escape. Horizontal and vertical resistance – Method of management of resistance. Immunization – Systemic acquired resistance

Host plant resistance

A physiological deviation from the normal functioning of the organism (i.e., the crop plant) caused by pathogenic organisms is a disease and may be caused by fungi, bacteria or viruses. The inherent ability of an organism (i.e., the crop plant) to resist or withstand the pathogen is called resistance. Disease resistance commonly met with in the plant kingdom relative in nature, total immunity being too rare. Its hereditary transmission from parent to off-spring is essentially "Mendalian", but often polygenic.

The earliest demonstration of the behaviour of "disease-resistance" as a character transmissible from parent to off-spring in the "Mendelian" fashion was given by Biffen (1905) in his work on yellow rust of wheat. Since then, intensive work has been done on this aspect which has proved the value of applying genetical principles in developing disease-resistant varieties of plants for effective control of diseases.

Resistant varieties can be the simplest, practical, effective and economical method of plant disease control. The use of resistant varieties cannot only ensure protection against diseases but also save the time, energy and money spent on other measures of control. In addition to these advantages, resistant varieties, if evolved, can be the only practical method of control of such diseases as viruses, phytoplasmas wilts, and rusts etc. in which chemical control is very expensive and impractical.

In crops of low cash value, chemical and other methods of control are often too expensive to be applied. In such crops development of varieties resistant to important diseases can be an acceptable recommendation for the farmer. Pathogenicity is the ability of a pathogen to attack a host. Pathogenicity includes virulence and aggressiveness. Virulent strains of pathogen cause much severe symptoms of the disease and they carry the virulence gene that enables it to attack a particular host genotype.

Virulence is due to the action of one or a few genes. An aggressive strain of a pathogen causes severe disease on all the host genotypes which they are able to attack and aggressiveness is polygenically inherited. Host – Pathogen relationship A disease is the result of an interaction

of genes governing resistance in the host with those governing pathogenicity in the pathogen. The resistance of a crop to a physiological race of the pathogen depends not only on the genotype of the host for resistance, but also upon the genotype of the pathogen for virulence or aggressiveness. Flor (1942) proposed the gene-for-gene hypothesis, according to which, for every gene for resistance in the host, there is a corresponding gene for pathogenicity in the pathogen.

It means that there are atleast two alleles at a locus controlling resistance/susceptibility in the host (R-r) and two alleles at a corresponding locus in the pathogen (V-v) controlling virulence / aggressiveness. Out of the four possible interactions between these alleles, only one combination leads to the expression of resistance. The demonstration of gene-for-gene relationship requires genetic studies of both the host and the pathogen.

Pathogen

VI v1 + Pathogen can infect; the host is R1 -+ susceptible r1 + + -

Pathogen cannot infect; the host is resistant

The demonstration of gene-for-gene relationship requires genetic studies of both the host and the pathogen

Vertical resistance (VR) and horizontal resistance(HR)

Van der Plank (1960) has discussed the whole issue of disease resistance in a different perspective. He calls the unstable and often complete type of resistance as vertical resistance and the more stable but somewhat incomplete resistance as horizontal resistance. If resistance to some races of a pathogen is more than to other races, it is called Vertical resistance. It is also called Perpendicular resistance, Physiological resistance, seedling resistance, hypersensitivity, race specific resistance or qualitative resistance. As it is conditioned by one or a few genes, it is called major gene or monogenic of oligogenic resistance.

Resistance to more than one race of the pathogen or to many or all races of the pathogen is called Horizontal Resistance. It is non-specific resistance governed by polygenes. It is severally termed as non-specific, general, polygenic, minor gene, mature plant, adult, quantitative resistance, partial or field resistance or tolerance. HR causes reduction in the number and rate of sporulation of the pathogen on the host and slows down the infection rate. HR includes tolerance slow development of disease, escape and exclusion mechanisms besides

hypersensitive reaction. The difference between vertical resistance and horizontal resistance are given in table.

Differences between vertical and horizontal diseae resistance * Detectable by analysis of variance of a suitable experiment

Feature	**Vertical resistance**	**Horizonal resistance**
Pathotype-specificity	Race specific	Race nonspecific
Nature of gene action	Oligogenic	Polygenic; rarely oligogenic
Response to pathogen	Usually, hypersensitive	Resistant response
Phenotypic expression	Qualititative	Quantitative
Stage of expression	Seedling to maturity	Expression increases as plant matures (Adult plant)
Selection and evaluation	Relatively easy	Relatively difficult
Risk of 'boom and burst'	Present (rarely durable)	Absent (durable)
Suitable for: a. Host b.Pathogen	Annuals but not perennials Immobile pathogen, e.g., Soil pathogens, but for mobile air-borne, pathogens	Both annuals and perennials All pathogens
Need for specific deployment of resistant varieties	Critical for success with mobile pathogens	None
Need for other control measures	Likely	Much less likely
Host-pathogen interaction *	Present	Absent
Efficiency	Highly efficient against specific races	Variable, but operates against all races

Vertical resistance to specific races is generally governed by a single (monogenic) dominant gene or by a few dominant genes. Some of these genes may be multiple alleles as in leaf rust gene, Lr2 that accords resistance to *Puccinia recondite tritici.* In that locus, four genes designated as Lr2a, Lr2b, Lr2c and Lr2d are present and are tightly linked. Each of these genes accord resistance to a different spectrum of races and hence can be differentiaited from one another. Such multiple alleles exist on Sr9 locus of wheat for *P.graminis tritici* and gene Pi-k in rice for resistance to *Pyriculariva grisea.* The tight linkage between the multiple alleles permits an efficient transfer of all these genes in one attempt.

'Horizontal resistance' (HR) reduces the rate of disease spread and is evenly spread against all races of the pathogen. The low terminal disease severity in HR is assumed to result from polygenic resistance. Morphological features such as size of stomata, stomatal density per unit area, hairiness, waxiness and several others influence the degree of resistance expressed. Partial resistance, dilatory resistance, lasting resistance are some other terms coined for denoting horizontal resistnce.

The phenomenon of slow rusting manifested as lesser number of pustules per unit leaf area, smaller size of uredosori and increased latent period in some wheat cultivars is a typical example of this type of resistance. Although it is preferable to use varieties that have both vertical and horizontal resistance, most of the resistant varieties carry only one or few (2 or 3) major genes of vertical resistance. If varieties are resisitant only to some of the races of pathogen and if the pathogen is airborne, then new races evolve easily, as happens with cereal rusts, the powdery mildlew and *Phytophthora infestans.* Appearance of new races lead to breakdown of resistance of the popular, ruling genotype. As a result, varieties with vertical resistance need to be replaced at frequent intervals.

Boom and burst cycle

In varietial improvement programmes, it is easy to incorporate the monogenic vertical resistance genes. But the success of exploiting the monogenic host resistance invariably does not last long. Whenever a single gene-based resistant variety is widely adopted, the impact would be the arrival of new matching pathotypes.

These pathotypes soon build up in population to create epidemics and eventually the variety is withdrawn. This phenomenon is generally called " boom and burst". The avoid the implications of boom and burst phenomenon, use of durable host resistance is advocated in several crops. Durable resistance remains effective even though it may be widely grown ovoer a long period of time, in an environment that favours the disease. For example, oat variety, Red Rust Proof is still resistant against crown rust even after a hundred years. Wheat varieties, Thatcher and Lee have withstood stem rust for 55 and 30 years, respectively. Cappelle Desprez expresses at adult stage, a moderate resistance to yellow rust and this has been maintained for the last 20 years.

Two of the genes like Lr34 for resistance of leaf rust and Sr2 for resistance to stem rust have been recognized for durability. Wheat cultivars such as HD2189, HP1102, DL153-2, DL803-3 and DL802-2, which possess Lr34 with other gene combinations have a good degree of resistance and hae become popular with growers. So far, there is not precise way available to identify the genetic components that are associated with durable resistance. Nor does dissociation of genes for virulence totally explain the basis of varietal durability, though it is likely to be the most plausible reason Boom and burst cycle-a characteristic of vertical resistance Resistance to virus and virus vectors Resistane to plant pathogenic viruses is generally oligogenic in nature.

For example, the host pathogen reaction to the barley yellow dwarf virus (BYDV) is controlled by detectable single gene. The discovery of Yd2 gene in Ethiopial barley further confirms that against some of the viral diseases, vertical resistance is very much functional. Antiobiotics is the most common phemomenon where the host plant metabolites interfere with the normal life and growth of the insects following feeding activity.

Invariably, the adult body weight, fecundity and various facets of multiplication of the insects are adversely affected. The number of life cycles completed in a given period of time is also less. Therefore, in plants that exhibit antibiosis towards crop maturity, there is marked reduction in the level of pest infestation (virus vector population) and host damage. Mechanism of disease resistance or Nature of disease resistance Disease resistance is governed by several in-built mechanisms of the host, plants against infection by the pathogen. They are disease escape, disease endurance or tolerance and true resistance.

a. Disease escape

It is a prevention mechanism that causes the host to escape pathogenic infection. Early or late maturity of the crop may prevent physical contact of the pathogen with the host. Mechanical and anatomical barriers such as thick cuticle, waxy bloom on leaves and stem, stomatal regulation prevent penetration of spores. Ergot, a fungal disease of inflorescence in cereals caused by *Claviceps purpurea* does not affect varieties of wheat and barley in which the flowers remain closed until pollination occurs. Erect leaves of barley avoid deposition of spores of *Erysiphe graminis tritici* in contrast to prostrate leaves. Early maturing varieties of groundnut escape early leaf spot infection (*Cercospora arachidicola*) and early varieties of wheat escape rust and loose smut infection.

A change in planting season has also been successfully employed as a measure of securing escape, e.g., the leaf rust of sugarcane (*Puccinia sacchari*) in the canal areas of Bombay severely affects cane when planted in June, but is of minor importance or absent in crops sown in October. Disease escape confers pseudo-resistance.

b. Disease endurance

The host after being infected by the pathogen tolerates the infection and suffers less damage. It does not result in any substantial decrease in yield. This is brought about by influence of external factors. It is a well-known phenomenon that plants fertilized with phosphatic and potash manures are more tolerant to disease; this is the case in wheat against rust infection. Rice crops fertilized by silicates are "resistant" to blast (P*yricularia oryzae*) in Japan. Wheat crops fertilized by potash and phosphatic manures are highly tolerant to mildew and rust infection. The fertilizers act indirectly to arrest vegetative growth and promote early maturity, better straw and strengthening tissues to protect the plant which form a bulwark against pathogenic invasion.

c. True resistance

It is the ability of the host plant to resist or withstand the attack of a pathogen. True resistance is inheritable and much less subject to environmental influence. It is specific in character. The basis of resistance may be morphological, functional, structural or protoplasmic. Functional nature of resistance is determined by opening of the stomata, time of opening of flowers and time of maturity, rate of cork formation and cambial activity.

Structural characters include the proportion of strengthening tissues, fibre content, nature of middle lamella, corky layers, number and structure of stomata and lenticels and their sizes. Protoplasmic factors controlling resistance are related to cell contents and include acids, tannins, anthocyanins, chemical constituents and their proportion, antibiotic activity and hypersensitivity present in the plant cells and in addition biological antagonism of the protoplasm of the host and the pathogen. True resistance, however, is of a specific character and is determined by the defence equipment and activities of the plant itself against the parasitic invasion and is therefore not subject to any appreciable modifications by external factors.

Methods of breeding for disease resistance

The methods of breeding varieties resistant to diseases do not differ greatly from those adopted for other characters. The following methods are used:

1. Introduction,
2. Selection,
3. Hybridization followed by selection,
4. Back cross method,
5. Induced mutagenesis,
6. Development of multilines and
7. Tissue culture techniques

1. Introduction

It is a very simple and inexpensive method. Varieties resistant to a particular disease elsewhere may be thoroughly tested in the regions in which they are proposed to be introduced. Their yield performance and disease resistance should be confirmed by large scale cultivation. It is possible that a variety resistant in one region need not be resistant in another region due to variation in the physiological race of the pathogen or due to a much different agroclimatic condition in the new location.

Introductions have served as a useful method of disease control. For example, Ridley wheat introduced from Australia has been useful as a rust resistant variety. Manila, a rice variety introduced in Karnataka from the Philippines, has tolerance to blast, bacterial leaf blight and sheath blight. Intan, a Javanica type rice variety introduced in Karnataka from Indonesia is highly resistant to blast. Munal, a rice variety introduced in West Bengal from the U.S.A. is tolerant to blast, bacterial leaf blight and leaf folder (pest). Some of IRRI rice varieties such as

IR 20, IR.24, IR.28, IR.34, IR.36 and IR .50 possess resistance to one or more diseases. Early varieties of groundnut introduced from U.S.A. have been resistant to laf spot (*Cercosora arachidicola).*

Kalyan Sona and Sonalika wheat varieties originated from the segregating materials introduced from CIMMYT, Mexico and were rust resistant. Introduftions also serve as sources of resistance in breeding programmes. For example, African pearlmillet (*P. americanum)* introductions have been used for developing downy mildew resistant male sterile lines (Tift 23A cytoplams) for use in hybrid pearlmillet production. This is an important development in the hybrid pearlmillet programmes since the original male sterile lines Tift 23A and 23D2A were extremely susceptible to downy mildew.The introduction of Co.475 variety of sugarcane in Mumbai has conquered red rot but brought in leaf rust and whip smut to the fore.

2. Selection

This is better method than introduction and has more chances of success in obtaining disease-resistant plants. The work of selection is carried out either in the naturally infected fields under field conditions or under artificially inoculated conditions. The resistance in such individuals will occur in nature by mutation. To ensure the resistant character of a plant, large population of crop plant may be exposed to the attack of pathogen under artificial conditions and the non-infected plants may be chosen. Suvarnamodan rice of Kerala is a pure line of ARC. 11775 and is highly tolerant to blast.

Sugandh of Bihar is a selection from Basmati rice of Orissa tolerant to bacterial leaf blight. Rice varieties Sudha (Bihar), Sabita, Nalini (West Bengal), Patel 85 (Madhya Pradesh), Janaki(Bihar), Improved White Ponni (Tamil Nadu), Ambika (Maharashtra), are some of rice selections resistant to one or more diseases. MCU 1 cotton, a selection from Co 4, is resistant to Kufri Red, a potato selection from Darjeeling Red Round is a disease resistant variety.

3. Hybridization

When selection of resistant varieties is not feasible, resistant varieties may be evolved by crossing the susceptible popular variety with resistant wild variety where in the resistant gene or genes transferred into the genetic make up of susceptible variety. Very often the F1 from crosses may be resistant but carry the other undesirable qualities of the resistant parent. The bad qualities are removed by several back crossing of F1 with the susceptible parent may ultimately yield a resistant progeny with good agronomic characteristics.

Under certain circumstances pedigree or bulk method of selection is followed to obtain a resistant variety. In this method, the crosses are made till F2 population is got. Selections are made in F2 generation for superior genetic traits including disease resistance. By continued selfing, selections are made through F3 to F5 or F6 generations and the best variety is selected. This method is suited for small grains and beans but unsuited to fruits and vegetables.

4. Back cross method

Back cross method is widely used to transfer disease resistance from wild species. Wild species are rice sources of disease resistance. Interspecific hybridization is made to transfer the gene or genes for resistance to the cultivated species. Resistance to grassy stunt virus from *Oryza nivara* to *O.sativa*, late blight resistance from *Solanum demissum* to cultivated potato, rust resistance from *durum* to *aestivum* wheat are some of the examples involving interspecific hybridization. Depending upon the number of genes governing resistance and the nature of the gene, whether dominant or recessive, the procedure varies. The number of back crosses to the cultivated species may be five to six. Once the back cross progeny resemble the cultivated parent, then they are selfed and segregating progeny screened for disease resistance.

5. Induced mutagenesis

While following mutation breeding for disease resistance, a large number of mutation progeny should be produced and screened under artificial epiphytotic condition to select resistant plants. MCU10 cotton, a resistant variety to bacterial blight was evolved in Tamil Nadu by subjecting seeds of a susceptible variety CO4 to gamma rays followed by rigorous screening and selection 6. Development of multilines The concept of multilines was first suggested by Jensen(1952) and developed by Borlaug (1959) for evolving multiline varieties to resist stem rust in wheat. A multiline variety is a composite of genetically similar lines, except that each line possesses a different gene for resistance to the pathogen.

Lines that are genetically similar, except for one gene, are called isoline. It is assumed that gene for resistance in each isoline contributes resistance to a separate physiological race or group of races. Genes for disease resistance are transferred by backcrossing from donor varieties to a common disease susceptible, but agronomically superior, recurrent parent. Isolines are generated differing only in the gene for disease resistance. The isolines are composited to synthesize a multiline variety. The isolines are maintained for resynthesizing the multiline

whenever needed. A multiline variety is composed of a mixture of resistant and susceptible genotypes and provides a buffering effect against rapid development of disease. It will provide resistance or tolerance to a broad spectrum of races of a pathogen. If new races of the pathogen are identified at a later stage, additional isolines resistant to the newly arisen races may be constituted and incorporated.

Care should be taken to see that there is uniformity for height, maturity and other features in the multiline. Though multilines provide stability of yield due to reduction of damage by pathogens, the limitations of multiline varieties are that the yield level of multiline varieties is limited to that of the recurrent parent, 4 to 5 years are required to stabilize isogenic lines and the pathogen may produce new races at a faster rate than the development of a multiline. Multiline varieties have been developed for resistance to stem rust and stripe rust of wheat and crown rust of oats. The first multiline variety in wheat, 'Miramar 60' was developed and released in Columbia to combat the attack of yellow rust. 'Miramar 63' and 'Miramar 65' were resistant to stem rust and stripe rust. 'Yoqui 50', 'Crew' and 'Tumult' are a few other wheat multilines. Kalyan sona and Sonalika-based multilines of wheat resistant to different races of rust have been developed in India.

7. Tissue culture technique

Tissue culture techniques to produce somaclonal variation for disease are developed in different crops. Somaclonal variations for disease resistance are reported in *Zea mays* for *Drechslera maydis* race T-toxin resistance, in *Brassica napus* for resistance/tolerance to *Phoma lingam*, early and late blight resistance in potato, *Pseudomonas* and *Alternaria* resistance in tobacco, besides smut and rust disease resistance in sugarcane.

Lecture 29

Application of biotechnology in plant disease management – Importance, production of pathogen free plants through tissue culture techniques

In modern terms "biotechnology' is defined as the manipulation, genetic modification and multiplication of living organisms through novel technologies, such as tissue culture and genetic engineering, resulting in the production of improved or new organisms and products that can be used in a variety of ways.

Genetic engineering is the technology by which it is possible to isolate particular gene from one organism, insert them into the genome of another organism and make them to express at right time. Cells of plants can be cultured in special nutrient medium and whole plants can be regenerated from cultured cells. This technique of growing plants in *vitro* is called "Tissue culture".

In calli derived from infected tissues not all cells uniformly carry the pathogen. Only 40% of the single cells mechanically separated from TMV - infected tobacco callus contained the virus. The two possible reasons for the escape of some cells of a systemically infected callus from virus infection are -. a) virus replication is unable to keep pace with cell proliferation, and b) some cells acquire resistance to virus infection through mutagenesis. Cells resistant to virus at back may even exist in the parent tissue together with susceptible ones. Several disease resistant plants have been evolved using somoclonal variation. Out of 370 tomato plants regenerated from calluses six showed resistant to TMV. Similarly, late blilght *(Phytophthora infestans)* - resistant potato plants and bacterial blight of rice resistant calli have been evolved.

The pathogen produced secondary metabolites can be used to screen calluses for evolving disease resistant plants. Toxins will kill the calluses, but the mutant toxin resistant calluses will survive. The regenerated toxin resistant calluses yielded disease resistant plants. Brown spot pathogen *(Helminthosporium oryzae)* produced a host specific toxin for which resistant plants have been successfully developed. Similariy, *Helminthosporium maydlis* - toxin resistant maize plants, *Phytophthora infestans* - resistant tobacco plants, *H. sacchari* resistant sugarcane plants have been evolved. Somaclonal variation refers to the tissue culture derived variation- Plants regenerated from somatic cells, using tissue culture. are not genetically uniform but display significant genetic variability. This variability is very high when compared to spontaneous mutation. Somacional variation has been deryionstrated in a large number of plant species

(wheat, rice, oats, maize, tobacco, potato, sugarcane, brassica, etc.) for various traits such as resistance to fungal, viral and bacterial diseases. The procedure involves growing of cell cultures for several cycles on nutrient medium without any selective agent, followed by regeneration of plants.

The regenerants and their progenies are screened for disease resistance. Embryo rescue and protoplast fusion techniques are important to obtain hybrids among incompatible species and introgression of alien genes for disease resistance. In number of cases, useful genetic variability in the cultivated germplasm for resistance to diseases is either limited or lacking. Under such situations, wild germsplasm seems to be a reservoir of useful genes for disease resistance. In the incorporation of alien genes, several crossability barriers are encountered. In many cases, the hybrid embryo aborts. However, the excised hybrid embryos when cultured on nutrient medium ran be grown to plantlets. To incorporate alien genes from divergent sources, embryo rescue appears to be promising.

Tissue culture in conduction with recombinant DNA technology is becoming increasingly important to insert foreign genes and produce transgenic plants. For successful infection of virus particles, the coat protein should be removed from viral RNA. If the host is made to synthesize coat proteins in large amount, naked viral RNA formation will be negligible. The host coat protein will encapsulate the RNA of the virus and prevent its multiplication. This will result in reduction and delay in symptom development. Eg. Transgenic tobacco plants expressing the tobacco mosaic virus coat protein protected the plants against this virus.

The expression of the viral genome in transgenic plants also conferred resistance to virus infection. These regions include portion of the viral replicas as well as, antisense RNA to coat protein. Transgenic tobacco plants transformed with a DNA copy of the satellite RNA of cucumber mosaic virus (CMV) were shown to produce large amounts of satellite RNA following inoculation with CMV and symptom development was greatly reduced.

Proteins with the ability to inhibit the growth of fungi *in vitro* are abundantly present in plants. Constitutive expression of these genes in transgenic plants may render these plants to fungus resistant. Transgenic tobacco plants constitutively expressing bean chitinase have been shown to display enhanced resistance to *Rhizoctonia solani*. Recently, tobacco plants expressing a ribosome inactivating protein (RIP) from barely showed resistance to *R. solani.* The RiPs do

not inactivate self ribosomes and show activity towards ribosomes of distantly related species including those from fungi.

The constitutive expression of the groundnut stilbene synthase gene in transgenic tobacco plants results in the synthesis of resveratrol (phytoalexin) and the transgenic plants show resistance to *Botrytis cinerea.*

Transgenic tobacco plants expressing acetyltransferase which detoxifies the tabtoxin, show resistance to *Pseudomonas syringae* pv. *tabaci.* More recently, chitinase gene from *Manduca sexta,* tobacco horn worm, has been cloned into *P.fluorescens* to increase their antagonistic potential against R.solani.

Meristem or shoot tip culture

Meristem and shoot tip culture are used to eliminate virus from infected germplasm. It has long been observed that the rapidly growing meristems of plants are usually free of viruses, or at least have much lower concentration of viruses than nonmeristem cells. This situation has been exploited forthe production of virus-free plants by meristem culture. It is commanly used in cassava, potato, sweet potato and ornamental plants.

"Virus-free" the term has been loosely used in literature. Plants infected with more than one type of virus and also may carry some unknown viruses. Thus, a plant can be claimed as free of only those viruses for which specifictests have givenne gative result sowever, the term "virus-free" is still retained by horticulturists for its commercial value.

Pathogen attack does not always lead to death of the plant. Many viruses may not even show visible symptoms. However, the presence of viruses in the plants can reduce the yield and quality of crops. It is well known that the distribution of viruses in plants is uneven. In infected plants, the apical meristems are generally either free or carry a very low concentration of the viruses. In the older tissues, the titre of the viruses increases with increasing distance from the meristem tips.

Five main possibilities have been suggested to explain the mechanisms underlying the 'resistance'of meristems to viruses.

(i) Exclusion of the viruses from the meristems by lack of suitable vascular or plasmodesmatal connections.

(ii) Competition for key metabolites by the rapidly dividing meristem cells.

(iii) The production of substances in meristem cells that result in breakdown of the virus.

(iv) Deficiency in some key components of the machinery of virus replication, and

(v) Presence of inhibitors of virus replication.

Factors affecting virus eradication

Factors such as culture medium explant size and culture storage influence the virus eradication. In addition, heat treatment before or during culture significantly influences the efficiency of this technique. The physiological stage of the explants also affects virus elimination by meristem tip culture.

(i) The success in obtaining complete plants can be considerably improved by the choice of the culture medium. The major features of the culture medium to be considered are its nutrients, growth regulators and physical mature.

(ii) The size of meristem tip is an important factor governing regeneration capacity of meristems and to obtain virus free plants. For example, in cassava, meristems exceeding 0.2 mm size regenerated to plantlets, but those less than 0.2 mm size developed either Gallus or callus with roots. In general, the larger the meristem, the greater is the number of regenerated plants, but the numberof virus free plant is inversely proportional to the size of meristem cultured.

(iii) For meristem - tip cultures light incubation has generally proved better than dark incubation. The optimum light intensity for initiating tip cultures of potato is 100 lux, which should be increased to 200 lux after 4 weeks. The cultures are generally stored understandard culture room temperatures (25 ± 2ºC).

(iv) Meristem tips should, preferably be taken from actively growing buds. Tips taken from terminal buds gave better results than those from axillary buds.

Meristem tip culture to eliminate Cassava Mosaic Virus

Rapidly growing vegetative buds are excised, rinsed with sterile distilled water and then disinfected by immersing them in mercuric chloride solution (0.1%) for 2-3 minutes. The buds are then rinsed with several changes of sterile distilled water. Under the microscope, 3-4 leaf primordia (0.3 to 0.6 mm in size) is removed from the bud with a sterile scalpel. The buds are then aseptically transferred to Murashige and Skoog (MS) medium in test tubes and incubated at 25 ± 2’C in light, for 45 days. The plantlets are then removed from the test tubes, washed in tab water and kept in Hoagland solution for 3-4 days for hardening. The plantlets are transferred to pots containing peat soil and vermiculite at 3:1 ratio and kept in mist chamber for 5-7 day. The plants are then transferred to glass house for further study.

Lecture 30

Disease Management by Biotechnological Methods

The use of genetically modified organisms and or modern techniques (genetic engineering, tissue culture etc.) with biological systems for disease control is known as biotechnology. Genetic engineering or Genetic manipulation is the deliberate alteration of the composition of a genome by man. A growth of cells in a laboratory nutrient medium is known as tissue culture i.e. the technique of growing of plants in *vitro*. Cells of plants can be cultured in special nutrient medium and whole plants can be regenerated from cultured cells. Plant biotechnology is used for rapid clonal propagation of plants. It can help to produce industrial plant products under tissue culture conditions Biotechnological methods are employed to control important plant diseases which are not amenable to control by usual methods.

Genetic engineering

Genetic Engineering is the technology by which a particular gene is isolated from one organism and inserted into the genome of another organism and made to express at the right time.

Vectors for transfer of genes

Genetic engineering has been used to manage plant virus diseases. For transfer of genes to plants vectors are needed in which the gene to be transferred will multiply several folds. The most effective gene vector developed is the Tumour inducing plasmid of *Agrobacterium tumefaciens* from which the Tumor inducing genes have been removed *A.tumefaciens* induces tumors (crown galls) through di-plasmid (tumor-inducing) which is a circular double stranded DNA molecule containing up to 2,00,000 base pairs organized into several genes.

The Ti-plasmid is transferred from the bacterium into the cell. A specific region of the plasmid, the T-DNA, is transferred from the plasmid to the nucleus of the plant cell. It becomes integrated into the plant nuclear genome, and is transcribed. Cauliflower mosaic virus (CaMV) is the only plant virus with double-stranded DNA genome. As it has DNA genome, it is used as a possible vector in introducing foreign genes into plant. It is possible to insert a non-viral gene into CaMV genome and obtain expression of the gene in the infected plant. The viral promotor regions from CaMV are effective for

obtaining expression of other genes in plant cells. The genes to be expressed is now fused to a promotor element from CaMV and a gene of *A.tumifaciens*. They are then introduced into the plants using *A. tumefaciens* Ti-DNA transformation.

DNA construction

Messenger RNA is extracted and exposed to an enzyme reverse transcriptase which synthesizes a complimentary single stranded DNA. The complimentary DNA (cDNA) is exposed to another enzyme, DNA polymerase, which produces the double stranded cDNA. The cDNAs are inserted into the plasmids of *A. tumefaciens*.

Coat-protein expression in transgenic plants

Example: Transgenic tobacco plants expressing coat protein gene protected the plants against TMV. Transgenic tobacco plants showing resistance to alfalfa mosaic virus and tobacco rattle virus have also been developed. Transformation using a gene encoding the viral nucleocapsid protein of tomato spotted wilt virus (TSWV) has yielded transgenic tobacco plants that are resistant to TSWV. The expression of the viral genome in transgenic plants gives resistance to virus infection. Transgenic tobacco plants transformed with a DNA copy of the satellite RNA of cucumber mosaic virus (CMV) are shown to produce large amounts or satellite RNA following inoculation with CMV and symptom development is greatly reduced.

Satellite RNA expression in transgenic plants

Satellite RNAs are associated with several viruses. They are packaged into virus particles along with the genomic RNAs of the helper virus. They are not part of the viral genome and have no obvious sequence relationships with the helper virus. The presence of the satellite RNA suppresses the disease severity in many hosts. Hence transgenic plants which express satellite RNA have been produced to manage virus diseases. e.g., Transgenic plants of tobacco expressed the synthesis of satellite tobacco ring spot virus and reduce the virus disease incidence. Satellite RNA expressing tobacco plants against Cucumber Mosaic Virus (CMV) and Tobacco aspermy virus have been synthesized.

MIC RNA expression in transgenic plants

A DNA copy is made of one or more sections of the viral genome that include the initiation codon for proteins vital to virus replication. The DNA copy is inserted in the host-cell genome, Cells then produce an `antisera RNA' called mic RNA (mRNA-

interfering complementary to 5' end of the gene). The mic RNA hybridizes in vivo with the viral mRNA blacking translation. The mic RNA is inserted into the plants using the Ti plasmid of A. *tumefaciens*. Plants regenerated from the transformed cells will be resistant to the particular virus. This possibility is also being exploited for the control of virus diseases.

Use of RFLP markers for cloning resistance genes

Molecular markers *viz*., isozymes and DNA markers (Restriction Fragment Length Polymorphisms - RFLPs; Random Amplified Polymorphic DNA - RAPD and others) are being used in several areas relevant to identification of disease resistance genes. Some of the disease resistance genes using random DNA markers have been identified.

Disease resistance genes mapped using RFLP markers

Plant	**Pathogen**
Tomato	*Fusarium oxysporum*
Citrus	*Phytophthora* spp.

Detoxification of pathotoxin

Pathogens that produce pathogenesis-related phytotoxins usually also have the capacity to metabolize i.e. detoxify, these compounds. The search for genes encoding the enzyme(s) performing the key catabolic step(s) should thus lead to a convenient source of resistance, which can be engineered into plants to protect them from the effects of the toxin. A gene encoding a tabtoxin acetyltransferase from the pathogen, *Pseudomonas syringae p*v. *tabaci* which causes wild fire disease of tobacco was isolated and transferred into tobacco under a strong constitutive promotor. The transgenic plants expressed this gene and, when treated with either the pathogen or its toxin, did not produce the chlorotic lesions typical of wild fire disease.

Activation of plant defense mechanism-Phytoalexins

Phytoalexins have long been known to accumulate in certain plants upon infection by pathogens. The production of phytoalexins is also triggered by mechanical stimulation, ultraviolet (UV) irradiation, stress and a variety of chemical elicitors. Phytoalexins are part of the localized hypersensitive response at the site of damage or

pathogen ingress, which involves cell trauma and death. The importance of phytoalexins in the defense response is underscored by experiments and pathogenicity in *Nectria haematococca* was correlated to its ability to detoxify the phytoalexin, pisatin, by way of demethylation. By transferring the demethylase gene from Nectria, *Aspergillus nidulans*, a non-pathogen on peas, was rendered insensitive to pisatin.

Defense related genes

a. Single gene defense mechanism

There are some defense proteins which do not require any intermediate step both for their synthesis and their expression require only few steps and those genes encoding such proteins are called single gene defense mechanism. Chitinases and glucanases are those proteins belonging to single gene defense mechanism.

Chitinases and glucanases

Chitinases are abundant proteins found in wide variety of plants. Although the physiological function of chitinases is not known, there is strong correlative evidence that they are defense proteins with antifungal activity. Chitin is a major structural component of cell walls of many fungi. The low constitutive activity of chitinase found in many plants can be dramatically induced by wounding or by infection of the tissue with fungal pathogens. Chitinase in concret with ß-1,3-glucanase (capable of degrading glucans present in fungal cell wall), degrades fungal cell walls and inhibits fungal growth at hyphal tips and has been shown to associate with hyphal walls in plants.

The chitinase and glucanase enzymes are having direct action against several fungal pathogens compared to other defense related proteins. Since lytic enzymes are encoded by single genes, these defense should be high amenable to manipulation by gene transfer. The first reports of success with this approach was the expression of bean vacuolar chitinase gene under the control of the strong constitutive gene under the control of the strong constitutive promoter of the cauliflower mosaic virus (CaMV) 35 S transcript in tobacco and *Brassica napus*, which resulted in decreased symptom development by *Rhizoctonia solani*, the causative agent of post-emergence damping off.

An endochitinase gene (from genomic tomato DNA library) was introduced into *Brassica napus.* var. *oleifera*. The transgenic *Brassica* showed enhanced resistance against several fungal pathogens like *Cylindrosporium concentricum, Phoma lingam* and

Sclerotinia sclerotiorum under field conditions when compared to non-transgenic plants. More recently, chitinase gene from *Manduca sexta*, tobacco horn worm, has been cloned into *P. fluorescens* to increase their antagonistic potential against *R. solani.*

b. Multigenic defense mechanism

Defense responses such as phytoalexin biosynthesis or lignin deposition in the cell wall require the action of many genes.

Peroxidases

Anionic peroxidases in the cell wall catalyze the production of phenolic radicals for the oxidative polymerization of lignin from cinnamyl alcohols. In tomato, there is a marked induction of two linked genes encoding highly anionic peroxidases in an incompatible interaction with an avirulent form of *Verticillium albo-atrum*, with only weak induction in the compatible interaction with a virulent form of this vascular pathogen. Expression of one of these genes in transgenic tobacco under the control of either its own promoter or the CaMV 35s promoter resulted in massive increase in anionic peroxidase activity and these plants apparently showed a significant increase in resistance to *Peronospora parasitica* as judged by symptom development and fungal sporulation.

Activation of defense genes by chemicals

Several classes of compounds have the potential to act as inducers of natural resistance mechanisms in horticultural crops and chemicals with such indirect modes of action may offer attractive alternatives or supplement to existing contact/systemic fungicides in integrated disease management. Increase was found to occur in response to salicylic acid treatment as well as oligosaccharides and glycoproteins originating from either fungal cell wall or host cell walls, the so called elicitors. Recently, chitosan seed treatment has been found to induce defense related genes like chitinase and glucanase in tomato and consequently the Fusarium crown and root rot diseases were significantly reduced. Pre-treatment with 2, 6-dichloroisonicotinic acid was highly effective in significantly reducing both anthracnose (caused by *Colletotrichum lindemuthianum*) and rust (caused by *Uromyces appendiculatus*) diseases in bean plants.

Cell and tissue culture

Tissue culture approach is one of the oldest techniques in the field of molecular biology and it is applied in several ways for the development of disease resistance cultivars in agriculture and horticulture.

a. Somaclonal Variation

In the past two decades, several advances have been made in culturing of isolated plant cells and tissue under controlled conditions in vitro. When plants are regenerated from cultured cells, they exhibit new phenotypes, sometimes at high frequencies. If these are heritable and affecting desirable traits, such "somaclonal variation" can be incorporated into regular breeding programmes.

However, the finding of specific traits by these methods is largely left to chance and hence inefficient. Rather than relying on this undirected process, selection in vitro aims to specific traits by subjecting large populations of cultured cells to the action of a selective agent in the petridish. For purpose of disease resistance, this selection can be done by fungal pathogens, culture filtrates of pathogens or isolated phytotoxins that are known to have a role in pathogenesis. The selection will allow only those cells to survive and proliferate that are resistant to the challenge. Plants regenerated from resistant cells often display a resistant phenotype when evaluated with either the toxin or the pathogen itself.

Disease resistant plants from tissue culture

Plant	Culture System	Selection	Resistance to Pathogen
Potato	Protoplasts	SCV	*Phytophthora infestans* *Alternaria solani*
	Callus	CF	*Fusarium oxysporum*
Tomato	Callus	Fusaric	*Fusarium oxysporum*
	Protoplasts	acid	
Banana	Meristem	SCV	*Fusarium oxysporum*
Strawberry	Callus	SCV	*Fusarium oxysporum*

(SCV- plant regeneration without selection; CF crude culture filtrate)

Although this method has obviously yielded some impressive results, it also has its drawbacks; *viz*, i. Many pathogens do not produce pathogenesis specific toxins useful for selection ii. Culture filtrates are rather artificial and neither pathogens nor plant cells grown together in vitro behave quite as they would in a natural environment iii. The selection approach can only detect mutations in plant genes that are expressed at the time that selection is applied.

In order to be useful, new resistance traits, whether selected or not, must be heritable sexually or in the case of vegetatively propagated crops must be transmitted through vegetative propagules. The pathogens produced toxins can be used to screen calluses (cultured cells) which may regenerate resistant plants. The toxins will kill the calluses, but the mutant toxin resistant calluses will survive. The toxin-resistant calluses yield disease resistance plants. Vidhyasekaran obtained brown spot resistant rice plants using *Helminthosporium oryzae toxin*. Similarly, *H. maydis* resistant maize plants, *H. sacchari* resistant sugarcane plants and *Phytophthora infestans* resistant tobacco plants have been evolved.

b. Anther culture

In this method, the plants are produced directly from microspores (immature pollen grains). Through anther or microspore culture, one has immediate access to unique and rare combinations of genes representing the recombination of the genetic material contributed by the parents of the cross. Through anther culture, followed by chromosome doubling, such gene combinations can be fixed in their homozygous state as instant inbreds in a single step. Over the past two decades, anther culture has become widely accepted as a tool in cultivar development. This technique can be particularly useful for producing plants with novel combinations of resistance genes for managing fungal diseases.

c. Protoplasmic fusion

This generates hybrid cells by merging the total cellular components of somatic cells from which the cell walls have been removed to produce protoplasts. The incompatibility preventing sexual fertilization between species is thus avoided and viable hybrids have been created, even between unrelated distance species. Disease resistance genes have thus been transferred by protoplasts fusion from wild species into potato.

Lecture 31

INTEGRATED PLANT DISEASE MANAGEMENT (IDM) – CONCEPT, ADVANTAGES AND IMPORTANCE

Integrated plant disease management can be defined as a decision-based process involving coordinated use of multiple tactics for optimizing the control of pathogen in an ecologically and economically. The implications are:

- ✓ Simultaneous management of multiple pathogens
- ✓ Regular monitoring of pathogen effects, and their natural enemies and antagonists as well
- ✓ Use of economic or treatment thresholds when applying chemicals
- ✓ Integrated use of multiple, suppressive tactics.

Principles of Plant Disease Control

1. **Avoidance**—prevents disease by selecting a time of the year or a site where there is no inoculum or where the environment is not favorable for infection.
2. **Exclusion**—prevents the introduction of inoculum.
3. **Eradication**—eliminates, destroy, or inactivate the inoculum.
4. **Protection**—prevents infection by means of a toxicant or some other barrier to infection.
5. **Resistance**—utilizes cultivars that are resistant to or tolerant of infection.
6. **Therapy**—cure plants that are already infected

Factors affecting occurrences

Factors which affect Plant diseases are micro-organisms, including fungi, bacteria, viruses, mycoplasmas, etc. or may be incited by physiological causes including high or low temperatures, lack or excess of soil moisture and aeration, deficiency or excess of plant nutrients, soil acidity or alkalinity, etc. Factors that limit the rate of disease development are the relatively low amounts of inoculum in the lag stage and the paucity of healthy plants available to the inoculum in the stationary stage.

The causative agents of disease in green plants number in a tens of thousands and include almost every form of life. But primary agents of disease may also be inanimate. Thus nonliving (abiotic) agents of disease include mineral deficiencies and excesses, air pollutants, biologically produced toxicants, improperly used pesticidal chemicals, and such other environmental factors as wind, water, temperature, and sunlight. Nonliving things certainly qualify as primary agents of disease; they continuously irritate plant cells and tissues; they are harmful to the physiological

processes of the plant; and they evoke pathological responses that manifest as the symptoms characteristic of the several diseases. But the abiotic agents of disease in plants. The abiotic agents of plant disease are termed noninfectious, and the diseases they cause are termed noninfectious diseases.

Micro-organisms

The micro-organisms obtain their food either by breaking down dead plant and animal remains (saprophytes) or by attacking living plants and animals (parasites). In order to obtain nutrients, the parasitic organisms excrete enzymes or toxins and kill the cells of the tissues of the host plant, as a result of which either the whole plant or a part of it is damaged or killed, or considerable disturbance takes place in its normal metabolic processes.

Parasites

One of the factors causing plant diseases is parasites, those living organisms that can colonize the tissues of their host-plant victims and can be transmitted from plant to plant. These biotic agents are, therefore, infectious, and the diseases they cause are termed infectious diseases. The infectious agents of plant diseases are treated in the standard textbooks on plant pathology.

Ability to produce an inoculum

The parasitic pest must produce an inoculum, some structure that is adapted for transmission to a healthy plant and this can either parasitize the host directly or develop another structure that can establish a parasitic relationship with the host. For example, inocula for viruses are the viral particles (virions); for bacteria, the bacterial cells; for fungi, various kinds of spores or the hyphal threads of mold; for nematodes, eggs or second-stage larvae.

Agents/ Media for transportation of inoculum

The inoculum must be transported from its source to a part of a host plant that can be infected. This dispersal of inoculum to susceptible tissue is termed inoculation. Agents of inoculation may be insects (for most viruses and mycoplasmalike organisms and for some bacteria and fungi), wind (for many fungi), and splashing rain (for many fungi).

Wounds, Natural openings

The parasite must enter the host plant, which it can do (depending on the organism) in one or more of three ways; through wounds, through natural openings, or by growing directly through the unbroken protecting surface of the host. Viruses are literally injected into the plant as the homopterous insect carrier probes and feeds within its host. Bacteria depend on wounds

or natural openings (for example, stomates, hydathodes, and lenticels) for entrance, but many fungi can penetrate plant parts by growing directly through plant surfaces, exerting enormous mechanical pressure and possibly softening host surfaces by enzymatic action.

Availability of food

For occurrence of disease one of the factor affecting is, availability of nourishment to grow within its host. This act of colonizations is termed infection. Certainly the parasite damages the cytomplasmic memberanes of the host cells, making those membranes freely permeable to solutes that would nourish the parasite And parasitism certainly results from enzymatic attacks by the parasite upon carbohydrates, proteins, and lipids inside the host cell. The breakdown products of such complex molecules would diffuse across the damaged host-cell membranes and be absorbed by the parasite in the form of sugars, amino acids, and the like. Air-borne parasites of foliage, flower, and fruit.

Preventive and control measures

A. PREVENTIVE MEASURES

Cultural practices

Cultural practices usually influence the development of disease in plants by affecting the environment. Such practices are intended to make the atmospheric, edaphic, or biological surroundings favorable to the crop plant, unfavorable to its parasites. Cultural practices that leads to disease control have little effect on the climate of a region but can exert significant influence on the microclimate of the crop plants in a field. Three stages of parasite's life cycle namely, Survival between crops, production of inoculum for the primary cycle and inoculation can be control by following preventive measures.

Survival between Crops

Organisms that survive in the soil can often be controlled by crop rotations with unsusceptible species. Depending on the system, either of two effects results. Catch crops have been used to control certain nematodes and other soil-borne pathogens. Soil-borne plant pathogens can be controlled by biological methods. Plant parasites may be controlled by antagonistic organisms that can be encouraged to grow luxuriantly by such cultural practices as green manuring and the use of appropriate soil additives. The soil-invading parasite thus becomes an amensal in association with its antagonist. Soil-borne plant parasites may also be killed during their over-seasoning stages by such cultural practices as deep ploughing (as for the

pathogen of southern leaf blight of corn), flooding (as for the cottony-rot pathogen and some nematodes), and frequent cultivation and fallow (as for the control of weeds that harbor plant viruses). Plant diseases caused by organisms that survive as parasites within perennial hosts or within the seed of annual plants may be controlled therapeutically. Therapeutic treatments of heat and surgery are applicable here; those involving the use of chemicals will be mentioned later. Removal of cankered limbs (surgery) helps control fire blight of pears, and the hot-water treatment of cabbage seed controls the bacterial disease known as black rot. Heat therapy is also used to rid perennial hosts of plant-parasitic nematodes.

Production of Inoculum for the Primary Cycle

Environmental factors (particularly temperature, water, and organic and inorganic nutrients) significantly affect Inoculum production. Warm temperature usually breaks dormancy of overseasoning structures; rain may leach growth inhibitors from the soil and permit germination of resting spores; and special nutrients may stimulate the growth of overseasoning structures that produce inoculum.

Dispersal of inoculum and inoculation

Cultural practices that exemplify avoidance are sometimes used to prevent effective dissemination. A second hierarchy of regulatory disease control is plant quarantine, the legally enforced stoppage of plant pathogens at points of entry into political subdivisions. The Plant Quarantine Act of the United States governs importation of plant materials into the country and requires the state govt. to enforce particular measures. Also, states make regulations concerning the movement of plant materials into them or within them. E.g., Florida imposes quarantine against the citrus-canker bacterium, which was eliminated from the state earlier by means of cooperative efforts led by the Florida Department of Agriculture.

Sample inspection

One of the preventive measures to control the diseases is the use of sample inspection method. Laboratory evaluation of the representative sample drawn by the certification agency for the determination of germination, moisture content, weed seed content, admixture, purity, seed-borne pathogens.

B. Control Measures

Chemical Control

The pesticidal chemicals that control plant diseases may be used in very different ways, depending on the parasite to be controlled and on the circumstances it requires for parasitic activities. E.g., a water-soluble eradicative spray is applied once to dormant peach trees to rid them of the overwintering spores of the fungus of peach-leaf curl, whereas relatively insoluble protective fungicides are applied repeatedly to the green leaves of potato plants to safeguard them from penetration by the fungus of late blight. Also, systemic fungicidal chemicals may be used therapeutically.

The oxathiin derivatives that kill the smut fungi that infect embryos are therapeutic, as is benomyl (which has systemic action against powdery mildews and other leaf infecting fungi). Volatile fungicides are often useful as soil-fumigating chemicals that have eradicative action.The chemical control of plant diseases is classified in three categories: seed treatments, soil treatments, and protective sprays and dusts.

Seed Treatments

Chemical treatments of seed may be effective in controlling plant pathogens in, on, and around planted seed. Seed treatment is therapeutic when it kills bacteria or fungi that infect embryos, cotyledons, or endosperms under the seed coat, eradicative when it kills spores of fungi that contaminate seed surfaces, and protective when it prevents penetration of soil-borne fungi into seedling stems. Certified seed is usually given treatment necessary for the control of certain diseases. Seed treatment is of two types; viz., physical and chemical. Physical treatments include hot-water treatment, solar-heat treatment (loose smut of wheat), and the like. Chemical treatments include use of fungicides and bactericides. These fungicides are applied to seed by different methods. In one method, the seed in small lots is treated in simple seed-treaters. The seed-dip method involves preparing fungicide suspension in water, often at field rates, and then dipping the seed in it for a specified time.

Some chemicals commonly used to control plant diseases

Chemical and use	Relative toxicity	
	Oral	Dermal
Seed treatments (all fungicides)		
Chloraneb	Low	Low
Dichlone	Low	High
Thiram	Moderate	High
Carboxin (systemic and therapeutic)	Low	Low
Soil treatments		
Methyl bromide[b] (general pesticide)	Very high	Very high
PCNB (fungicide)	Low	Moderate
SMDC [vapam] (fungicide, nematicide)	Moderate	Moderate
MIT ["Vorlex"] (fungicide, nematicide)	Moderate	Moderate
D-D mixture (nematicide)	Moderate	Low
Plant-protective treatments		
Copper compounds (fungicides, bactericides)	Moderate	Low
Sulfur (fungicide)	Low	Moderate
Maneb (fungicide)	Very low	Low
Zineb (fungicide)	Very low	Low
Captan (fungicide)	Very low	Very low
Dinocap (fungicide for powdery mildews)	Low	Low
Streptomycin (bactericidal antibiotic)	Very low	Low
Cyclohexamide[b] (fungicidal antibiotic)	Very high	Very high
Benomyl (protective and therapeutic fungicide)	Very low	Very low

The oxathiins (carboxin, DMOC) used to kill embryo infecting smuts of cereal grains have little effect on other organisms, most eradicative and protective chemicals have a wide range of fungicidal activity; they are effective against most seed-infesting and seedling-blight fungi. But specific seed-treatment chemicals often work best to control a given disease of a

single crop-plant species. Moreover, the toxicity of chemicals to seeds varies, and farmers should use only the compounds recommended by the Cooperative Extension Service of their country and state.

Copper and mercury-containing compounds were first used as seed-treating chemicals. But copper is toxic to most seeds and seedlings, and mercury has been banned from use in seed treatments because of the danger it poses to humans and animals. Organic compounds now widely used as protective and eradicative seed treatments include thiram, chloraneb, dichlone, dexon, and captan.

Soil Treatments

Soil-borne plant pathogens greatly increase their populations as soils are cropped continuously, and finally reach such levels that contaminated soils are unfit for crop production. Chemical treatments of soil that eradicate the plant pathogens therein offer the opportunity of rapid reclamation of infested soils for agricultural uses. Preplanting chemical treatment of field soils for the control of nematode-induced diseases, and fumigation of seedbed and greenhouse soils (with methyl bromide, for example) is commonly practiced to eradicate weeds, insects, and plant pathogens. Field applications of soil-treatment chemicals for fungus control are usually restricted to treatments of furrows. Formaldehyde or captan applied is effective against sclerotia-producing fungi that cause seedling blights, stem rots, and root rots of many field crops. Other soil-treatment fungicides are vapam and "Vorlex." Soil treatments made at the time of planting are most effective against parasitic attacks that come early in the growing season.

Protective sprays and dust

Protective fungicides prevent germination, growth, and penetration. In order to use protective fungicides effectively, the farmer must not only select the right fungicide for the job, but also apply it in the right amount, at the right times, and in the right way. Too little fungicide fails to control disease; too much may be toxic to the plants to be protected. The farmer and applicator, therefore, must always follow use instructions to the letter. Timing of applications is also critical.

Advantages

Integrated approach integrates preventive and corrective measures to keep pathogen from causing significant problems, with minimum risk or hazard to human and desirable components of their environment.

Some of the benefits of an integrated approach are as follows:

- Promotes sound structures and healthy plants
- Promotes the sustainable bio based disease management alternatives.
- Reduces the environmental risk associated with management by encouraging the adoption of more ecologically benign control tactics
- Reduces the potential for air and ground water contamination
- Protects the non-target species through reduced impact of plant disease management activities.
- Reduces the need for pesticides and fungicides by using several management methods
- Reduces or eliminates issues related to pesticide residue
- Reduces or eliminates re-entry interval restrictions
- Decreases workers, tenants and public exposure to chemicals
- Alleviates concern of the public about pest & pesticide related practices.
- Maintains or increases the cost-effectiveness of disease management programs

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