Importance of Plant Disease, Scope and Objective of Plant Pathology

Shraddha Karcho
Shraddha.karcho@gmail.com
JNKVV College of Agriculture ,Tikamgarh

Plant Pathology is a branch of agricultural science that deals with the study of fungi, bacteria, viruses, nematodes, and other microbes that cause diseases of plants. Plants diseases and disorders make plant to suffer, either kill or reduce their ability to survive/ reproduce. Any abnormal condition that alters the appearance or function of a plant is called plant disease.

The term ‘Pathology’ is derived from two Greek words ‘*pathos*’ and ‘*logos*’, ‘*Pathos*’ means suffering and ‘*logos*’ Means to study/ knowledge. Therefore Pathology means “study of suffering”. Thus the Plant Pathology or Phytopathology (Gr. Phyton=plant) is the branch of biology that deals with the study of suffering plants. It is both science of learning and understanding the nature of disease and art of diagnosing and controlling the disease.

Importance of Plant Diseases

The study of plant diseases is important as they cause loss to the plant as well as plant produce. The various types of losses occur in the field, in storage or any time between sowing and consumption of produce. The diseases are responsible for direct monitory loss and material loss. Plant diseases still inflect suffering on untold millions of people worldwide causing an estimated annual yield loss of 14% globally with an estimated economic loss of 220 billion U. S. dollars. Fossil evidence indicates that plants were affected by different diseases 250 million year ago. The Plant disease has been associated with many important events in the history of mankind of the earth.

- The crop loss due to diseases is estimated to be approximately 30-50%.

- Cultivated plants are often more susceptible to diseases than are their wild relatives.
- Important environmental factors that may affect development of plant diseases are temperature, relative humidity, soil moisture, soil pH, soil type, and soil fertility.
- Each pathogen has an optimum temperature for growth. High soil-moisture levels favors development of destructive water mold fungi, such as species of *Aphanomyces*, *Pythium*, and *Phytophthora*.
- High humidity favors development of the great majority of leaf and fruit diseases caused by fungi and bacteria.
- Soil pH, a measure of acidity or alkalinity, markedly influences a few diseases, such as common scab of potato and club root (*Plasmodiophora brassicae*) of crucifers.
- Raising or lowering the levels of certain nutrients also influences the development of some infectious diseases. Most control measures are directed against inoculums of the pathogen and involve the principles of exclusion and avoidance, eradication, protection, host resistance and selection, and therapy.

Important Famine in World

Late blight of potato-1841-51 (Irish famine): The late blight of potato, a diseased caused by the fungus, *Phytophthorainfestans*, is a famous example of what a plant disease can do to change the course of history. In 1845, this diseasedestroyed the potato crop of Ireland where potato constituted the staple diet of the majority in rural areas. The disease had started in Ireland, England and part of the continental Europe as early as 1830 and was causing some damage every year, resulting in food shortage. It was reported that in 1840 the population of Ireland was 8 million which was reduced to 4 million after the famine.

Coffee rust 1867-1870 (Sri Lanka): The coffee and tea were equally consumed in England because these were available in plenty from such occupied countries as India, Sri Lanka and Malaysia. Sri Lanka used to produce maximum coffee in the world. In 1867, coffee rust attacked the plantations in Sri Lanka and by 1893, export of coffee from Sri Lanka had declined by 93%. The economic crisis forced the planters to cut down coffee plants and take to tea planting. When coffee rust was spreading in Sri Lanka the science of plant pathology was just developing and control measure of the disease were not known. The system of monoculture in coffee plantations of Sri Lanka was considered a contributoryfactor in devastations caused by the coffee rust which was not prevalent in coffee growing countries of South America.

Bengal Famine 1942 (India): In the last year of Second World War (1943) Bengal had to face a serious famine. One of the reasons to which this famine has been attributed was the loss in yield of the rice crop due to attack of *Helminthosporium* leaf spot which had been affecting the crop for the last several years. Situation was similar to the Irish potato famine but not so catastrophic.

In India wheat rust had been considered to cause a loss of over Rs. 40 million annually. In the year of epidemics there have been a losses amounting to Rs. 500 million or more. Although introduction of dwarf high yielding varieties has reduced the losses to a great extent even now thefarmers lose 8-10%of the expected yield due to rusts. The loose smut of wheat is estimated to cause an average loss of 3% every year. The 'Molya' disease, caused by a nematode is another example. The disease of wheat and barley prevalent in most parts of Rajasthan causes a loss of Rs. 30 million in barley and 40 million in wheat every year. Different smuts of sorghum are responsible for an annual loss of Rs. 100 million. 5% to 75% loss in chickpea due to *Ascochyta blight* was reported from Rajasthan during 1982. Wilt of pigeon pea causes 5-10% loss every year in U.P. and Bihar.

Scope and Objectives of Plant Pathology

Scope and responsibilities of plant pathology is unlimited. Its ultimate goal is to prevent and control plant diseases of economic importance. Responsibilities of the science of plantpathology may be summarized as under.

- ✓ Study of etiology, symptoms, predisposing factors and recurrence of such diseases.
- ✓ Plant pathology deals with different aspects of plant diseases and has wide scope than human pathology which only deals with only one aspect*i.e.* plant health.
- ✓ The branch focuses on understanding how hosts, pathogens, and environments interact to cause plant diseases and on understanding how to control plant diseases.

In recent years plant pathologists have begun to specialize in particular aspect. The fields in which notable advances have been made are:

- ✓ Interaction between host and pathogen at chemical, molecular and genetic level.
- ✓ Plant virology, Mycology, chemistry of fungi toxicity.
- ✓ Disease forecasting and Plant Quarantine.

On practical aspects much advances have been made in plant protection chemicals; breeding for disease resistance. Increased population emphasizes the application of all possible means to meet the food requirements

- ✓ Expansion of crop area
- ✓ Improved methods of cultivation
- ✓ Increased use of fertilizers
- ✓ Improved varieties
- ✓ Increased irrigation
- ✓ Crop protection

The science of plant pathology has four main objectives:

1. To study the living, non-living and environmental causes of plant diseases.(Etiology)
2. To study the mechanisms of disease development by pathogens.(Pathogenesis)
3. To study the interactions between the plants and the pathogen.(Epidemology)
4. To develop the methods of controlling the diseases and reducing the losses caused by them.(Control/ Management)

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History of Plant Pathology with special reference to Indian work

Pawan Amrite
pawanamrite@gmail.com
JNKVV, Jabalpur

- The development of science of Plant Pathology in the modern era in India as in other countries followed the development of mycology. The study of fungi in India was initiated by Europeans in the 19th century. They used to collect fungi and send the specimens for identification to the laboratories in Europe.
- During 1850-1875, D.D. Cunningham and A. Barclay started identification of fungi in India itself. Cunningham made a special study of rusts and smuts. DD Cunningham identified the causal organism of red rust of tea in Assam caused by Cephaleurous virescens.
- K.R. Kirtikar Pusa (1885) was the first Indian scientist who collected and identified the fungi in the country.
- TS Ramakrishan Studies and contributed to genera Pythium, Phytophthora, Colletotrichum, and the rusts. Wrote monograph on 'Diseases of Millets' published by ICAR
- E.J. Bulter who is also known as the 'Father of Plant Pathology' in India, initiated an exhaustive study of fungi and diseases caused by them in 1901 at Imperial Agricultural Research Institute at Pusa (Bihar). During his stay of 20 years in this country, he made a scientific study of mostly fungal plant diseases known in India at that time. The diseases studied by him for the first time included wilt of cotton and pigeon pea, different diseases of rice, toddy palm, sugarcane, potato and rusts of cereals. He wrote a monograph on

'Pythiaceous and Allied Fungi'; and a classic text book, 'Fungi and Diseases in Plants' in 1918.

- J.F. Dastur (1886-1971), a colleague of Butler, was the first Indian Plant Pathologist who is credited with detailed studies of fungi and diseases in plants. He studied the genus Phytophthora and diseases caused by it in castor and potato. He is internationally known for the establishment of Phytophthora parasitica from castor.
- T.S. Sadasivan developed the concept of vivotoxins and worked out the mechanism of wilting in cotton due to *Fusarium oxysporum* f.sp. *vasinfectum*.
- Mitra in 1937 AD recorded Tilletia indica, a new bunt (Karnal bunt) on wheat. The disease was thought, erroneously, to be soil borne. Later studies showed that it was air borne, and the infection was not systemic (Mundkar, 1943 AD)
- G.S. Kulkarni published exhaustive information on downy mildew and smuts of sugarcane and pearl millet.
- B.B. Mundkur started work on control of cotton wilt through varietal resistance. He was also responsible for the identification and classification of large number of Indian smut fungi. His most significant contribution to plant pathology will be remembered through the 'Indian Phytopathological Society' which he started almost single handedly in 1948 with its journal 'Indian Phytopathology'. He also authored a text book entitled, 'Fungi and Plant Diseases'.
- M.K. Patel (Father of Indian plant bacteriology) established a school of plant bacteriology at the College of Agriculture, Poona (Pune). He reported the first new species, *Xanthomonas uppalii* on *Ipomoea muricata* in 1948. Advocated the family Phytobacteriaceae to include all plant pathogenic bacteria.
- M.K. Patel, V.P. Bhide and G. Rangaswami pioneered the work on bacterial plant pathogens in India.

- Yeshwant Laxman Nene reported “Khaira” disease of rice at Pantnagar due to zinc deficiency (1965 AD) and authored the book "Fungicides in Plant Disease Control"

- Dr. K.C. Mehta (Father of Indian Rust) of Agra College, Agra investigated the life cycle of cereal rusts in India during the first half of 20th century. Wrote monograph on "Further studies on cereal rust in India". Dr. R. Prasada trained by Dr K.C. Mehta continued the work on rusts and added to the knowledge of linseed rust.
- Luthra and Sattar (1953) developed the solar heat treatment of wheat seed for the control of loose smut.
- S N Das Gupta carried out exhaustive studies on black tip of mango.
- G. Rangaswami authored 'Diseases of Crop Plants in India' and 'Bacterial Plant Diseases in India.
- Jeevan Prakash Verma started the pioneering work on *Xanthomonas campestris* pv. *malvacearum* causing bacterial blight of cotton. He laid a solid foundation of Indian Plant Bacteriology with his students.
- A. Mahadevan studied biochemical changes in diseased plants and enzymes. He wrote the book "Microorganism in Diseased Plants"
- S. Nagarajan and H. singh (1975) Formulated 'Indian Stem Rust Rules' for *Puccinia graminis tritici*
- S. Nagarajan (1978) Using climatic and weather based informations to identify Puccinia path in India.
- CD Mayee contributed to the understanding of the ground nut rust, sunflower downy mildew. Wrote 'Phytopathometery'.
- RS Singh Wrote "Plant diseases", a book known as 'Bible of Plant Pathology.

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Concepts and terms in Plant Pathology

Vijay Yadav
vijaypatho@gmail.com
JNKVV, College of Agriculture, Ganjbasoda

Plant Pathology (phytopathology) is defined as the study of the organisms (infectious organisms) and environmental conditions (physiological factors) that cause disease in plants, the mechanisms by which disease occurs, the interactions between these causal agents and the plant (effects on plant growth, yield and quality). Plant pathology also involves the study of pathogen identification, disease etiology, disease cycles, economic impact, plant disease epidemiology, plant disease resistance, how plant diseases affect humans and animals, pathosystem genetics, and management of plant diseases. It also interfaces knowledge from other scientific fields such as mycology, microbiology, virology, biochemistry, bio-informatics, etc. Since plant pathology is directly relevant to man's need to grow enough food and fiber to sustain civilization.

Causes of plant diseases

In strict sense, the causes of plant diseases are grouped under following categories:

1. Animate or biotic causes: Pathogens of living nature are categorized into the following groups.

(i) Fungi (ii) Bacteria (iii) Phytoplasma (iv) Rickettsia-like organisms (v) Algae (vi) Phanerogams (vii) Protozoa (viii) Nematodes

2. Mesobiotic causes :

These disease incitants are neither living or non-living, e.g. (i) Viruses (ii) Viroides

3. In animate or abiotic causes: In true sense these factors cause damages (any reduction in the quality or quantity of yield or loss of revenue) to the plants rather than causing disease. The causes are:

(i) Deficiencies or excess of nutrients (ii) Light (iii) Moisture (iv) Temperature (v) Air pollutants (vi) Lack of oxygen (vii) Toxicity of pesticides (viii) Improper cultural practices (ix) Abnormality in soil conditions (acidity, alkalinity)

When a plant becomes diseased :

When the ability of the cells of a plant or plant part to carry out one or more of essential functions is interfered with by either a pathogenic organism or an adverse environmental factor, the activities of the cells are disrupted, altered, or inhibited, the cells malfunction or die, and the plant becomes diseased. At first, the affliction is localized to one or a few cells and is invisible. Soon, however, the reaction becomes more widespread and affected plant parts develop changes visible to the naked eye. These visible changes are the symptoms of the disease. The visible or otherwise measurable adverse changes in a plant, produced in reaction to infection by an organism or to an unfavorable environmental factor, are a measure of the amount of disease in the plant.

Disease in plants, then, can be defined as the series of invisible and visible responses of plant cells and tissues to a pathogenic organism or environmental factor that result in adverse changes in the form, function, or integrity of the plant and may lead to partial impairment or death of plant parts or of the entire plant.

Plant diseases are caused by pathogens. Hence a pathogen is always associated with a disease. In other way, disease is a symptom caused by the invasion of a pathogen that is able to survive, perpetuate and spread.

Plant disease diagnosis

Diagnosis of plant diseases requires consideration of various biotic and abiotic factors which may be involved in the causation of disease, as well as a sound knowledge of the host plant symptoms and signs. Many variables may influence each situation, including the state of the host, its cultural history, weather conditions, soil and general site characteristics. A good understanding of the "normal host" is essential, and experience is invaluable.

The complexity of the etiology (cause) of the disease usually determines the difficulty of diagnosis. Many diseases in which a single pathogen is the principal causal agent have distinguishing and characteristic associated symptoms and signs. Diseases with more complex etiology may have symptoms which suggest several possible causes, and may be difficult to diagnose precisely.

Steps in disease diagnosis

1. Identify the host
2. Determine the signs and symptoms of the disease
3. Identify the pathogen
4. Identify the disease
5. Prove pathogenicity - follow Koch's Postulates

Adverse effect of pathogens and Environmental factors on host :

Pathogenic microorganisms, i.e., the transmissible biotic agents that can cause disease and are generally referred to as pathogens, usually cause disease in plants by disturbing the metabolism of plant cells through enzymes, toxins, growth regulators, and other substances they secrete and by absorbing foodstuffs from the host cells for their own use. Some pathogens may also cause disease by growing and multiplying in the xylem or phloem vessels of plants, thereby blocking the upward transportation of water or the downward movement of sugars, respectively, through these tissues. Environmental factors cause disease in plants when abiotic factors, such as temperature, moisture, mineral nutrients, and pollutants, occur at levels above or below a certain range tolerated by the plants.

Adverse effect of diseases on physiology of host :

Infection of roots may cause roots to rot and make them unable to absorb water and nutrients from the soil; infection of xylem vessels, as happens in vascular wilts and in some cankers, interferes with the translocation of water and minerals to the crown of the plant; infection of the foliage, as happens in leaf spots, blights, rusts, mildews, mosaics, and so on, interferes with photosynthesis; infection of phloem cells in the veins of leaves and in the bark of stems and shoots, as happens in cankers and in diseases caused by viruses, mollicutes, and protozoa, interferes with the downward translocation of photosynthetic products; and infection of flowers and fruits interferes with reproduction. Although infected cells in most diseases are weakened or die, in some diseases, e.g., in crown gall, infected cells are induced to divide much faster (hyperplasia) or to enlarge a great deal more (hypertrophy) than normal cells and to produce abnormal amorphous overgrowths (tumors) or abnormal organs.

Plant Disease Management:

The word ‘control’ is a complete term where permanent ‘control’ of a disease is rarely achieved whereas, ‘management’ of a disease is a continuous process and is more practical in influencing adverse affect caused by a disease. Disease management requires a detail understanding of all aspects of crop production, economics, environmental, cultural, genetics and epidemiological information upon which the management decisions are made.

Importance of the Plant Diseases:

Globally, enormous losses of the crops are caused by the plant diseases. The loss can occur from the time of seed sowing in the field to harvesting and storage. Important historical evidences of plant disease epidemics are Irish Famine due to late blight of potato (Ireland, 1845), Bengal famine due to brown spot of rice (India, 1942) and Coffee rust (Sri Lanka, 1967) etc. Such epidemics had left their effect on the economy of the affected countries.

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Important Plant Pathogenic Organisms

Usha Bhale
ushabhale55@gmail.com

Important plant pathogenic organism - Fungi, Bacteria, Fastidious Vascular Bacteria.

Plant diseases are caused by a number of organisms which ultimately lead to the loss in crop yield both quantitatively and qualitatively. The disease is defined as malfunctioning process that is caused by continuous irritation which results in some suffering producing symptoms.

On the other hand any agent that causes suffering of the plant is called as a pathogen. Various types of abiotic factors are also involved in the production of plant diseases. The disease or sufferings of the plant that is caused by the abiotic/environmental factor is called disorder. The major groups of (organism) pathogen/agent causing plant diseases are:

A. Biotic Agents

(i) Fungi	(ii) Bacteria	(iii) Fastidious vascular bacteria
(iv) Protozoa	(v) Phytoplasma	(vi) Spiroplasma
(vii) Algae	(viii) Nematodes	(ix) Phanerogamic higher plants

Biotic agents Usually causes diseases in plants by disturbing the metabolism of plant cells

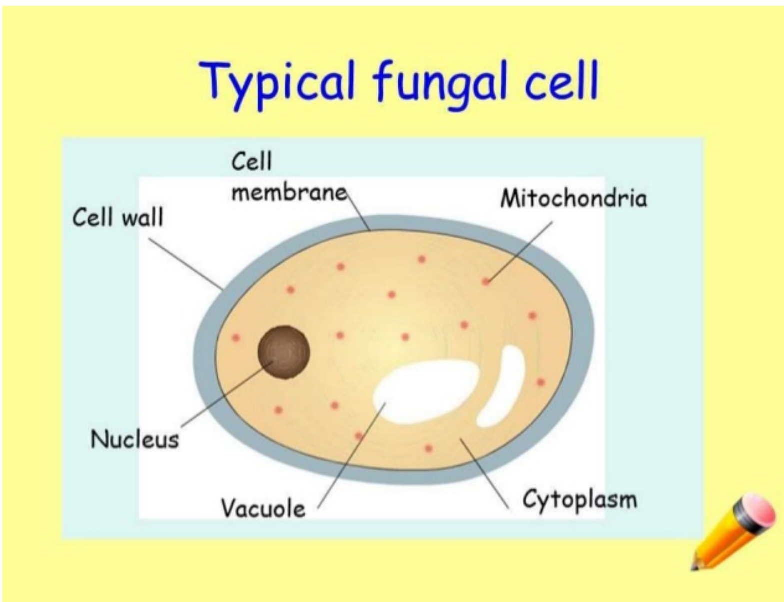
(a) through the **secretion of-** enzymes
Toxins
Growth regulators

Other substances

(b) By growing and multiplying in- Xylem vessels,
Phloem vessels

B. Mesobiotic agents - Viruses
Viroids

Biotic Factors of Plant Disease



Fungi are-

Eukaryotic (cells have membrane-bound neclei and a number of membrane-bound cytoplasmic organelles, such as mitochondria, ribosome, golgi apparatus, vacuoles, endoplasmic reticulum etc.).

Achlorophyllous (lack chlorophyll pigments. So, they are incapable to produce their food by photosynthesis. They always depend on others for food (Heterotrophic in nature).

Flamentous branched somatic structures and multi-cellular microorganism, few are unicellular composed of individual microscopic filaments called hyphae. The hyphae grow apically, branched form a network of hyphae, is termed as a mycelium.

Cell wall mainly composed of carbohydrates namely chitin and glucans, the walls of some species also contain cellulose. Plant cell walls are composed mainly of cellulose. Animals do no have cell wall.

Reproduction by both sexually and asexually. Both sexual and asexual reproduction often results in production of spores. Nuclei are typically haploid and hyphal compartments are often multinucleate. Ex, the **Oomycetes** and some yeast possess diploid nuclei.

Habitate may be free-living as saprophytes or may form intimate relationships like symbiosis, mutualism or parasitism with other organisms. They obtain nutrients by measn of absorption.

Many fungi display bright colours arising from other cellular pigments, ranging from red to green to black.

Classified into different groups

Nutrition (Saprophytes, Obligate Saprophytes, Facultative Parasite, Parasite, Pathogen, Obligate Parasite, Facultative Saprophytes, Necrotroph) growth habit, ability to grow on artificial media,

Mode of reproduction- (Sexual, Asexual), presence or absence of different structures, mode of survival etc. Majority of the plant diseases we have seen are caused by the fungi and cause heavy loss to the growers.
Plant diseases are grouped in many ways :-

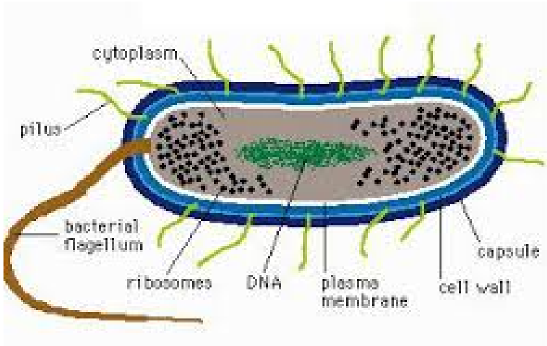
(A) Symptoms they causes — eg. Rots, wilts, spots, blights, rust, smut
(B) Plant organs they affect — eg. Stem diseases, Foliar diseases, Root diseases
(C) Types of plants species affected — eg. Field crops, vegetables, flowers, turf

Some of the important plant diseases caused by fungi are:

Name of the diseases	**Causal organism**
Late blight of potato	*Phytophthora infestans*
Rice blast disease	*Pyricularia grisea*
Brown spot of rice	*Dreschlera oryzae*
Coffee rust	*Haemilea vestarix*
Downy mildew of grapes	*Plasmopara viticola*
Rust of wheat	*Puccinia graminis tritici*

Phytopathogenic Bacteria

Bacteria are prokaryotes. It consists of a single cell with a simple internal structure. Unlike eukaryotic DNA, which is neatly packed into a cellular compartment called the nucleus, bacterial DNA floats free, in a twisted thread-like mass called the nucleoid. Bacterial cells also contain separate, circular pieces of DNA called plasmids.



Important characteristics of Phytopathogenic Bacteria:

Shape- Straight to curved rods with rigid cell walls (except filamentous bacteria)
Some bacteria assume irregular shapes like " V, Y, L"
Example- *Corynebacterium (clavibacters*) – 'V' shape
Agrobacterium and *Erwinia* - 'L' shape

Carbohydrate - decomposition is mostly aerobic or oxidative
Example- *Erwinia* (facultative anaerobe)

Mostly Gram negative, rarely Gram positive
Example Gram +ve – Streptomyces, Corynebacterium, Clavibacter

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

PPB can be identified based on flagellation, carbohydrate metabolism and pigment production. These are passive invaders i.e. enter into the plants through wounds or natural openings.

Survival – The bacteria survive inside or outside of seed, and in plant debris and spreads by means of water, rain, insects and agricultural implements.

All are susceptible to phages. (Phages are virus that kills bacteria)

All are non-spore forms except **Bacillus Sp**.

None of them cause human and animal diseases

Cell wall rigid and made up of chitin or cellulose

Incubation period – 36-48 hrs at 25 ^{0}C

Habitate – Saprophytic, symbionts

Distribution – About 1600 species of bacteria are present in air, water, soil and in food items all over world

Dispersal- depend on outside agents. They do not spread on the wind as many fungi do. They disseminated by means of splashing water. Many bacterial can spread simply by touching an infected plant and then by touching a healthy plant. They also transmitted by insect vectors, nematode and human.

Penetration- cannot penetrate the cuticle of plants but enter the plant through a wound or natural opening.

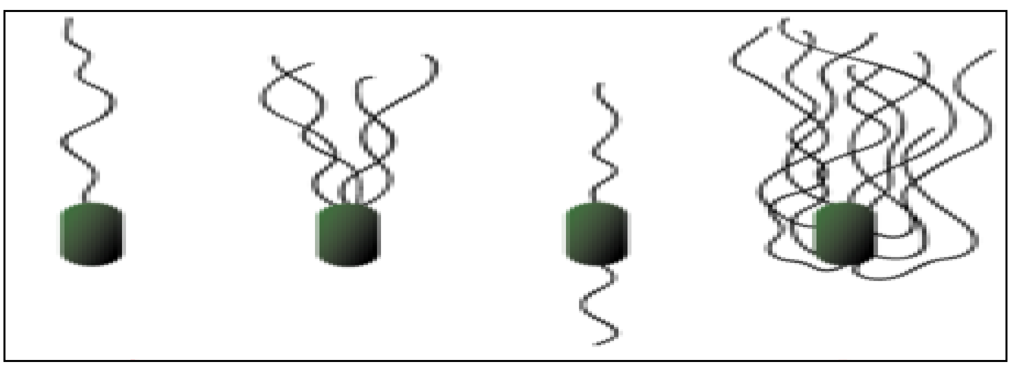
Some of the important diseases caused by bacteria are :

Name of the diseases	**Causal organism**
Fire blight of apple and pear	*Erwinia amylovora*
Bacterial Leaf Blight of rice	*Xanthomonas campestris pv. oryzae*
Bacterial wilt o solanaceous crops	*Ralstonia solanacearus*
Citurs canker	*Xanthomonas campestris pv. citri*
Common scab of potato	*Streptomyces scabis*
Crown gall of apple	*Agrobacterium tumefaciens*

Classification of Bacteria

Bacteria can be classified based on the following characterstics:-

1. Based on shape- Coccus, Bacillus, Spirillum, Vibrio
2. Based on staining characters- Gram positive bacteria, Gram negative bacteria
3. Based on arrangement of flagella- Atrichous bacteria, Monotrichous bacteria, Amphitrichous bacteria, Lopotrichous bacteria, Peritrichous bacteria.



4. Based on nutrition requirement- Autotrophs, Heterotrophs, Chemoautotrophs, Saprophytic bacteria, Symbiotic bacteria, Pathogenic bacteria
5. Based on oxygen requirement- Aerobes, Anaerobes
6. Based on temperature dependence- Thermophilic, Mesothermic, Hypoctermic
7. Based on DNA relatedness (phylogenic relationship)

Fastidious Vascular Bacteria

Fastidious vascular bacteria are similar to the phytopathogenic bacteria but they are introduced directly into the sugar-rich phloem sieve tubes or into the water transporting xylem elements by vascular-feeding insects.

The fastidious vascular bacteria may be Fastidious phloem limited bacteria and Fastidious Xylem Limited bacteria (XLB).

The fastidious Phloem limited bacteria are very small bacilli and generally possess Gram-negative prokaryotic cell morphology.

Fastidious xylem limited bacteria are Walled bacterial pathogens those inhabit the water transporting cells of the xylem of their host plants and are transmitted by xylem feeding sharpshooters and spittlebugs, members of the leafhopper family.

Example- Citrus greening disease, Cucurbit yellow vine, Almond leaf scorch, Alfalfa dwarf, Phony Peach, Ratoon stunting, Plum leaf scald.

L. 05

Pathogenesis, Factors Affecting Disease Development, Disease Triangle and Tetrahedron.

K. S. Baghel & S.K.Tripathi
Ksbaghel1974@gmail.com
Krishi Vigyan Kendra, Rewa

PATHOGENESIS :

Pathogenesis is a series of events that happened in succession during a pathogenic relationship of a pathogen and host which leads to disease, therefore in other terms it also refers to the origin, development and resultant effects of disease from the initial appearance of disease all the way to its end stages .The term pathogenesis comes from Greek word for ‘disease’ and ‘beginning’. The study of pathogenesis is important to diagnose and manage diseases.

FACTORS AFFECTING DISEASE DEVELOPMENT.

Disease development in brief involves a number of distinct events including the dissemination of pathogen to the host, prepenetration, penetration of the pathogen into the host, invasion and spread of the pathogen, reproduction of pathogen and the survival of pathogen.

There are seven major events in disease cycle;

- Inocultation
- Penetration
- Infection
- Invasion
- Reproduction
- Dissemination
- Survival

Inoculation: It is the process by which the pathogen come in contact with its host. Inoculation is the initial contact of a pathogen with a site of plant where infection is possible. The pathogen that lands or brought into contact with the plants is called the inoculum.

Types of Inoculum :

- Primary Inoculum
- Secondary Inoculum

Inoculum that survives dormant in off season and originate infection during crop season is called **primary inoculums**, and the infection it caused are called **primary infections**. An inoculum produced from primary infection is called a **secondary inoculum** and the infection it caused are called **secondary infections**.

Source of Inoculum:

- Soil: Bacteria, fungus viz *Rhizoctonia, Sclerotinia*
- Infected plant parts: Seed, cuttings, bulbs, corns, tubers etc.

- Diseased debris: *Alternaria* , *Pytophtohra*
- Alternate hosts: Rust
- Collateral hosts: Viruses, Powdery mildews etc.

Penetration: The process by which pathogen enter its host. This process is divided into

Pathogens penetrate plant surfaces by direct penetration of cell wall, through natural openings, or through wounds. Most of the fungi penetrate through one of these ways. Bacteria enter in plants mostly through wounds, whereas viruses and viroids and protozoa enter through wounds made by vectors. Parasitic higher plants enter into the host by direct penetration and nematodes enter plants directly or sometimes through natural openings.

Infection: It is the process by which pathogens establish contact with susceptible cells or tissues of the host and procure nutrients from them in other terms establishment of organic relationship of the pathogen with susceptible cells of the host called infection.

Types of infection : Successful infections result in the appearance of symptoms, i.e. discolored , malformed, or necrotic areas on the host plants termed as local or systemic infection. Some infection, remain latent, they do not produce symptoms right away but at a later they appears during favorable environmental conditions and suitable host.

Invasion: The spread of pathogens into the host are called invasion. Various pathogens invade hosts in different ways and to different extent.

- Ectoparasite : When pathogenic fungi produce mycelium only on the surface of the plant but send haustoria into the epidermal cells. E.g. Powdery mildew
- Endoparasites : Some fungi produce mycelium that grows only in the area between cuticle and the epidermis. e.g. wilts, viruses etc. Endoparsites

further divides into sub-cuticular pathogens (Apple scab), sub-epidermal pathogens (Rust) and vascular pathogens (*Pseudomonas solanacearum*)

- Ecto-endo parasites : Most fungi spread into all the tissues of the plant organs either by growing directly through the cells as an intracellular mycelium or by growing between the cells as an intercellular mycelium. e.g. Potato canker (*Corticium solani*).

Reproduction: Plant pathogens reproduce in a variety of ways.

- Fungi reproduce by means of spores, which may be either asexual (mitospores, i.e. products of mitosis) or sexual (meiospores, i.e. products of meiosis). Parasitic higher plants reproduce just like plants, i.e. by seeds. Bacteria and mollicutes reproduce by fission in which one mature individual split into two. Viruses and viroids are replicated by the cell. Nematodes reproduce by means of eggs.

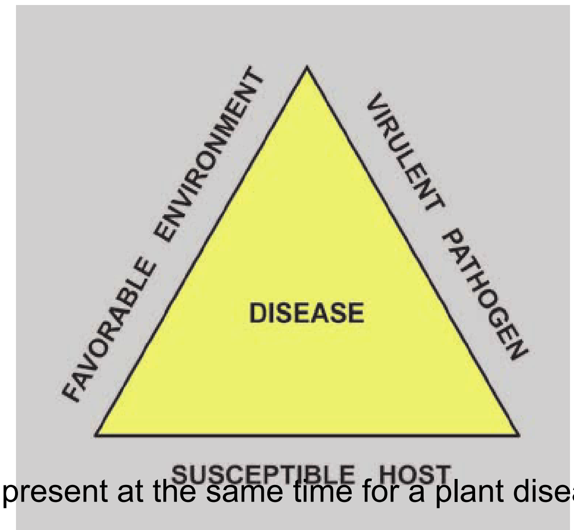
Dissemination: It refers to transfer of inoculum either passively i.e. by wind, water, insect, man, animals, machinery or actively move on own power some bacteria, pythium (Zoospores) fungal spores expelled forcibly.

Survival : Survival of pathogens takes place through-

- Infected crop debris
- Seeds
- In soil
- On growing plants
- Infected material on host plants
- In propagating material
- Alternate host
- Collateral host
- As dormant structures e.g. sclerotia, chlamydospores.

Disease Triangle

The disease triangle drawing most likely was first published by Stevens in 1960. Although earlier plant pathologists certainly recognized the interaction among plant, pathogen, and environment. They refers it as existence of a disease caused by a biotic agent absolutely requires the interaction of a susceptible host, a virulent pathogen, and an environment favorable for disease development.

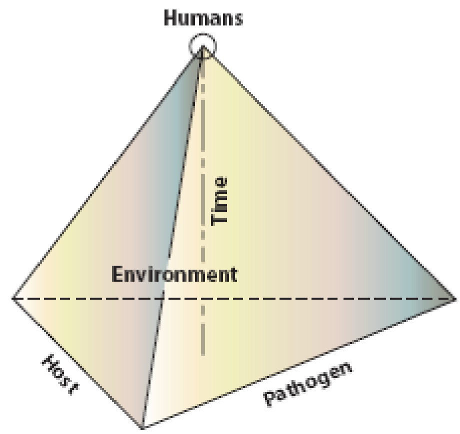


Three factors must be present at the same time for a plant disease to occur. If any one of the three is missing, plant disease does not occur.

The factors are:

- A susceptible host
- A virulent pathogen (one that can cause disease), and
- A suitable environment

Tetrahedron: Plant pathologists have elaborated on the disease triangle by adding one or more parameters .Additional parameters have included humans, vectors, and time. Of these, only time is absolutely required so other elements represent special case applications. A three-dimensional disease pyramid or tetrahedron has been the most common figure drawn after addition of a single parameter. Adding more than one parameter while retaining the pyramidal shape is possible by drawing a base with four line segments.



Humans factor into the disease triangle because the influence of human activity on disease is pervasive in agriculture and, perhaps to a lesser degree, in lower input systems such as forestry and range management. Indeed, it is difficult to ignore such elements as cultivation practices that affect a pathogen's life cycle, genetic manipulation of plant hosts through breeding and genetic engineering, planting large expanses of genetically similar plant populations, and various environmental manipulations such. These factors can profoundly affect the occurrence and severity of a particular disease.

Some important terminologies in Plant Pathology:

1.	**Alternate host**	One of two kinds of plants on which a parasitic fungus (e.g., rust) must develop to complete its life cycle.
2.	**Appressorium**	The swollen tip of a hypha or germ tube that facilitates attachment and penetration of the host by a fungus.
3.	**Collateral host**	The wild host of same families of pathogen in which pathogen survive when primary host is not available.
4.	**Concomitant**	Propagules of pathogen present along with the seed.

	contamination	
5.	**Contamination**	Intermixed with a pathogen, (of spore) not pure.
6.	**Cross protection**	The protection of host from disease by inoculating a strain or isolate, closely related to the pathogen. (protection maybe by competition or by induced resistance)
7.	**Disease**	Any malfunctioning of host cells and tissues that results from continuous irritation by a pathogenic agent or environmental factor and leads to development of symptoms.
8.	**Disease complex**	Plant disease where more than one pathogen is involved in infection process.
9.	**Disease cycle**	The chain of events involved in disease development, including the stages of development of the pathogen and the effect of the disease on the host.
10.	**Disease Syndrome**	The set of varying symptoms characterizing a disease collectively called a syndrome.
11.	**Disorder**	Malfunctioning due to abiotic causes.
12.	**Facultative parasite**	Occurs freely as saprophyte but they may also be parasites when food & environment are favourable.
13.	**Facultative saprophyte**	Originally parasite but after host death, can live as saprophytes.
14.	**Haustorium**	A simple or branched projection of hyphae into host cells that acts as an absorbing organ.
15.	**Hyperplasia**	A plant overgrowth due to increased cell division.
16.	**Hypersensitivity**	Excessive sensitivity of plant tissues to certain pathogens. Affected cells are killed quickly, blocking the advance of obligate parasites.
17.	**Hypertrophy**	A plant overgrowth due to abnormal cell enlargement.
18.	**Hypha**	A single branch of a mycelium.

	Immune	Cannot be infected by a given pathogen.
20.	**Incubation period**	The period of time between penetration of a host by a pathogen and the first appearance of symptoms on the host.
21.	**Infection**	The establishment of a parasite within a host plant following penetration.
22.	**Inoculum**	The pathogen or its parts that can cause infection; that portion of individual pathogens that are brought into contact with the host.
23.	**Inoculum potential**	Horsfall (1932) the number of infective particle present in the environment of the uninfected host.
24.	**Life cycle**	The stage or successive stages in the growth and development of an organism that occur between the appearance and reappearance of the same stage of the organism.
25.	**Monocyclic**	Having one cycle per season.
26.	**Mosaic**	Symptom of certain viral diseases of plants characterized by intermingled patches of normal and light green or yellowish color.
27.	**Mottle**	An irregular pattern of indistinct light and dark areas.
28.	**Mycelium**	Mass of hyphae that make up the body of a fungus.
29.	**Obligate parasite**	parasite which have not yet been grow apart from living cells. Can not grow in culture eg. Rust, powdery mildew.
30.	**Parasite**	An organism living on or in another living organism (host) and obtaining its food from the latter.
31.	**Pathogen**	An entity that can incite disease.
32.	**Pathogenesis**	Chain of events that leads to development of disease.
33.	**Pathogenicity**	The capability of a pathogen to cause disease.
34.	**Polycyclic**	Completes many (life or disease) cycles in one year.
35.	**Primary infection**	The first infection of a plant by the over wintering or over

		summering pathogen.
36.	**Primary inoculum**	The over wintering or over summering pathogen, or its spores that cause primary infection.
37.	**Resistance**	The ability of an organism to exclude or overcome, completely or in some degree, the effect of a pathogen or other damaging factor.
38.	**Secondary infection**	An infection caused by secondary inoculum.
39.	**Secondary inoculum**	Inoculum produced by infections that take place during the same growing season.
40.	**Sign**	The pathogen or its parts or products seen on a host plant.
41.	**Symptom**	The external and internal reactions or alterations of a plant as a result of a disease.
42.	**Virulence**	The degree of pathogenicity of a given pathogen.

L. 06

Classification of Plant Diseases

S.P. Mishra
spmagcrewa@gmail.com
JNKVV, College of Agriculture, Rewa

A) On the basis of their mode of perpetuation and mode of primary infection:

1) **Soil borne diseases**: In these diseases, the pathogens survive in soil or on infested plant debris lying in soil either as their resting spores or as mycelia strands and rhizomorphs. They all attack the root system of host plants.

   Eg: Damping off (*Pythium* sp.),Seedling blight (*Phytophthora, Fusarium* sp.)

2) **Air borne diseases**: Some pathogens infects the host plant through air and bring primary as well as secondary infection.
   Eg: Rusts, Powdery mildews.Loose smuts bring about secondary infection through air.
3) **Seed borne diseases**: Some pathogens survive as dormant mycelium in the seeds or other propagative structures of host plants. Eg. Loose smut of wheat (internally seed borne)

B) On the basis of their cause, diseases are classified as:

1) **Infectious plant diseases**: These diseases are caused by living agents,the pathogen. All pathogens are parasitic on plants. These are characterised by the ability of the pathogen to grow and multiply rapidly. Ex: Powdery mildews, Rusts.
2) **Non-infectious diseases:** These diseases do not spread from plant to plant (non-infectious).These diseases are caused due to abiotic factors(non parasitic or physiological). Eg: Black heart of potato.

C) On the basis of production and spread of the inoculum:

1) **Single cycle disease or simple interest disease:** In single cycle disease the increase of disease is mathematically analogous to simple interest disease.
2) **Multiple cycle or compound interest disease:** In multiple cycle diseases, the increase in disease is mathematically analogous to compound interest of money.
3) **Polyetic diseases:** These are also polycyclic diseases but they complete their disease cycle in more than one year over years. Eg.: Cedar Apple Rust

D) On the basis of plant parts affected:

1) **Localized**: If they affect only specific organs or parts of the plants. Eg.: Root

Rot, Leaf spot.

2) **Systemic**: If entire plant is affected. Eg.: Downy mildew, damping off.

E) On the basis of group of causal organisms:

1) **Fungal disease:** Caused by plant pathogenic fungi. **Eg. Anthracnose**
2) **Bacterial disease**: Caused by plant pathogenic bacteria. Example: Citrus canker
3) **Viral disease**: Caused by plant viruses. Eg. Rice tungro disease
4) **Phanerogamic phytopathogenic diseases**: Caused by phanerogamic plant parasites. Eg. Striga, Cuscutta.
5) **Nematode Diseases**: Diseases caused by plant pathogenic nematodes. Eg. Ear cocle of wheat.

F) On the basis of occurrence and consequent effects:

1) **Endemic:** When a diseases more or less constantly prevalent from year to year in a moderate to severe form in a particular country. E.g., Wart disease of potato is endemic to Darjeeling.
2) **Sporadic :** These diseases occurs at irregular intervals and location. Eg. Blights, Rusts.
3) **Pandemic :** These diseases occur all over the world and cause mass mortality. Eg. Late blight of potato.
4) **Epidemic or epiphytotic:** A disease occurring periodically but in a severe form involving major area of the crop. it may be constantly present in locality but assume severe form occasionally . Eg. Rust, Late blight, Mildews.
5) **Pandemic:** Diseases occurring throughout the continent or sub-continent resulting in mass mortality. Eg. Late blight of potato.

G) On the basis of organs affected:

1) **Fruit diseases:** In these diseases fruits are mainly affected Eg. Apple scab. (Venturia inaequalis)
2) **Root diseases:** In these disease, root is mainly affected**.** Eg.Root rot of papaya.(*Pythium aphanidermatum*)

3) **Leaf diseases:** Disease is localised in the foliage**.** Eg. Leaf spot of cotton. (Alternaria gossypii (Jacz.)

4) **Seedling diseases**: Seedlings are affected in which stem and root tissues rot. Eg. Damping off of seedling.*(Rhizoctonia sp.)*

H) On the basis of host crop plants affected:

1) Cereal diseases: Disease which affect cereal crops eg. Wheat,barley and oat.

2) Pulses diseases: Diseases which affect pulses crop. Ascochyta blight of chickpea**.**

3) **Millet diseases:** Diseases which affect millets. Eg. Green ear disease of Bajra.

4) **Vegetable diseases :** Diseases which affect vegetable crops.Eg. Early blight of Tomato caused by *Altrnaria solani.*

5) **Fruits diseases :** Diseases affect fruit crops.Eg. Apple Scab

6) **Ornamental plant diseases:** Diseases affecting ornamental plants. Eg. Chrysanthemum stunt.

7) Forest diseases: Diseases affecting forest trees and plantation. Eg. Sudden Oak Death (*Phytophthora ramorum*)

I) On the basis of symptoms produced on host plants:

1) Rusts : Caused by Basidiomycetes of the order Uredinales**. Eg. Stem rust of wheat.**

2) **Smuts :** Caused by fungus of order Uredinales,mass of black powedery spores and grains are not produced .Eg. Loose smut of wheat caused by ***Ustilago nuda tritici.***

3) **Wilts :**In this disease, the vascular system of plant is affected .Eg. Bacterial wilt of cucurbits caused by *Erwinia trachiephila.*

4) **Powdery mildews:** It is a disease of foliage, stem, flower and fruit.Eg.Powdery mildew of grapes.

5) **Rots :** In this disease, underground part of plant is infected.Eg. *Rhizoctonia* and *Phytophthora* root rot.
6) **Blight :** It is complete chlorosis ,yellowing and browning which results in death of the plant. Eg.Leaf blight of paddy.
7) **Leaf spots :**It may be caused by fungi or bacteria, spots are formed on leaves which results in complete yellowing and dropping of leaf. Eg.Septoria leaf spot in tomato
8) **Canker** : Canker is a dead area in bark or cortex of woody stem. Ex: Citrus canker

10 Anthracnose: an ulcer-like lesion that can be necrotic and sunken. These lesions can appear on the fruit, flowers and stems of the host - e.g. Apple Anthracnose of stems and or leaves (Cryptosporiopsis sp. Formally Pezicula sp.), or Dogwood Anthracnose (Discula distructiva)

11. Damping Off: it is a rapid collapse and death of very young seedling. Either the seed rots before emergence or the seedling rots at the soil line and falls over and dies. The most common genera involved are Fusarium, Rhizoctonia and Pythium.

12 Scab: localized lesion on host fruit leaves tubers and other plant parts. These infections usually result in a roughened, crust-like area on the surface of the host - e.g. Apple Scab (Venturia inaequalis) and Pear Scab (Venturia pirina).

13Dieback: progressive death of shoots and twigs generally starting at the tip of the infected plant part - e.g. Shoot Dieback of Apple due to Brown Rot of Cherry (Monilinia sp.) and Poplar Shoot Dieback (Venturia populina). Bacteria are probably more commonly associated with Diebacks (Pseudomonas syringae).

14Galls: enlarged parts of plant organs, usually caused by excessive multiplication or enlargement of plant cells - e.g. Camellia Leaf Gall (Exobasidium camelliae), Plum and Prune Black knot (Apiosporina morbosa), Pine Western Gall Rust (Peridermium harknesii), Clubroot - (Plasmodiophora brassicae) enlarged roots that look like clubs or spindles - e.g. Club rot of Crucifers (Plasmodiophora brassicae), Burr Knot of apples caused by environmental and/or genetic factors can be similar to bacterial galls.

15 Leaf Curls: curling, thickening & distortion of leaves - e.g. Almond Leaf Curl, Peach Leaf Curl, Pear Leaf Blister, Maple Leaf Curl and many more caused by Taphrina sp. Affects the blossoms, fruit, leaves and shoots of backyard peach and nectarine trees.

16 Downy mildews: : Symptoms appear as yellow to white patches on the upper surfaces of older leaves.This disease is caused by family Peronosporaceae.

L. 07

Abiotic Diseases and their management

Vibha Pandey
vibhapandey93@gmail.com
JNKVV, College of Agriculture, Rewa

Plants can be damaged by infectious microbes and; also by noninfectious factors that are collectively termed as "a biotic diseases" or "a biotic disorders". A biotic disorders are caused by nonliving factors, such as drought stress, sunscald, freeze injury, wind injury, chemical injury, nutrient deficiency, or improper cultural practices, such as overwatering or planting conditions. In contrast to biotic factors, a biotic problems often affect several species or plants of various ages; typically, damage is relatively uniform, doesn't spread and is often not progressive. A biotic problems are not associated with pests. They are often caused by a single incident and are related to environmental or physical factors or cultural practices. Once the responsible factor has dissipated and is no longer affecting the plant, the plant may grow out of the problem and develop new, normal appearing foliage. The common abiotic disorders in plants are discussed below.

1. ***Nutrient deficiencies and toxicity.***

1.1 Nutrient deficiencies

Nutrient deficiency reduces shoot growth and leaf size, cause leaf chlorosis, necrosis and dieback of plant parts. However, nutrient deficiencies cannot be reliably diagnosed on the basis of symptoms alone because numerous other plant problems can produce similar symptoms. There are general symptoms that can be expressed by deficiencies of nutrients but usually leaf and/or soil samples are needed to confirm the problem. Plant nutrient deficiencies are best diagnosed using plant tissue analysis. As opposed to soil nutrient analysis, plant tissue analysis allows one to determine plant nutrient uptake rather than plant nutrient availability. Because nutrient deficiencies lack visible signs, they are often mistaken for virus diseases. One of the best ways to diagnose nutrient disorders is the distribution of symptoms on the plant. Mobile nutrients are readily transferred within the plant to the growing points so symptoms appear on the lower (older) leaves of the plant. Conversely, immobile nutrients display symptoms on the meristem of the plant during nutrient deficiencies.

Nitrogen deficiencies may also result from infection by root pathogens such as root-knot nematodes (*Meloidogyne* spp.). Nitrogen deficiencies can cause increased susceptibility to certain leaf pathogens such as *Alternaria solani,* while excessive plant N levels may result in increased susceptibility to other pathogens such as *Botrytis cinerea*, or *Rhizoctonia solani.* However, phosphorus deficiency can result in poor growth and stunting, a blue/green hue to the leaves, and/or purple-colorations to stems and undersides of the leaves. Symptoms of iron deficiency first develop in the new growth which appears as yellow-green leaves, often with a striped appearance. Whereas, symptoms of K deficiency include necrosis (tissue death) on leaf margins, leaf curling and browning, and interveinal chlorosis. Plants that are deficient in K can be more prone to frost damage as well as certain diseases. Blossom end rot is a common symptom of Ca deficiency on fruits while other symptoms manifest as plant stunting, localized tissue necrosis, and leaf marginal chlorosis. Blossom end rot and other fruit disorders caused by Ca deficiency (e.g., bitter pit of apples) can often lead to secondary colonization by fungi. Moreover, Ca is a component of host response proteins to pathogen toxins, such as oxalic acid, which is utilized by some fungi such as *Sclerotium rolfsii* during infection. Magnesium deficiency results in chlorotic and necrotic tissues with an orange, red, or brownish color. Yellowing of the leaf margin is also common on many plant species. Early leaf senescence may also occur, particularly on older leaves as Mg is easily translocated through the plant. Over-application of K and/or Ca, which competes at soil cation exchange sites, can also lead to Mg deficiency. Similarly, over-application of Mg can lead to Ca deficiency; it is important to maintain a suitable Ca:Mg ratio in agricultural soils. Foliar and granular applications of Epsom salt can be used to remedy Mg deficiency in crop plants

Micronutrient toxicities are common in many production systems. Symptoms often include chlorosis or necrosis on leaf margins or tips, but leaf spotting, flecking, and other symptoms can also occur. Nutrient toxicity are triggered by excessively low or high soil pH. Micronutrient toxicities are particularly common in greenhouse floriculture. For example, Fe and Mn toxicity often occurs in greenhouse crops when the growing medium has a low pH. Excessive micronutrients can also occur when irrigation water or soil has significant concentrations of micronutrients.

1.2 *Herbicide, insecticide and fungicide phytotoxicity*.

Some herbicides cause root stunting or swelling, and could be confused with damage from nematodes. Others herbicides cause necrotic/chlorotic spots or blotches that resemble to foliar disease. Some herbicides cause mottled colors, distortion or vein banding that has similarity to viral disease. For example, the phenoxy herbicide 2-4D, a synthetic auxin, causes distortion in grape, cotton, tomatoes, and many other plants, which could be confused with a virus disease. Sometimes Diuron also causes discoloration along the veins in grapevine which could be confused with a virus disease or a nutritional problem. Insecticides and fungicides occasionally cause obvious plant damage and its symptoms vary widely. Generally, flower petals are more susceptible to damage from pesticide applications than leaves. The younger and more tender the leaves, the more susceptible they are to injury from pesticide applications. Hot weather can exacerbate the damage due to the chemicals cause. Pesticides that have systemic action can have a more profound effect. Some active ingredients can adversely affect the photosynthetic mechanism or other physiological processes and can result in a general leaf chlorosis, interveinal chlorosis, leaf curling and stunting. Emulsifiable concentrate (EC) formulations, soaps and oils can adversely affect the waxy surface layer that protects the leaf from desiccation. Applications with these products can result in the loss of the shiny appearance of a leaf, leaf spotting and necrosis. Pesticides applied as soil drenches can cause poor germination, seedling death, or distorted plant growth.

2. Physiological and Genetic Disorders

2.1 Physiological Disorders

There are numerous disorders that can occur because of environmental extremes such as light, temperature, water, or wind.

2.1.1Sunburn is damage to foliage and other herbaceous plant parts caused by a combination of too much light and heat and insufficient moisture. A yellow or brown area develops on foliage, which then dies beginning in areas between the veins. Sunscald is damage to bark caused by excessive light or heat. Damaged bark becomes cracked and sunken. High temperatures coupled with low soil moisture, plants may exhibit scorching on the margins of the leaves, premature leaf drop, and in severe cases entire plant death. Sometimes physiological changes result in abnormal color or growth habits. For example, geranium (*Pelargonium spp.*) when subjected to temperatures above 95°F (35°C), newly forming leaves may become "bleached" or white in color.

2.1.2 Frost damage causes shoots, buds and flowers to curl, turn brown or black and die. Hailstones injure leaves, twigs, and in serious cases even the bark. Chilling damage in sensitive plants can cause wilting of foliage and flowers and development of dark water-soaked spots on leaves that can eventually turn light brown or bleached, and die. Low-temperature injury can vary depending on the time of year and plant species. Newly expanding shoots are more sensitive than mature plant parts. If freezing temperatures are encountered after spring bud break, shoots can be severely injured or even killed. Chilling temperatures (above 32°F; 0°C) can damage newly expanding plant parts, resulting in a purplish coloration of foliage and possible necrosis. Woody parts of plants can also be injured by sub-freezing temperatures. Bark can crack, thereby exposing underlying wood to attack by pathogens or insects. Bark cracking from freezing injury greatly increases the susceptibility to infection by pathogens such as *Agrobacterium tumefaciens*, which causes crown gall on many ornamentals. Cold temperatures combined with freezing rain can also result in ice accumulation on limbs of woody plants, which can cause severe breakage.

2.1.3 In closed environments such as greenhouses and nursery storage areas, plants can be exposed to toxic levels of ethylene gas. Toxic levels of ethylene gas can cause premature abscission of flower buds, petals and leaves. Other symptoms include wilted flowers, chlorosis, twisted growth or downward bending of stems and leaves and undersized or narrow leaves.

2.1.4 In open environments, exposure of nursery plants to air pollutant gases such as ozone, carbon monoxide, nitrous oxides and sulfur dioxide can cause damage. Typical symptoms vary widely, but include slow growth and discolored, dying, or prematurely dropping foliage. Damage is often found where plants are located near sources of polluted air such as near freeways or industries or where weather and topography concentrate the pollutants.

2.1.5 Chronic excess of water, plants appear stunted and have underdeveloped shoots. In severe cases bleeding cankers on stems can occur. Adventitious roots may form at the root crown. Bark can split and wood may become water-soaked and discolored. Edema or corky, blister-like swelling can occur on the underside of leaves on plants growing in waterlogged soils. Edema can be worse during cloudy, overcast periods. In areas where waterlogged soils prevail for long periods of time, an odor of rotten eggs may be noticeable, due to sulfur gas production in the anaerobic soil.

2.2 Genetic Disorders

Sometimes plants or plant shoots exhibit an unusual and sudden change of color producing discrete markings of variegation. For example, a plant with entirely green leaves suddenly produces a shoot that has leaves with edges lacking green pigment, stripes, or blotches. A new shoot such as this is probably a chimera. It is produced when a genetic mutation occurs in a specific region of the growing tip resulting in a section with genetically different cells. The ostensible result of the genetic change is dependent on the arrangement of the genetically different cells in the shoot tip and their expression. This can lead to sometimes bizarre variegation forms or sometimes forms that are quite desirable. Sometimes variegation can be caused by viruses. Viruses usually cause non-uniform chlorosis, such as mosaics, while chimeras usually produce patterned forms such as variegation of color on leaf margins, stripes, or complete loss of pigment. Some viroids may also cause bleaching of pigments in leaves; such symptoms, however, are generally produced throughout the plant and are not restricted to a single shoot. Some nutrient disorders can cause variegation but these disorders usually do not arise from a specific shoot as with chimeras.

3. Air Pollution and Damaging Gases

Several gaseous air pollutants can cause injury to plants, including ozone, ethylene gas and sulfur dioxide.

3.1 Ozone

Ozone is produced when components of combustion/vehicle emissions such as hydrocarbons and nitrogen oxides react with oxygen and sunlight to form ground level ozone in the atmosphere. Its effects on plants can be mistaken for infectious diseases. Ozone can cause flecking, which could be mistaken for mite injury. Ozone can also cause bronzing, chlorosis and necrosis. Necrosis could be mistaken for a leaf spot caused by an infectious agent. In conifers, injury can include needle-banding and tip-burn.

3.2 Ethylene gas

Ethylene gas is another air pollutant, can build up in closed production areas such as greenhouses. Ethylene is a plant hormone that is utilized to signal ripening and senescing within plant tissues. It is colorless and odorless, making it difficult to detect and diagnose. Symptoms are variable, depending on the host species, host age, the ethylene concentration, and duration of exposure. Symptoms include curled leaves, flower abortion, distorted/twisted stems, leaf and petal abscission, and stunting. These symptoms can be mistaken for viral infection or herbicide injury. Tomatoes, peppers, and vinca are particularly susceptible and may be the first species to show symptoms in a greenhouse. In some plants, at least some damage occurs with ethylene levels as low as 0.01 to 0.1 ppm. Concentrations of 1-10 ppm cause major damage or even plant death.

3.3Sulfur dioxide

Contamination of air due to release of phytotoxic pollutants such as SO_2 may influence the composition of environment and consequently the host parasite relationship. SO_2 enters in plants through open stomata, the gas reacts with moisture and is converted into acid. The sulphite ions are about 30 times more toxic than sulphate ions. Two general types of symptoms designated as chronic and acute are produced by the plants due to the accumulation of sulphate and sulphite ions in the leaf tissue. Chronic injury occurs on exposure of plants to low concentration of SO_2 (less than 100 ppb) at which the rate of accumulation of the ions is slow the cells oxidize the sulphite ions and injury occurs until sufficient sulphate ions accumulate. This type of chronic injury is characterized by a general chlorotic appearance of the leaves. Cells are not killed but the chlorophyll is bleached which appears as a mild chlorosis or yellowing of the leaf or a silvering or bronzing of the lower leaf surface without necrosis. Acute injury results from the absorption of lethal quantities of SO_2 appears as marginal or intercostal areas of dead tissues, which are at full grayish green water soaked in appearance. In most plant species, these areas become bleached in original colour, upon drying and dead or necrotic areas may fall out leaving a ragged appearance to the leaf. In case of severe injury abscission layer develops at the base of petiole and the leaves fall down.

4. Equipment Injury

Human-inflicted damage can have a lasting effect on tree vigor. Lawn mowers, weed trimmers, or improper pruning with hedge trimmers or chainsaws can gouge, rip or split the trunk or limbs. Mower damage is a very common type of mechanical injury to landscape trees. Wounded areas can serve as infection courts (opening used by pathogens to enter a host) for microbial pathogens or insect pests that can cause cankers or wood decay problems. Heavy equipment used in the area of trees and landscape plants can result in compacted soils, reducing oxygen to the root systems and leading to a slow decline of the tree. Excavation to install sidewalks, irrigation systems or utility lines has a more direct impact by severing a portion of the root system. Corresponding branch dieback may show up on the same side of the tree on which the root system was damaged. Young trees and shrubs may die or decline within a season or two, while older trees may struggle and decline over a period of many years.

5. Damage due to Girdling

Girdling from guy wires, string, trunk wraps, vines or roots have a similar impact as equipment injury. Pressure or constriction of the bark may collapse phloem tissue and sometimes xylem tissue. The long-term impact of girdling is that fewer photosynthates go to the root system. This leads to the development of a smaller root system with less potential for water and nutrient uptake. Over time, affected trees tend to be smaller than normal, have poor leaf emergence and are less vigorous. Recovery from this type of injury is difficult.

6.Unusual Plant Growths

Other symptoms that can be mistaken for plant diseases but are actually abiotic in origin are sloughing bark and odd growths. In trees, bark that is unusually rough or that separates from the wood may be of concern. If this is a new event, then concern is probably warranted. If the tree loses its bark every year then this is more likely a normal occurrence. Sycamore trees tend to slough their bark off in early summer following a period of rapid growth. Sometimes the bark gradually falls off and sometimes appears to blow off within a couple of days. This process is normal and does not affect the health of the tree. Bumpy bark, burls, and other odd plant growths often look like symptoms of infectious diseases. However, burls, lignotubers and other growths on trees are usually the result of an injury. Burls frequently can be small or grow to a very large size. The bark covers the burl and remains intact rather than appearing cracked or sunken. Lignotubers frequently hold a cluster of buds that sprout rapidly in the spring. These gnarled growths look odd but they don't seem to have a major impact on the health of the tree.

L. 08

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

Sushma Nema & S.K.Tripathi

sushmanema@yahoo.com
JNKVV, Jabalpur

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).
1. 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.
1. Some are unicellular - e.g. yeasts.
1. 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.
1. Many reproduce both sexually and asexually - Both sexual and asexual reproduction often result in the production of spores.
1. Their nuclei are typically haploid and hyphal compartments are often multinucleate - Although the oomycota and some yeast possess diploid nuclei.
1. All are achlorophyllous - They lack chlorophyll pigments and are incapable of photosynthesis.
1. 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.
1. Possess characteristic range of storage compounds - e.g. trehalose, glycogen, sugar alcohols and lipids.
1. 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 myceli

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. In addition to giving anchorage, appressoria help the penetrating hyphae, branches to pierce the host cuticle.

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 host 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.

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.

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.

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. *).*

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 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.

Asexual spores

The spores produced asexual means are:

a. Sporangiospores
b. Conidia
c. Chlamydospores

a. Sporangiospores

Sporangiospores may bemotile (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'.

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 sogamous 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.

1. **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 carries them to the female gametangium, 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.

1. By the introduction of genetically different nuclei into homokaryon (Gr. homo=same + karyon = nut, nucleus), a soma in which all nuclei are similar.

1. By mutation, in a multinucleate homokaryon.The mutant nuclei subsequently survive, multiply and spread among the wild-type nuclei.

1. 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

1. Fusion between two nuclei

    a. Fusion between like nuclei

    b. Fusion between unlike nuclei

1. Multiplication of diploid nuclei side by side with the haploid nuclei

1. Occasional mitotic crossing-over during the multiplication of the diploid nuclei

1. Sorting out of diploid nuclei

1. Occasional haploidization of the diploid nuclei

1. 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 as 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.

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 and when the spore bearing branches bear conidia they are called conidiophores (as in Ascomycotina and Deuteromycotina). Aggregation of hyphae from stromatic or semistromatic structures and grows into compound sporophores. They bear layers of sporogenous cells and spores and form the fructifications and fruit bodies. e.g. pycnidia 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, *Penicillium claviforme, Doratomyces stemonitis, Ceratocystis ulmi.*

b. Sporodochium

Sporodochium is a Superficial, cushion-shaped asexual fruiting body consisting of a cluster of conidiophores. The conidiophores are packed tightly together and are generally shorter than those composing a synnema. e.g. *Epicoccum, Nectria.* **sporodochium:** (pl. sporodochia)

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.

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. 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.

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. Cleistothecia crack open at maturity by swelling of the contents. They are found in Eurotiales and Erysiphales (powdery mildews).

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 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, Ceratocystis, Podospora, Chaetomium, Xylaria, Claviceps* and *Cordyceps)* and 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*).

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: *Phytophthora infestans*

Genus = *Phytophthora*

Species = *infestans*

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

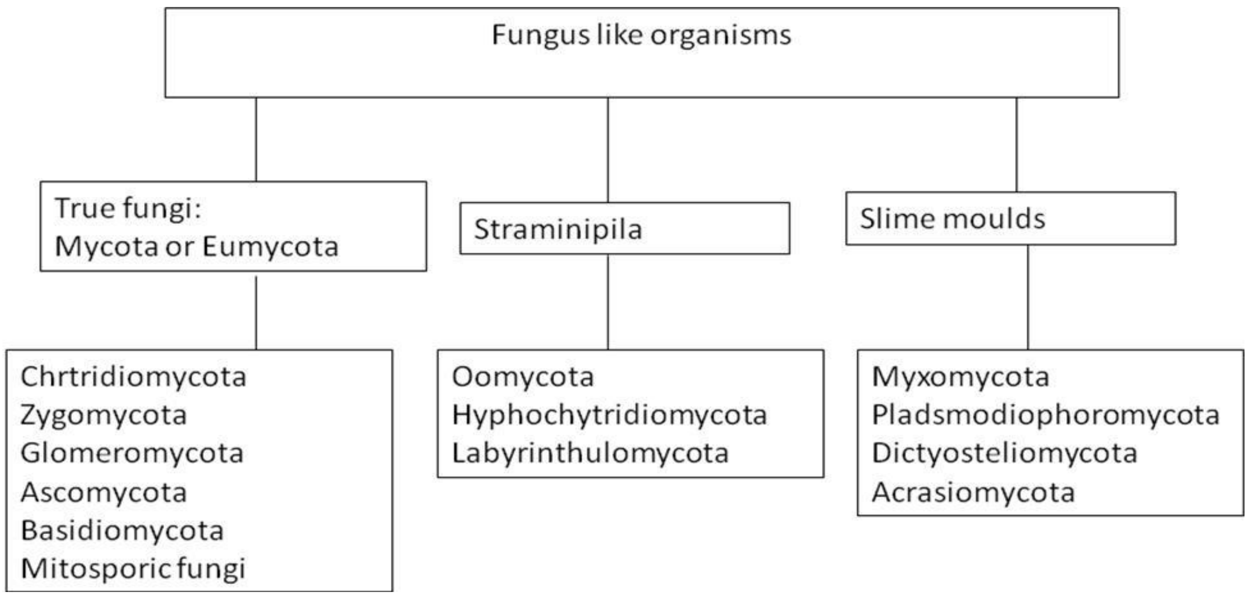
Zygospores… ZYGOMYCOTINA

Ascospores… ASCOMYCOTINA

Basidiospores… BASIDIOMYCOTINA

Perfect (sexual) state not seen … DEUTEROMYCOTINA

Classification of Fungi



L. 09

Bacteria and mollicutes: General morphological characteristics, basic methods of classification and reproduction.

Amita Pachori
Amitapachori9@gmail.com
JNKVV, PAWARKHEDA

Bacteria

_“Bacteria” = Plural form, “Bacterium” = Singular form

Bacterium is single-celled microorganism which is single cell that do not have cell organelles (mitochondria, endoplasmic reticulum, chloroplast etc.) or a true nucleus. Bacteria are microscopic unicellular organism they are true living organism that belongs to the kingdom prokaryotes.

Morphology of bacteria:

Bacterial morphology deals with size, shape, and arrangement of bacterial cells.

Size of Bacteria

Bacteria are microscopic organisms that are less than 3 micrometeres (μm) in size. Size of cocci range from 0.5 to 3 μm, and the size of a rod shaped bacteria range from 0.15 to 2 μm (width) to 0.5 to 20 μm (length).

Shape of Bacteria

Coccus or **Cocci** are bacterial cells that are spherical, and resemble tiny balls.
Eg. *Streptococcus*.

Bacillus or **Bacilli** are bacterial cells that are rod shaped, and resemble a pill.

Eg. *Bacillus anthracis*

Spiral bacteria have twisted or helical morphology that resembles little cork screws. Eg.Gastritis,

Some Bacteria have Other Shapes Such as:

Coccobacilli – Elongated spherical or ovoid form.

Filamentous – Bacilli that occur in long chains or threads.

Fusiform – Bacilli with tapered ends.

Arrangement of cells

Bacteria are also characterized based on how cocci and bacilli aggregate themselves.

Arrangement of cocci cells

Singly: Bacteria that appear as single cell, is just called as cocci

Diplococci: These cells are found in pairs and they are found attached to each other

Streptococcus: These bacteria form long chains and remain attached to each other

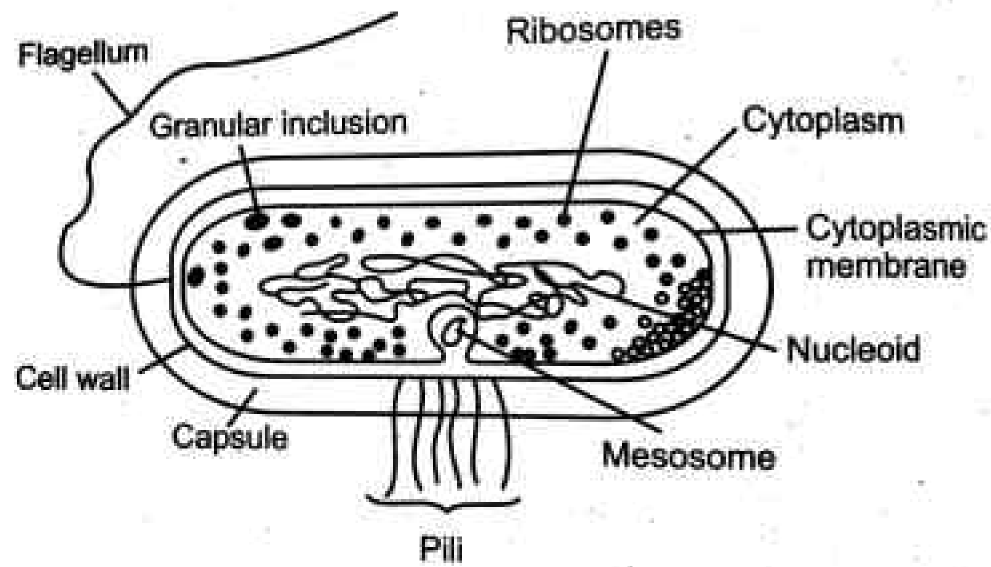
Staphylococcus: These bacteria are arranged irregularly in clusters like grapes

Arrangement of Bacilli

Singly: Bacteria that exists as single cell, called bacilli

Diplobacilli: These bacteria has two rod shaped cells which are attached to each other

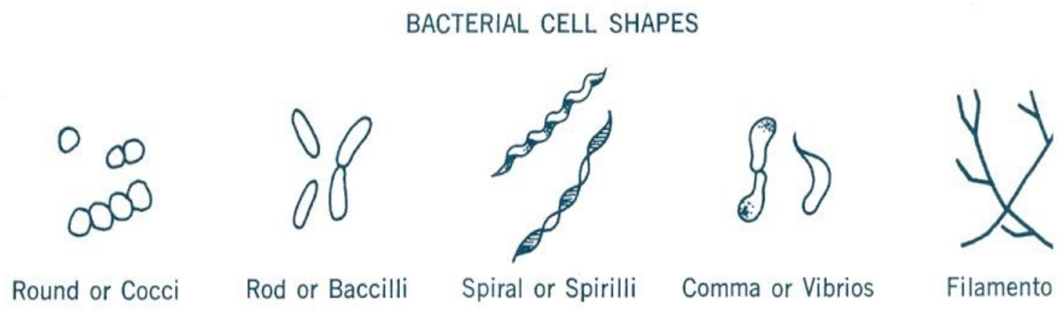
Streptobacilli: Cells are arranged as long chains in these bacteria

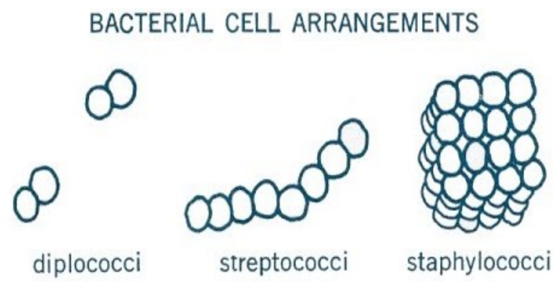


Morphological characteristics:

- Bacteria are single-celled organisms.
- They lack organelles such as chloroplasts and mitochondria.
- Do not have the true nucleus.
- Instead, their DNA, a double strand that is continuous and circular, is located in a nucleoid.
- The nucleoid is an irregularly shaped region that does not have a nuclear membrane.
- Bacteria also have a cell membrane and a cell wall that is often made of peptidoglycan. Together, the cellmembrane and cell wall are referred to as the cell envelope.
- Reproduction occurs through binary fission.
- Most numerous organisms on earth.
- Earliest life forms (fossils date 2.5 billion years old).
- Microscopic prokaryotes (no nucleus non membrane-bound organelles).
- Contain ribosomes.
- Infoldings of the cell membrane carry on photosynthesis and respiration.

- Surrounded by protective cell wall containing peptidoglycan (protein-carbohydrate).
- Many are surrounded by a sticky, protective coating of sugars called the capsule or glycocalyx (can attach to other bacteria or host).
- Have small rings of DNA called plasmids.
- May have short, hair like projections called pili on cell wall to attach to host or another bacteria when transferring genetic material.
- Most are unicellular.
- Found in most habitats.
- Most bacteria grow best at a pH of 6.5 to 7.0.
- Main decomposers of dead organisms so recycle nutrients.
- Some bacteria breakdown chemical and oil spills.
- Some cause disease.
- Move by flagella.
- Some can form protective endospores around the DNA when conditions become unfavorable; may stay inactive several years and then re-activate when conditions favorable.
- Once grouped together in the kingdom Monera.
- Classified by their structure, motility (ability to move), molecular composition, and reaction to stains (Gram stain)
- Most are heterotrophic (can’t make their own food).
- Can be aerobic (require oxygen) or anaerobic (don’t need oxygen).
- Can be identified by Gram staining (gram positive or gram negative).



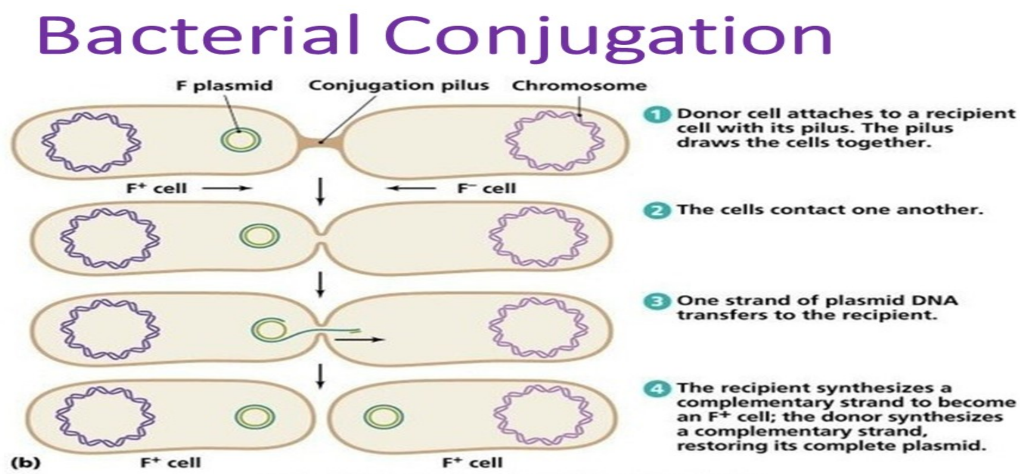


Reproduction:

- Most bacteria reproduce asexually by binary fission (chromosome replicates and then the cell divides), budding, fragmentation.
- Bacteria replicate (double in number) every 20 minutes under ideal conditions.
- Bacteria recombine genetic material in 3 ways –conjugation, transformation and transduction.

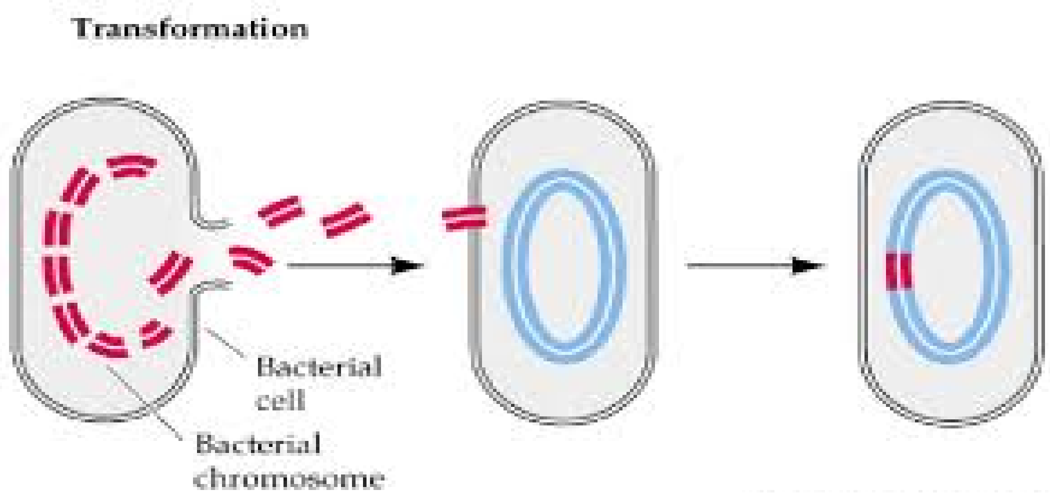
Conjugation:

- Sexual reproductive method.
- Two bacteria form a conjugation bridge or tube between them.
- Pili hold the bacteria together.
- DNA is transferred from one bacteria to the other.



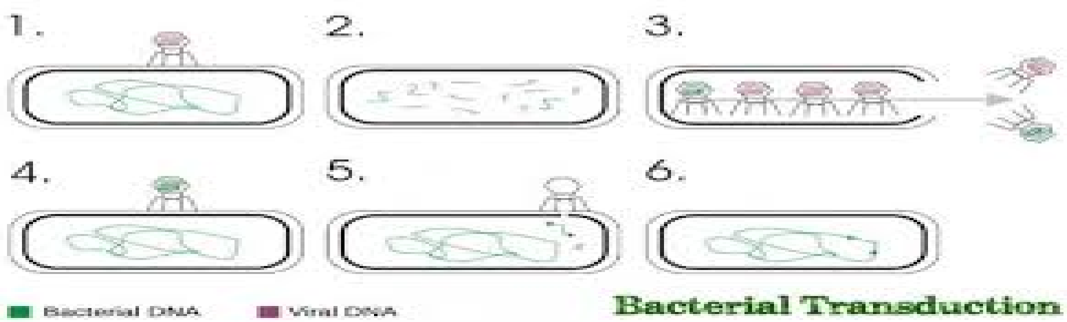
Transformation:

- Bacteria pick up pieces of DNA from other dead bacterial cells.
- New bacterium is genetically different from original.



Transduction:

- A bacteriophages (virus) carries a piece of DNA from one bacteria to another.
- Human insulin is produced in the lab by this method.



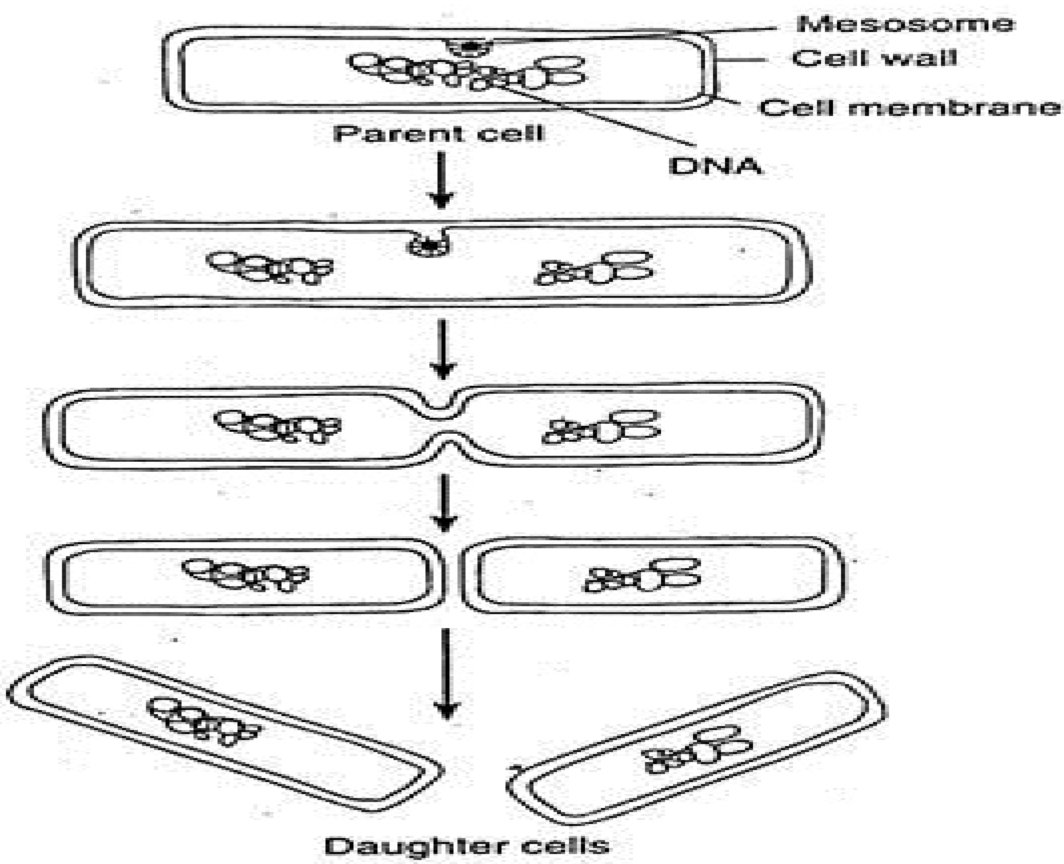
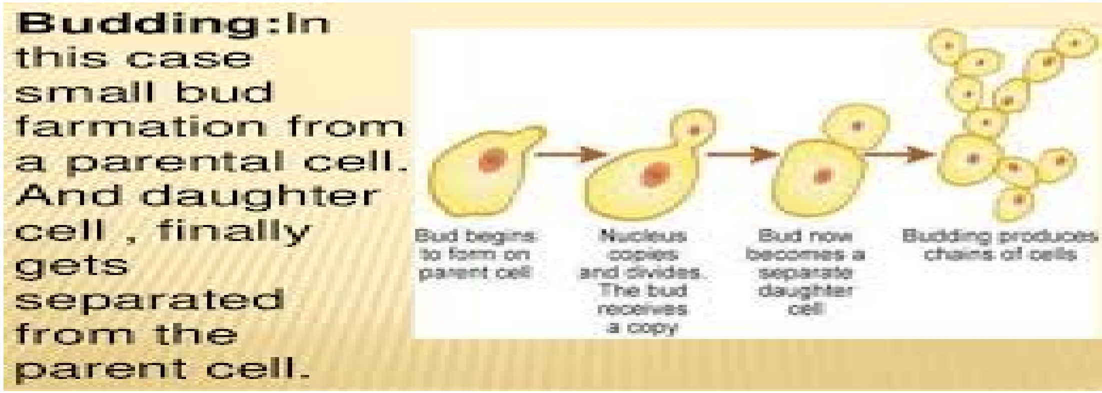
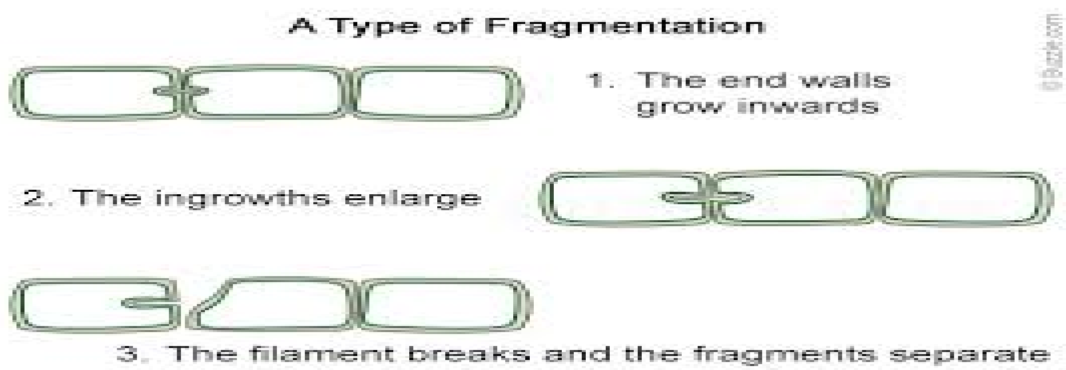
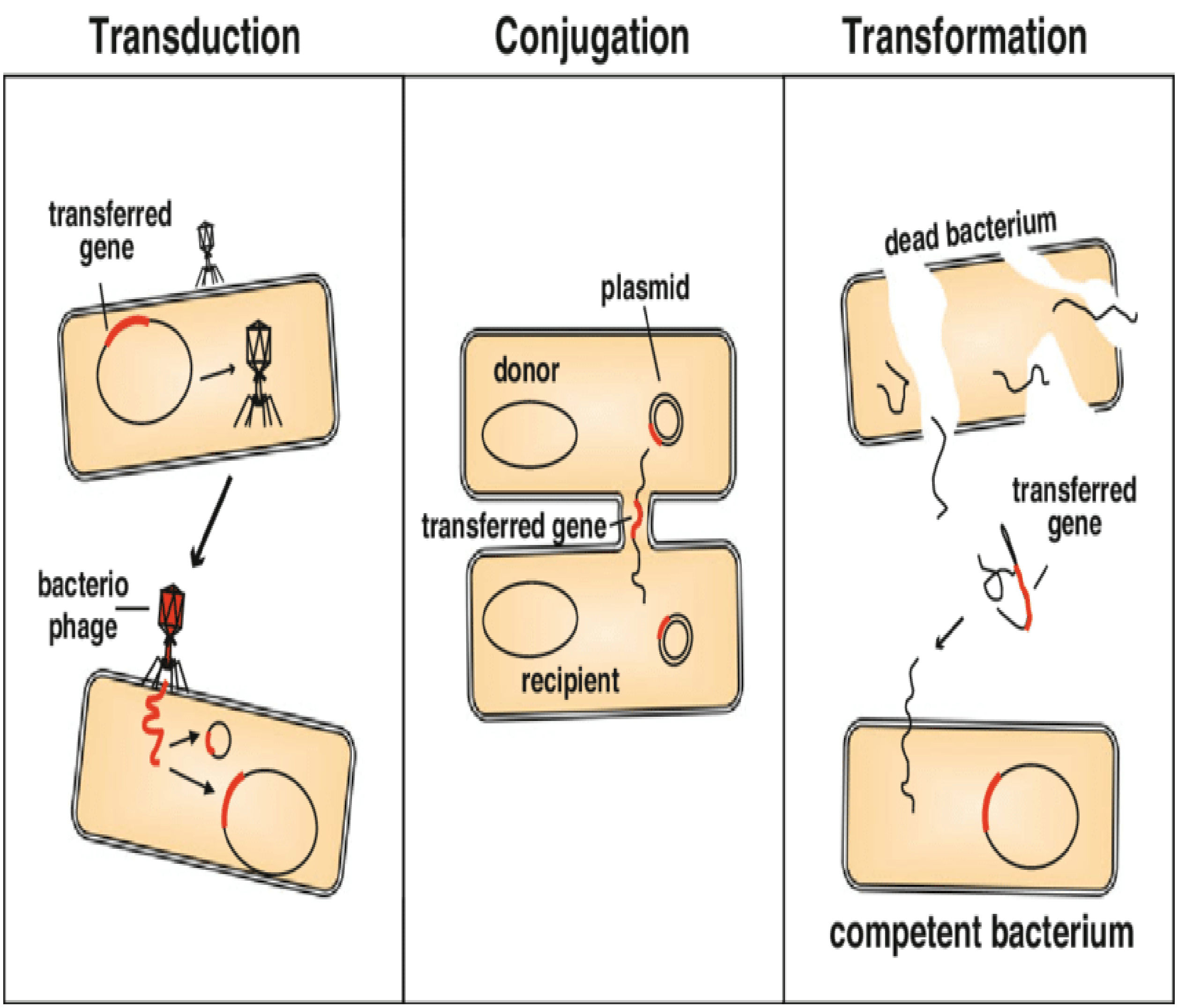
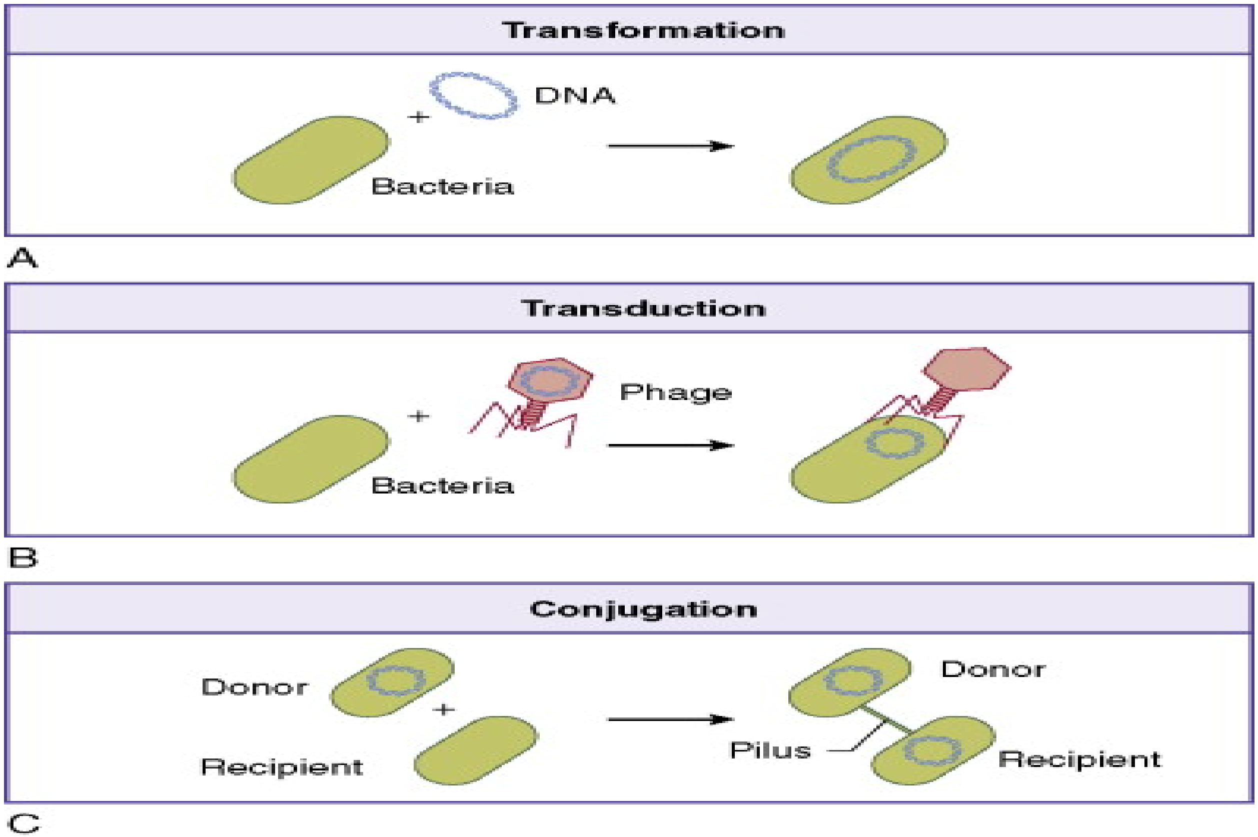


Fig. 2.20 : Binary fission of a bacterium


Budding:In this case small bud farmation from a parental cell. And daughter cell , finally gets separated from the parent cell.
Bud begins to form on parent cell
Nucleus copies and divides. The bud receives a copy
Bud now becomes a separate daughter cell
Budding produces chains of cells


A Type of Fragmentation
1. The end walls grow inwards
2. The ingrowths enlarge
3. The filament breaks and the fragments separate


Transduction
Conjugation
Transformation
transferred gene
bacterio phage
plasmid
donor
transferred gene
recipient
dead bacterium
transferred gene
competent bacterium



Mollicutes

Word is derived from the Latin

"Mollicutes" mollis = "soft" or "pliable", cutis = "skin".

- Mollicutes is a class of bacteria distinguished by the absence of a cell wall
- Individuals are very small
- Typically only 0.2–0.3 µm (200-300 nm) in size
- Have a very small genome size
- They vary in form
- Most have sterols that make the cell membrane somewhat more rigid
- Many are able to move about through gliding, but members of the genus Spiroplasma are helical and move by twisting
- The best-known genus in the Mollicutes is Mycoplasma
- Phytoplasma and Spiroplasma are plant pathogens associated with insect vectors.

Classification

Kingdom: Prokaryotae

Bacteria:Have cell membrane and cell wall

Division I: Gracilicutes (Gram negative bacteria)

Class: Proteobacteria- Mostly single celled bacteria

Family: Enterobacteriaceae

Genus:*Erwinia*

Family: Pseudomonadaceae

Genus:*Acidovorax, Pseudomonas, Rhizobacter, Rhizomonas, Xanthomonas*

Family: Rhizobiaceae

Genus:*Agrobacterium, Rhizobium*

Division-II: Firmicutes (Gram positive bacteria)

Class: Firmibacteria- Mostly single celled bacteria

Genus:*Bacillus, Clostridium*

Class: Thallobacteria (Branching bacteria)

Genus:*Arthobacter, Clavibacter, Curtobacterium, Rhodococcus, Streptomyces*

Mollicutes: (Mycoplasma like organism- MLO/Phytoplasma/Spiroplasma) Have only cell membrane and lake cell wall

Division-III: Tenericutes

Class: Mollicutes

Family: Spiroplasmataceae

Genus:*Spiroplasma*

Genus: Undefined, Known as Phytoplasma (MLO)

L. 10

Phytoplasma ,Spiroplasma ,Nematode,Viroids and Algae

Amrita Tiwari
Kvksidhi.2008@rediffmail.com
Krishi Vigyan Kendra, Sidhi

Phytoplasmas are obligate bacterial parasites of plant phloem tissue and of the insect vectors that are involved in their plant-to-plant transmission. Phytoplasmas were discovered in 1967 by japans scientists Phytoplasmas are characterized by the lack of a cell wall, a pleiomorphic or filamentous shape, a diameter normally less than 1 μm, and a very small genome They are transmitted from plant to plant by vectors (normally sap-sucking insects such as leafhoppers) in which they both survive and replicate. Phytoplasmas are Mollicutes, which are bound by a triple-layered membrane, rather than a cell wall.. A typical phytoplasma is pleiomorphic or filamentous in shape and is less than 1 μm in diameter. Like other prokaryotes, phytoplasmic . One characteristic symptom is abnormal floral organ development including phyllody, Many phytoplasma-infected plants develop a bushy or "witch's broom" appearance due to changes in their normal growth patterns of leaf-like structu. Phytoplasmas are spread principally by insect leafhoppers, planthoppers . phytoplasma disease in plants are generally seen as “yellows,” a form of disease common in

Many lant species.

Example of phytoplasmas

Aster yellows ,Peach yellows , Grapevine yellows, Lime and peanut witches’ brooms ,Soybean purple stem, Blueberry stunt

Spiroplasma:

Spiroplasma is a genus of mollicutes, a group of small bacteria without cell walls. Spiroplasma shares the simple metabolism, parasitic, lifestyle, fried- egg colony morphology and small genome of other mollicutes, but has a distinctive helical morphology, unlike mycoplasma.

Spiroplasma are helical, prokaryotic microorganisms associated with a few diseases in plants These organisms lack true cell wall the cell is surrounded by a triple-layered unit membrane

They are culturable phytopathogens forming ‘fried egg’ type of colonies similar to mycoplasmas the cell of Spiroplasma can vary in shape. They may be spherical. Slightly ovoid or helical spiroplasma show rapid rotary or screw motion there are no flagella present in these organisms spiroplasmas require sterols for their growth on culture media spiroplasmas are resistant to penicillin they are sensitive to tetracyclines spiroplasmas can be transmitted by insects, dodder and grafting the cell contains both DNA and RNA

Example of Spiroplasma: corn stunt and citrus stubborn diseases

Nematodes : Nematodes are thread like round worms that live in a wide range of environments including soil and fresh and salt water there are species of nematodes that feed on fungi, bacteria, protozoa, other nematodes and plants nematodes that feed on plant parts are called plant parasitic nematodes and are ubiquitous in agricultural soil.

Plant parasitic nematodes on the basis of scientific and economic important top ten order are determine plant parasitic nematodes

1. Root not nematodes (meloidogyna spices)
2. Cyst nematodes (heterodero species)
3. Root lesion nematodes (pratytenchus species)
4. The burrowing nematodes radopholus
5. Ditylenchus dipsaci
6. The pin wilt nematodes
7. The renifori nematodes

8. Xiphinema index (the only virus vactor nematodes)
9. Nacobbus abeerrans
10. Aphelen choides besseyi

Viroids:

Viroids Circular, uncapsulated, low molecular weight ssRNA molecules are known as viroids. Contain onlysingle stranded RNA as nucleic acid. They have much smaller size (the size of RNA, which consists of 147-375 nucleotides) and lower (100000 to 130000) molecular weight. Thus viroids are smaller than viruses i.e. less than one tenth the size of the genomes of the smallest known viruses. Viroids are circular. They cause diseases in plants only. So far, no animal or human disease has been shown to be caused by a viroid. They do not contain the protein coat- capsid. Viroids are found in meristematic tissues.

Example of viroids: Potato spindle tuber viroid, coconut cadang cadang viroid, citrus exocortis etc.

Viruses: Viruses are submicroscopic entities which replicate only in the living cell and consist of template nucleic acid either DNA or RNA, and typically surrounded by protein coat. Contain either DNA or RNA as nucleic acid. The complete fully assembled virus is termed the virion. They vary from 20-200 nm in size (the size of virus nucleic acid is 4-20 kb) They are generally bigger than viroids. They cause diseases in plants. Animals, including men. They contain protein coat called- ‘capsid’ Many viruses in addition to having a capsid also contain a virus encoded envelope. Viruses cause symptoms like-stunting mosaic phyllody discolouration symptoms like chlorosis vein clearing vein banding etc.

Algae: The algae the term ‘algae’ inclues a broad diverse assemblage encompassing all organism than perform organic photo synthesis other than embryophyte lead plants it is now well established than algae are on unnatural (i.e. non monophyletic) group formed by many evolutionary line ages with separate origins. This heterogeneity is reflected in the huge diversity observed in their size shape colour life history cell wall and chloroplast structure and secondary metabolites it mostly in aquatic habitats, have a simple called a ‘thallus’ and in most cases an autotrophic lifestyle, cephaleuros species are filametous green algae and parasites of higher plants.C. virescens is the most frequently reported algal pathogen of higher plants world wide and has the broadest host range anong cephaleuras species. Frequent rains and worm weather are favourable condition for these pathogens, The disease is called algal leaf spot, algal fruit spot and geen scurf, cephaleuros infections on tea and coffee plant have been called ;red rust’

L. 11

Virus: Nature, Structure, Replication and Transmission

Ashish Kumar
Ashishashish2612@gmail.com
JNKVV, Jabalpur

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1. Introduction

Viruses are unique class of widespread and economically important plant pathogens. Although, viruses are simple in structure and can't be observed with microscope, but can cause dangerous diseases in plants and animals. In plants they can cause various diseases like mosaics, leaf roll/curl, yellows, dwarfing/stunting, curly top/bunchy top etc. However, in animals they have been found to cause Polio, AIDS, Rabies and Influenza. One pathogenic virus can attack and produce disease in numerous plant genera, also many viruses can attack the same plant species. Outside living cells, the viruses behave like chemical molecules like TMV can survive in dried tobacco leaves for decades. Inside living cells, viruses behave like parasite and utilize the cell systems and cell resources for their own multiplication, thus exhaust the animal/plant cells. Viruses have characteristics common to both living and non-living systems. Because of their inability to grow independently, the virus cannot be considered as living. They are a cellular or non-cellular. But they also cannot be reduced to the status of chemicals since they reproduce inside the host cell. They are neither living 'organism' nor inert chemicals. They are intermediate of living and non-living.

2. Characteristics of Plant Viruses

Viruses are composed of nucleic acid core (genetic material) enveloped by a protein coat. The complete virus particle is known as virion. In viruses, only one type of nucleic acid (RNA/DNA) is present and mostly they have one kind of protein. Viruses do not have cell or any organization like that. Virus particles are mostly rod shaped or polyhedral with some modifications.

3. Composition and structure of Plant Viruses

Virus particles can be either rod shaped (rigid rods of flexuous threads) or spherical in shape (isometric or polyhedral). Some have cylindrical shape also. The protein coat, covering genetic material (DNA/RNA), makes the outer surface of virus particles which is made up of definite number of protein subunits. The elongated viruses may vary from 15x300nm (rigid rods) to 10x2000 nm (flexible threads). The bacillus like, cylindrical rod shaped particles measure 52-75x300-380 nm. The diameter of spherical viruses ranged from 17nm to 60nm. Some viruses consist of more than one unit, i.e. two or more distinct nucleic acid strands enveloped in same protein coat, even though, they may vary in size eg. Alfalfa mosaic virus has four components of different sizes. Similarly, spherical (isometric) viruses may have two or more components. In any multi-component viruses (rod/spherical) all nucleic acid strands must be present in plant cell for biological activities. Some spherical virus particles are made up of one type of nucleic acid (5-40%, RNA/DNA) and protein (60-90%). The elongated viruses have lower level of nucleic acid as compared to spherical viruses.

3.1 Viral Nucleic acid:

Viruses contain either RNA or DNA as genetic material. Most of plant viruses contain RNA as genetic material. The RNA can be single or double stranded (ssRNA or dsRNA). The RNA/DNA are long macromolecule made up of nucleotide subunits. The sugar present in DNA and RNA is deoxyribose and ribose sugars respectively, which are attached to phosphoric acid. The nucleotide unit holds a ring (the base) attached to a five carbon sugar which is attached to phosphoric acid. The RNA or DNA strands are formed as the sugar of one nucleotide reacts with phosphate of another nucleotide. Two pyrimidine base (adenine and guanine) interact with two purine bases (uracil and cytosine) in RNA strand. In DNA, the oxygen of one sugar hydroxyl is lacking and the base uracil is replaced by the thiamine base (methyl uracil).

3.2 Viral proteins:

Protein makes the coat or shell which cover the RNA/DNA (genetic material) in a virus particle. The proteins are made up of amino acids. The genetic material governs the amount and sequence of amino acids in protein, which differ for different viruses. For example the TMV has protein subunits of 158 amino acids arranged in a fixed sequence of s helix and makes the mass of 17,600 Daltons. These units are arranged in a helix containing 161/3 subunits per turn (49 subunits per three turns). The central hole of virus particle has a diameter of 4 nm while the diameter of virus particle is 18 nm. Each TMV particle has approximately 130 helix turns of protein subunits. The nucleic acid (RNA) is tightly packed between the helices of protein subunits.

A virus structure can be one of the following: icosahedral, enveloped, complex or helical.

3.2.1 Icosahedral:

These viruses appear spherical in shape, but a closer look actually reveals their arrangement as icosahedral. In these structures, the subunits are arranged in the form of a hollow, quasi spherical structure, with the genome within. An icosahedron is defined as being made up of 20 equilateral triangular faces arranged around the surface of a sphere.

The genetic material is fully enclosed inside of the capsid. Eg. Poliovirus, rhinovirus, and adenovirus.

3.2.2 Envelope:

This virus structure is a conventionally icosahedral or helical structure that is surrounded by a lipid bilayer membrane, meaning the virus is encased or enveloped. Here the nucleocapsid is surrounded by a lipid bilayer membrane and is comprised of host-cell lipids, also called an envelope. It also contains virally encoded proteins, often glycoproteins which are trans-membrane proteins. These viral proteins performs many purposes, such as binding to receptors on the host cell, playing a role in membrane fusion and cell entry and can also form channels in the viral membrane.

3.2.3 Complex:

These virus structures have a combination of icosahedral and helical shape and may have a complex outer wall or head-tail morphology. The head-tail morphology structure is unique to viruses that only infect bacteria and are known as bacteriophages

3.2.4 Helical:

This virus structure has a capsid with a central cavity or hollow tube that is made by proteins arranged in a circular fashion, creating a disc like shape. The disc shapes are attached helically creating a tube with room for the nucleic acid in the middle eg. Tobacco Mosaic Virus (TMV).

4. Replication of Plant Viruses:

Viruses act similar to organisms while they are inside living host cells and during this parasitic mode they produce their replica (replicate), grow in number (multiply), mutate and even recombine to give rise to new forms i.e. strains (create variability). Cell nucleus, nucleolus and cytoplasm are the sites for viral replication. The caulimoviruses and Gemini viruses, potex viruses and tobamoviruses replicate inside nucles and viruses move out into cytoplasm. The bromoviruses, potyviruses, nepoviruses and comoviruses replicate in cytoplasm. In terms of reproduction, viruses differ from other cellular organism; prokaryotic (binary fusion) and eukaryotic (sexual and/or asexual), viruses lose their identity due to disassembly of virion inside host cell. The protein coat is removed and lost in plant cell followed by replication of viral genome by host cell machinery. The behavior of virus particles inside host cell has been conducted on isolated protoplasts (plant cells without cell wall), callus tissues and the cells of vector. Hamilton (1974) described replication of plant viruses in following steps:

4.1 Inoculation and Entry

Life activities of virus particles are confined only inside living host cells. Viruses depend on some agency to get entry into host cell. Viruses placed on intact plant surface fail to cause infection, as they are incapable of entering the host cell. There is always a requirement of minor injury in plant cell in case of mechanically transmitted viruses and this facilitate the entry of viruses into cell system. However, some abrasive agents like carborandum powder are added to inoculums during experimental inoculations which create minor entry points for the viruses. In nature large number of viruses depend for their spreads (horizontal movement) and entry (inoculation) on minor natural injuries or insect vectors, which 'transmit' them (place directly inside/cell) while feeding on plants. When virus makes contact with with protoplast they may get in through pinocytes, the small perforations in all membrane.

4.2 Un coating of Viral Genome

The ability and process of un coating of viral genome largely depend on structure of virus particles (coat-proteins). The protein coat of virus particle is removed in early stages of infection process and thus, genome (nucleic acid) becomes free (Eg. In TMV, genome become free within 10 minutes of inoculation). This is prerequisite step of activity (replication/expression) of genome. It is believed that removal of protein coat is both physical as well as enzymatic process; however the exact place of uncoating is not completely known. The rod shaped viruses attach to some sites on cell membrane.

4.3 Synthetic Phase

The synthetic phase (parasitic phase) starts when the virus genome/nucleic acid (RNA/DNA) is free, from the protein envelop and here the genetic material replicated and many replicas are produced. After replica formation synthesis of viral protein takes place.

The replication of viral genomes for different types of nucleic acid takes place in following manner:

i. **Positive sense ssRNA virus:** Replication in ssRNA i.e. mono-partite viruses (eg. Tobacco Mosaic Virus) is a simple process. The single chain of nucleotides (RNA) is called as +ve sense strand and functions directly as mRNA (messenger RNA). The genetic information can be directly translated using ribosomes, t-RNA and amino acids of host system. The viral nucleic acid can be of two types mono-cistronic or poly-cistronic.
ii. **Negative sense ssRNA virus:** Some RNA viruses contain negative sense strand. These viruses cannot directly act as mRNA for synthesis of enzyme proteins which are required for replication. These viruses require specific transcriptase/polymerase (from host cell), which is incorporated into the virus particle. Now positive strand RNA, complementary to parent RNA, is synthesized and infection proceeds in the same manner as described earlier in case of +ve sense ssRNA virus. Eg. Lettuce necrotic, yellow mosaic virus and potato yellow dwarf virus.
iii. **Double stranded RNA virus:** Certain viruses like wound tumor and rice dwarf virus contain double stranded RNA in virion where both positive and negative RNA strand are present. There are 10-12 segments of RNA, all contained in same particle, each segment of genome is separately transmitted into a single mRNA using replicase enzyme present in the core of particle. However, the positive sense strand plays role in following two manners:

(a) Translated into proteins
(b) Act as template for negative strand RNA

iv. **DNA viruses**: Some plant viruses contain DNA as genetic material instead of RNA like in Cauliflower Mosaic Virus. The caulimoviruses have dsDNA (double stranded DNA) and Gemini viruses contain ssDNA (single stranded DNA). In the process of replication of DNA viruses, once DNA becomes free from coat protein, it utilizes replicase from host cell and can replicate. The caulimoviruses contain dsDNA (double stranded DNA) and only one strand is transcribed into mRNA using the host enzymes.

4.4 Protein Synthesis:

The viral RNA acts as mRNA and gets translated at ribosome for production of proteins, which are specific to each virus species. The host amino acids are arranged in a specific sequence, aided by tRNA and factors required for initiation and termination of protein synthesis. In this way, protein coat of virus particles is synthesized at the expense of host plant cells.

4.5 Assembly of Virions

The assembly of virus particles (virions) takes place at the end of synthetic phase (production of viral nucleic acid and protein). This may takes place in nucleus (complete virus particles-virions: come out) or in cytoplasm or in viroplasm (electron-dense mass). The assembly of nucleic acid and viral proteins seems to be a spontaneous process, but there must be some information needed for their assembly. In this way, the nucleic acid is packed inside protein coat and once the nucleic acid is packed inside protein coat, the virion assembly is irreversible. The virus cannot enter another reproductive/infective cycle inside same cell.

5. Transmission of Plant Viruses

Viruses are active (parasitic) only inside living host cells. Viruses cannot move on their own and the movement of virions may be within plant tissues or outside plants helped by various agencies. Depending upon nature of crop and relationship with vector various agencies are employed during short and long distance dispersal (transmission) of viruses. In viral epidemiology, the efficiency of virus vectoring agency is the most important aspect. The other important means of virus spread is via seed/vegetative parts i.e. propagating material and by contact in mechanical transmission.

For causing new infections, viruses have to move out of infected host cells. Cell to cell movement of viruses within plants takes places through. Plasmodesmata are the connections between adjacent cells. Per day movement of viruses is approximately 1.0 nm. For faster movement of viruses within plants, they enter and move through phloem. Once the viruses are loaded in phloem, they become systemic and move towards the sink tissues (growing apical tissues, fruits or storage roots/stems). Then from phloem, the virus can move into adjacent parenchymatous cells. In this way, they enter the new tissues for further spread. Viruses causing mosaic type symptoms may be confined in certain cells/tissues.

5.1 Mechanical Transmission

One of the important means of field spread of viruses is mechanical or sap transmission of plant viruses. The processes like physical contact/rubbing of infected parts facilitate the transfer of virus in sap and in similar fashion mechanical contact or rubbing with healthy tissue provide opportunity of inoculation, through minor injuries. This is one of the easy ways to establish presence of virus is some suspect plant specimens. Comparatively high concentration of virus particles of 1000 or more is required for each infection. Certain host plants, which are extra sensitive or local lesion hosts are utilized as indicator plants. These are used to verify presence of particular virus, based on known reaction.

5.2 Transmission through Propagative Material

Most plant viruses associated with diseased plants are systemic, thus present in all plant parts/cells and in this way, they may spread with seed or vegetative plant parts. There are fair chances of spread of plant viruses if grafts or buds or plant cutting, are used as means of propagation. Important commercial crops like potato, sugarcane and ornamentals face the issue of quality/disease free seed/planting material.

5.3 Transmission with seeds:

Some plant viruses are carried on the seed coat. They may be present as surface contaminants (TMV on tomato seeds) or inside the seed (endosperm/embryo). Viruses considered under true seed transmission are carried in embryo. For this the early infection of plant and invasion of embryonic tissue by virus, prior to pollination and formation of female gametes is required. After fertilizations, the embryonic sac (containing embryo and endosperm) is separated from direct vascular connection of mother plants. Majority of unstable viruses are lost. These reasons explain why majority of plant viruses are not transmitted through seeds. Plant viruses like bean common mosaic, bean yellow mosaic, lettuce mosaic, soybean mosaic etc. are transmitted by seed and pollen.

5.4 Transmission through Insects

In case of virus, the vectors help in their dispersal or transmission to ensure the continuity of infection chain. In fact, epidemiology of virus disease depends on behavior of vector. Hence, virus-vector relationship is biologically, ecologically and economically important. Insects and mites play the role of vectoring viruses efficiently or viruses have used the plant- insect /mites relationship for a 'ride' from source (diseased plants) to targets (healthy tissue/plants). Aphid, leafhopper, psylla, treehopper, planthopper, beetle, thrip, whitefly, grasshopper, mealy bug and plant bug are various groups of insects/mites involved in transmission of various viruses. Eg. Transmission of rice dwarf virus takes place by leaf topper (*Inazuma dorsalis* and *Nephotetix cicticeps*), cucumber mosaic viruses is transmitted by aphid (*Aphis gossypi*) and potato lea roll viruses is transmitted by aphid (*Myzus persicae*).

Virus-vector relationship: The process of viral disease development is complicated by involvement of vectors (living organism) in host – pathogen interaction. Virus-vector relationship plays important role in disease development and influence the host range, and to some extent the evolutionary process in long-term. The virus-vector relations is largely based on acquisition feeding period (The time period for which virus free vector must feed on a virus infected plant to acquire virus), acquisition access period (Period for which vector is allowed to feed on source of virus), latent period (Duration after which a vector becomes able to transmit virus i.e. viruliferous), inoculation access/feeding period (The time period for which vector must feed before it is able to inoculate viruses into plants (inoculation feeding period) and transmission threshold period (Minimum period required by vector for acquisition and subsequent transfer to a virus free plant).

Depending upon the duration for which the vectors could transmit viruses and the intimacy of their relationship, viruses have been categorized into three categories:

(a) **Non-persistent viruses**: The acquisition and inoculation periods are few seconds to a minute (very small). Vectors acquire viruses during probing or feeding and without any latent period, vector can transmit virus. The period of retention/persistence is also very brief. It is basically a mechanical association and virus is lost during molting. Aphids are commonly involved in non-persistent transmission and fasting before feeding enhances their transmission efficiency.

(b) **Persistent viruses**: These viruses have more evolved or specific relationship with their vectors. The up-take and passage of virus through insect system (alimentary canal, gut wall, circulation in body fluid-haemolymph and finally coming out with saliva) result in an intimate biological relationship.Persistent viruses are also called circulative virus. . Eg. Rice dwarf virus and wheat streak viruses are passed to next generation of vectors through eggs. The passage of viruses to the progeny is called as transovarial transfer.

(c) **Semi-persistent viruses**: This category has the plant viruses, which share certain features with non-persistent and persistent viruses. They take a little longer to acquire viruses (3-4 min), suggesting that virus may be neither circulative nor persistent. In this type of viruses, pre-acquisition fasting does not improve transmission efficiency and infectivity is lost after molting. Phloem borne viruses are picked up and transmitted without latent period.

5.5 Transmission by Nematodes:

The nematodes are important carriers of plant viruses. Members of genera *Longidorus* and *Xiphinema* transmit polyhedral nepoviruses such as grapevine fanleaf virus, tomato ring spot, arabis mosaic. *Trichodorus* and *Paratrichodorus* transmit tobacco rattle and pea early browning virus.

5.6 Transmission by mites:

The mites acquire viruses and wind may help in spread of disease to distances. Eg. *Aceria cajani* transmit sterility mosaic virus in pigeon pea, *Aceria tulipae* transmits wheat streak mosaic virus. The nymphs of mites acquire wheat streak mosaic virus and transmit in persistent manner.

5.7 Transmission by fungi:

The fungal transmission is more prevalent in temperate climate (cool wet conditions). *Olpidium brassicae* transmit the tobacco mosaic virus, tobacco stunt virus and Lettuce big vein virus. *Synchytrium endobioticum* transmits potato virus X. *Spogospora subterranea* transmits potato curly top virus.

Transmission by dodder:

Several plant viruses are passively transported from diseased plants to healthy plants by thread like tubular structures of dodder. Certain viruses multiply in dodder. Eg. Potato leaf roll, barley yellow dwarf, citrus tristeza are transmitted by different species of *Cuscuta*.

L. 12

Phanerogamic plant parasites

A.K.Jain

akjagcrewa@gmail.com

Jnkvv, College of Agriculture, Rewa

Phanerogamic parasites are flowering plants which lead a parasitic life on other living plants and cause considerable loss in yield. About 2500 species of phanerogamic parasites belonging to 11 families have been recorded throughout the world. The phanerogamic plant parasites invade the stem and root of the host plant to get food material. Some of the parasites are chlorophyll less and entirely depends on the host plants for their food. They are called total or holo parasites. Some parasites possess chlorophyll and manufacture carbohydrates. But depend on the host for minerals, salts and water. These are called partial or semi parasites.

Classification of phanerogamic parasites : Broadly these parasites are classified in two groups.

1) **Stem parasites:** These parasites attack on stem of the host plant and get their nourishment. These are two types.
    i. **Total or holo stem parasites** : These phanerogamic parasites are devoid of chlorophyll and remain entirely depend on host plant for their existence. Ex. Dodder or Amarbel (*Cuscuta* spp.)
    ii. **Partial or semi stem parasites** : These phanerogamic parasites have chlorophyll and can synthesize their food in the presence of sun light. But depends on host plant for minerals and water. Ex. Banda (*Loranthus* spp.)
2) **Root parasites :** These parasites attack on root of the host plant and get their nourishment. These are two types.

i. **Total or holo root parasites :** These phanerogamic parasites are devoid of chlorophyll and remain entirely depend on host plant for their existence. Ex. Broomrapes (*Orobanche* spp.)

ii. **Partial or semi root parasites :** These phanerogamic parasites have chlorophyll and can synthesize their food in the presence of sun light. But depends on host plant for minerals and water. Ex. Witch weed (*Striga* spp.).

Important phanerogamic plant parasites

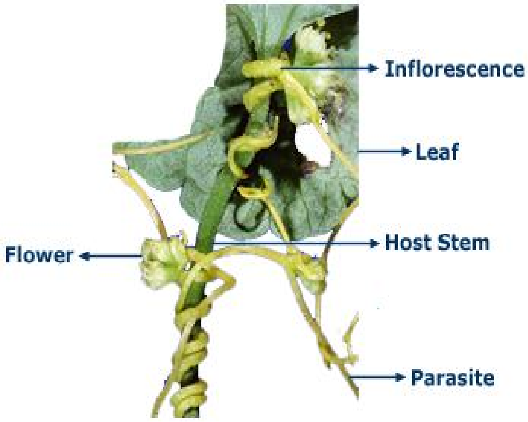
1) Dodder or Amarbel or Love-vine (*Cuscuta* spp.)

Cuscuta is a very fast growing parasite which attack trees, shrubs, fruit plants and vegetables but not cereal plants. These are non-chlorophyllous, leafless, rootless having yellow orange or pink thread like twining stems, which attack to the stems and other parts of the host plant. The stem of *Cuscuta* may be single but generally tangled mass of interwining stems may be seen. This is a total or holo stem parasite and is dependent on the host for their nourishment and existence. When the stems of *Cuscuta* come in contact with the host, minute root like organs known as haustoria penetrate the host cortex for getting food. Thus host plant suffers from malnutrition. Plant mat be dwarf and vitality of the host plant is reduced. Yellowing of the leaves of host plant with less flowers and fruits may be seen. In case of severe attack, the affected parts or entire plant may be die.

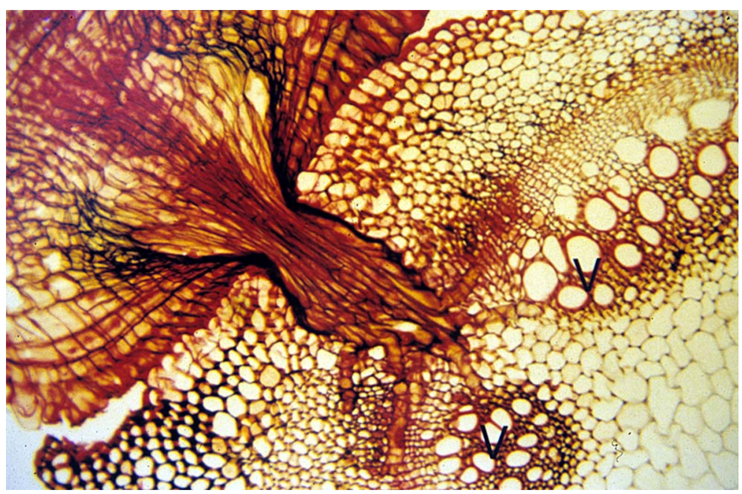
Cuscuta spp. produces tiny white, pink or yellowish flowers in clusters. The ovary is biloculate, style may be distinct and fruit is a capsule in which abundant tiny greyish reddish brown rough seeds are produced. A single plant may be produce 3000 seeds in capsules.The *Cuscuta* seeds fall on the soils and remain dormant for a long period. Under favourable conditions, the seeds germinate and produce tiny colourless seedlings with a spiral growth at the upper most portions. The seedlings survive only for short time in the absence of host. If host is present, the contact between host and parasite is established and the portion of the seedling embedded in the soil gradually shrivels and disappears. The parasite may be spread by seeds or stem portion moved by irrigation water or as dry straw carried by wind, birds or cattles.

Management

- **i.** Use of dodder free seeds for planting.
- **ii.** Crop rotation for 4 to 5 years should be adopted.
- **iii.** Dodder plants should be manually removed to avoid the losses.
- **iv.** Flow of irrigation water from infected field to healthy field should be restricted.
- **v.** Manures contaminated with dodder seeds should not be used.
- **vi.** Use of clean agricultural implements and restricted movement of domestic animals in affected areas.
- vii. Foliar spray of herbicides like 2, 4-D, and pentachlorophenol @ 0.3-0.4% is reported to control the *Cuscuta.*



***Cuscuta* on host plant**



Association of *Cuscuta* with the host tissues through haustoria

2). **Banda (*Loranthus also known as Dendrophthae* spp.)**

Loranthus is a partial or semi stem parasite and attacks on fruits and forest trees. The most common host is the mango tree and Madhuca latifolia. Loranthus has green leaves, long tubular orange coloured flowers with small red berries and devoid of root system, but develops root like absorbing organ known as haustoria.

The haustoria penetrate deep into the host tissues and drain water and minerals from the host to parasite continuously resulting withering of branch. Sometimes, parasite produces a creeping branch which grows closely along with the host stem and forms haustoria at regular intervals. Approximate 20 to 30% losses have been reported due to *Loranthus*.

The parasite is disseminated mainly through its seed carried by the birds. The birds are attracted by the small red berries and seeds adhere to the branches have sticky property. Thus easily carried by the birds. Droppings of the seeds get deposited on the other trees mainly at the junction of a branch and main stem. The natural fall of berries from higher to lower levels of the same host trees also ensure continuous infestation. The parasite causes damage by preventing the production of new growth by the host.

Management

i. The most common control is hand picking of parasite at early stages of its growth or cut the infected branches.
ii. Injection of copper sulphate and 2,4-D into the affected branches have been found effective.
iii. Foliar spray of diesel oil emulsion (30-40%) in soap water has been found effective in eradication of parasite from mango trees.

Loranthus or *Dendrophthae* on host plant

3). **Broomrapes (*Orobanche* spp.)**

Broomrape is a total or holo root parasite affecting mainly dicots namely tobacco, brinjal, tomato, cauliflower, turnip, sunflower, melons, broadbean and other solaneceous and crucifer plants. In India, tobacco crop is badly affected by the *Orobanche*. In northern India and Andhra Pradesh it is called *Tokra* and *Malle*, respectively.

Broomrape is an annual fleshy flowering plant of about 10 to 15 inches with cylindrical pale yellow or brownish red stem, thickened at the base and covered with small thin scaly leaves. White and tubular flowers appear in the axis of leaves. The fruits are capsular and contain abundant tiny black seeds. The seeds remain dormant in the soil for many years. The seeds germinate in the soil due to stimulants present in the root exudates of susceptible host. Several growth regulators like ethylene, cytokinins, gibberellins and coumarins are also reported to induce seed germination.

Broomrapes have no green tissues and the haustoria penetrate the roots of host plant. It forms a nodule of tissues which fuses with the tissues of the host. A large number of parasitic stems may be seen breaking the soil around the host plant and parasitic roots may be seen interwined with the roots of host plant. As a result food supply is diverted to the parasitic plant resulting in stunting of host plant, chlorosis of leaves and even death of plant due to severe attack.

Management

- **i.** Uprooting and destruction of parasitic plant before flowering.
- **ii.** Long dry period during summer result in reducing the seed population in the soil.
- **iii.** Use of trap or catch crops is effective to control the broomrape. For example, chilli should be grown after the affected crop. It induced the seed germination of parasite and in absence of suitable host seeds may die. *Carum ajown* is a trap crop for *Orobanche cernua*.
- **iv.** Insects like *Sciara* spp. eat seedlings and stem of *Orobanche*. *Agromyzid* fly and *Phytophthora orobanchiae* are reported to attack *Orobanche*.
- **v.** Soil drenching with copper sulphate (25%) solution is reported to destroy the Orobanche.

Orobanche attack on host plant

4). **Witch weed (*Striga* spp.).** Witch weed is a partial or semi root parasite but obligate in nature. Numerous species of witch weed parasitize cereals, maize, millets, sugarcane and tobacco. Most common species occurring in India are *Striga densiflora, S. asiatica, S. hermonthica , S. lutea* and *S. euphrasoides*. *Striga* plants are 9 inch to 2 feet with bright green, slightly hairy stem and long narrow leaves. They usually developed in clusters in and around the host plant. Flowers are small, brick red or yellowish or white in colour produced on aerial parts . A single plant can produce 50000 to 500000 tiny brown seeds in capsules and can remain viable for 12 to 40 years. The life cycle from seed germination to seed setting needs 90-120 days. The roots of Striga are watery white without root hairs and obtain water as well as nutrients from the host plant with the help of haustoria. Germination of Striga seeds are stimulated in the presence of root exudates of the specific host. After germination, the parasite grows below the soil surface for about 1-2 months and produces underground stems and roots. The seeds are disseminated through rain, irrigation water, flood and winds.

Striga is a pest of low fertile soil and usually the infection decreases if nutrients especially nitrogen and phosphorus are applied in sufficient quantities. Trap crops should be cultivated for at least three consecutive years in order to reduce parasitic weed. These crops stimulate the suicidal germination of *Striga* and reduces the *Striga* seed bank in the soil.

Management

- **i.** Uprooting and destruction of parasitic plant before flowering.
- **ii.** Flood irrigation is effective in eliminating the parasite.
- **iii.** Intercropping with pigeon pea is recommended to reduce the *Striga* infection.
- **iv.** Trap crops like cotton, soybean, lentil should be grown before growing main crop. As soon as, the *Striga* plant emerges they should be destroyed by ploughing or weedicides.

v. Catch crop like sudan grass may be planted to stimulate a high percentage of the parasite seeds to germinate, but destroyed or harvested before the parasite can reproduce.

vi. Application of nitrogenous fertilizers was found to reduce the seed germination of *Striga* seeds.

vii. Soil drenching with 2-3% copper sulphate solution up to a depth of 4-6 inches has been found to kill the parasite.

viii. Foliar spray of 2,4D @ 0.5 to 1 kg ha^{-1} at 3-4 weeks intervals has been found effective to control seed production.

Striga on host plant

L. 13

Classification, Morphology and Symptoms caused by Plant parasitic nematodes

Jayant Bhatt
Jayant187@rediffmail.com
JNKVV, Jabalpur

Classification of Nematode

The word taxonomy was coined by de Condolle (1875) and means "arrangement by law" (taxis = arrangement, nomos = by law). It can be defined as theory and practice of classifying organisms. The process of classifying (=classification) is the grouping of organisms in a system or order. The organisms are grouped to

gether and discriminated from other such groups on the basis of certain characters known as taxonomic characters. They may be morphological, physiological, ecological, genetical etc. The classification of plant parasitic nematodes is presently based on the morphological characters. Besides qualitative morphological characters certain quantitative characters (measurements) are also used for classifying nematodes.

Nematodes are placed in the group invertebrate, Kingdon Animalia. Under separate phylum, Nemata/ Nematoda.

The following are the characteristics of members of the phylum Nemata.

1. Inhabit marine, freshwater and terrestrial environments as free – livers and parasites.
2. Bilateraly symmetrical, triploblastic, un segmented and pseudocoelomates.
3. Vermiform, round in cross – section, covered with a three – layered cuticle.
4. Growth accompanied by molting of juvenile stages, usually four juvenile stages.

5. Oral opening surrounded by 6 lips and 16 sensory structures.
6. Possess unique cephalic sense organs called amphids.
7. Body wall contains only longitudinal muscles connected to longitudinal nerve chords by processes extending from each muscle.
8. Unique exscretory system containing gland cells or a set of collecting tubes.
9. Longitudinal nerve cords housed within the thickening of the hypodermis.

A. Order- Tylenchida

I. Stoma has protrusible stomato stylet.
II. Three parts oesophagus.
III. The caudal alae is not provided by ribs.
IV. Cuticle has distinct annulations.

The order Tylenchida is redivided into two suborders namely- Tylenchina and Criconematina.

I. Sub-order- Tylenchina

i. Dorsal oesophageal gland opens into the lumen of oesophagus anterior to median bulb near the stylet base.
ii. Males often have bursa.
iii. Median bulb is round and is not occupying the whole body diameter.

It comprises three super families as follows:

1. Super family- Tylenchoidea
2. Super family- Hoplolaimoidea
3. Super family- Heteroderoidea

A. Super family- Tylenchoidea

I. Procorpus and median bulb separated by more or less pronounced constriction.
II. The terminal bulb well developed.
III. They are ecto or migratory parasites and both sexes are vermiform.
IV. Bursa generally present, often large.
V. The eggs are not deposited in gelatinous matrix.

It include following families:

1. Family- Tylenchidae : eg. *Tylenchus*

2. Family- Tylenchorhynchidae: eg. *Tylenchorhynchus*
3. Family- Neotylenchidae: eg. *Neotylenchus*
4. Family- Anguinidae: eg. *Anguina tritici, Ditylenchus*

B. Super family- Hoplolaimoidea

I. Body annulations strongly devloped.
II. The stylet is strong with prominent base knobs
III. Head sclerotization is distinct.
IV. The oesophageal glands overlap the intestine.
V. The caudal alae extend to the tail tip.
VI. The female may be vermiform or swollen while males are vermiform.

It include following families:

1. Family- Dolichodoridae : eg. *Dolichodorus, Belanolaimus*
2. Family- Haplolaimidae: eg. *Haplolaimus, Rotylenchus, Rotylenchulus*
3. Family- Pratylenchidae: eg. *Pratylenchus, Rhadopholus, Hirschemanniella*
4. Family- Nacobbidae: eg. *Nacobbus*

C. Super family- Heteroderoidea

I. The females are saccate, pyriform or lemon shaped, sessile and males are vermiform.
II. The tail is short and without caudal alae in males.
III. Females with two ovaries and males have terminal spicules.
IV. The eggs may be retained in the female body which turns into cysts or deposited in gelatinus matrix.
V. There is pronounced sexual dimorphism.

It include following families:

1. Family- Heterodoridae : eg. *Heterodera, Globodera*
2. Family- Melodogynidae: eg. *Melodogyne*

II. Sub-order- Criconematina

i. The procorpus and median bulb confluent, large and terminal bulb is small. The valve in median bulb is present.

ii. The males often have reduced stylet and oesophagus or even these may be absent.
iii. Rectum and anus are poorly developed.
iv. The cuticle is generally strongly striated with annules.
v. The females have strongly striated with annules.
vi. The females have strongly developed and elongated stylet.
vii. The vulva is situated at posterior end and ovary is monodelphic.
viii. The bursa may be absent or poorly developed.

It comprises two super families as follows:

1. Super family- Criconematoidea
2. Super family- Tylenchuloidea

A. Super family- Criconematoidea
   I. Coarse cuticle with annulations, large annules sometimes with spines or scale like projections.
   II. In some nematodes, the cuticle sheath is present.
   III. The adult female is stout but vermiform.
   IV. The length ranges from 0.1 to 0.2 mm.

   It include following families:
   1. Family- Criconematidae : eg. *Criconema, Criconemaoides*
   2. Family- Hemicycliophoridae: eg. *Hemicycliophora, Hemicriconemoides*

B. Super family- Tylenchuloidea
   I. The cuticle annulations are fine or very thick.
   II. The adult females are swollen, subspherical, saccate or elongate.
   III. The males are with or without stylet.
   IV. The tail is long and bursa is absent.
   V. The excretory pore is located for backward or in normal position.

   It include following families:
   1. Family- Tylenchulidae : eg. *Tylenchulus, Paratylenchus*
   2. Family- Sphaeronematidae: eg. *Trophonema, Sphaeronema*
   3. Family- Meloidoderitidae: eg. *meloidoderita*

B. Order- Aphlenchida

I. The dorsal oesophageal gland opens within the median bulb of oesophagus.
II. The males are without caudal alae except in Aphlenchus and Metaaphlenchus.
III. The median bulb is angular and occupying the entire body diameter.

The order Aphlenchida is redivided into one suborders namely- Aphelenchina and two
super families as follows:

1. Super family- Aphelenchoidea
2. Super family- Aphelenchidoidea

A. Super family- Aphelenchoidea

I. The males are with bursa, spicules of normal shape and gubernaculums is present.
II. The oesophageal glands may form long overlapping lobe or may not overlap the intestine.
III. The lateral line with 6 to 14 striae at mid body.

It include following families:

1. Family- Aphelenchidae : eg. Aphelench*us*
2. Family- Paraphelenchidae: eg. *Paraphelenchus*

B. Super family- Aphelenchidoidea

I. The spicules are thorne shaped and gubernaculums is present.
II. The stylet is with or without basal knobs.
III. The oesophageal glands forming long overlapping lobe on dorsal side of intestine.
IV. The lateral lines are four or less in number.

It include following families:

1. Family- Aphelenchoididae : eg. *Aphelenchoides, Rhadinaphelenchus.*
2. Family- Anomyctidae: eg. *Anomyctus*
3. Family- Entaphelenchidae: eg. *Entaphelenchus*

C. **Order- Dorylaimida**

I. The stroma is with mural tooth or an axial spear called as odanto or onchio stylet.
II. Two part oesophagus in which the anterior part is slender and the posterior part expanded with 3 to 5 gland nuclei.
III. The amphids are of variable shape.
IV. The gland duct opens posterior to nerve ring.

The order Dorylaimida is redivided into two suborders namely- Dorylaimina and Diphtherophorina.

Sub order- Dorylaimina

i. The amphids are slit or pore like.
ii. The anterior part of oesophagus is a narrow tube encircled by nerve ring while posterior part swollen and muscular.
iii. Stoma is provided with odontostylet.
iv. The excretory duct is absent or weakly developed.
v. The males are with paired testes, prominent spicules but gubernaculums absent.

This suborder includes 5 super families out of which Longidoroidea contains plant parasitic nematodes:

1. Dorylaimoidea
2. Actinolaimoidea
3. Leptochoidea
4. Belondiroidea
5. Longidoroidea

Super family- Longodoroidea

I. The males and females have similar tails.
II. The spear is greatly attenuated with long extensions.
III. The posterior enlarged part of the oesophagus is reduced in length.
IV. One pair of subventral gland nuclei in the posterior oesophagus.

It include following families:

1. Family- Longidoridae : eg. *Longidorus*

2. Family- Xiphinematidae: eg. *Xiphinema*
3. Family : Xiphidoridae : eg. *Xiphidorus*

Sub order- Diphtherophorina

i. The amphids are postlabial and pouch like.
ii. Plump body and cuticle is thick and loose.
iii. Onchiostylet is composed of dorsal tooth and supporting structures.
iv. The anterior portion of oesophagus is a narrow while posterior part swollen and pyriform to elongate.
v. The basal bulb provided with one dorsal and two subventral uninucleate glands.
vi. The excretory pore is present.
vii. The females are with paired reflexed ovaries. The amles are with single testis with spicules and gubernaculums.

This suborder includes 2 super families.

1. Trichodoroidea- Contains plant parasitic nematodes.
2. Diphterophoroidea

Super family- Trichodoroidea

I. Anterior portion of oesophagus is narrow and cylindrical while posterior portion is expanded.
II. The anterior tip of a dorsal tooth formed by cell in anterior oesophagus, is solid and strong, while posterior portion of stylet is hollow.
III. The males are with single testis, spicules are simple and curved.
IV. The female is with one or two ovaries.

It include Familu Trichodoridae which contains genera *Trichodorus* and *Paratrichodorus*.

General Morphology of Nematodes

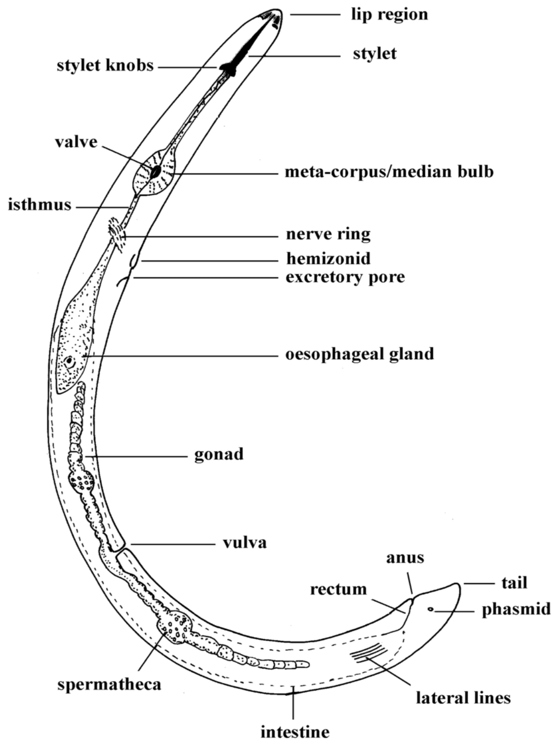
Nematodes have adopted themselves to all the environment but they are similar in morphology and life stages. Certain basic principles are common to all nematodes. Nematodes are triploblastic, bilaterally symmetrical. Un segmented, Pseudocoelomate, vermiform and clourless animals. The plant parasitic nematodes are slender elongate, spindle shaped or fusiform, tapering towards both ends and circular in cross section. The length of the nematode may vary from 0.2 mm to about 11.0 mm (*Paralongidorus maxximus*) and the body width vary from 0.01 to 0.05 mm. In few genera, the females on maturity assume pear shape (Meloidogyne), globular shape (Globodera), reniform (*Rotylenchulus reniformis)* or saccate (*Tylenchulus semipenetrans*). Radially symmetric traits (triradiate, tetraradiate and hexaradiate) exist in the anterior region. The regions of intestine, excretory and reproductive systems show tendencies towards asymmetry. The nematodes have one or two tubular gonads which open separately in the female and into the rectum in the male which also have the copulatory structures.

The free living saprophytic nematodes are generally larger in size. The animal and human parasitic helminthes may have length of few centimeters to even a meteer or more.

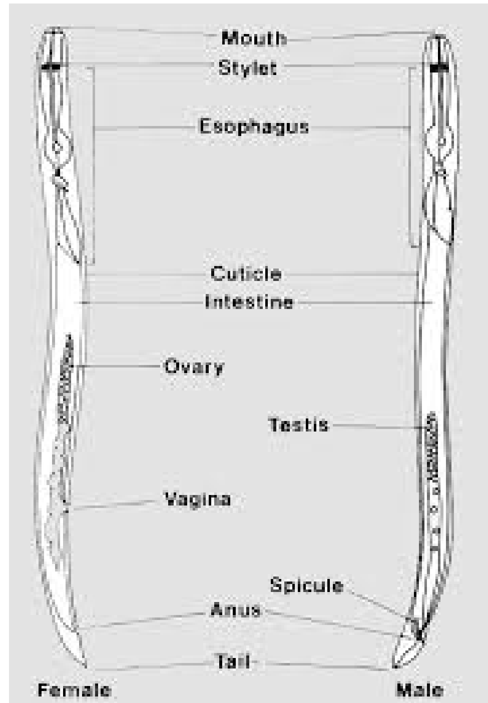
The anterior end starts with the head, which consists of mouth and pharynx bearing the cephalic papillae or setae. The portion between the head and the oesophagus is known as the neck. Beginning at the anus and extending to the posterior terminus is the tail.

Longitudinally the body is divided into four regions as dorsal, right lateral, left and ventral. All the natural openings like vulva, excretory pore and anus are located in the vental region. The Nematodes do not possess a specialized circulatory or respiratory system.

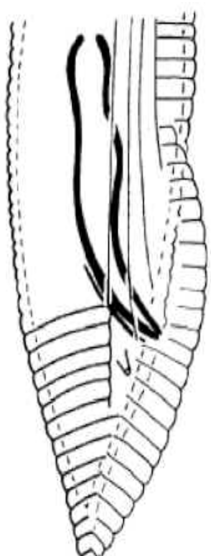
The nematode body is divided into three regions. They are the outer body tube or body wall, inner body tube (digestive tract) and body cavity or pseudococoelome. General morphology of different parts of nematode is depicted in Fig. 1 and 2.



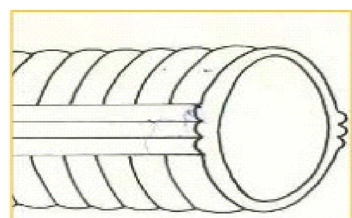
The-important-morphological-features-of-a-plant-parasitic-nematode



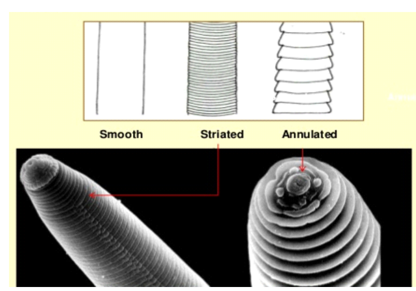
Female and Male nematode



Caudal alae

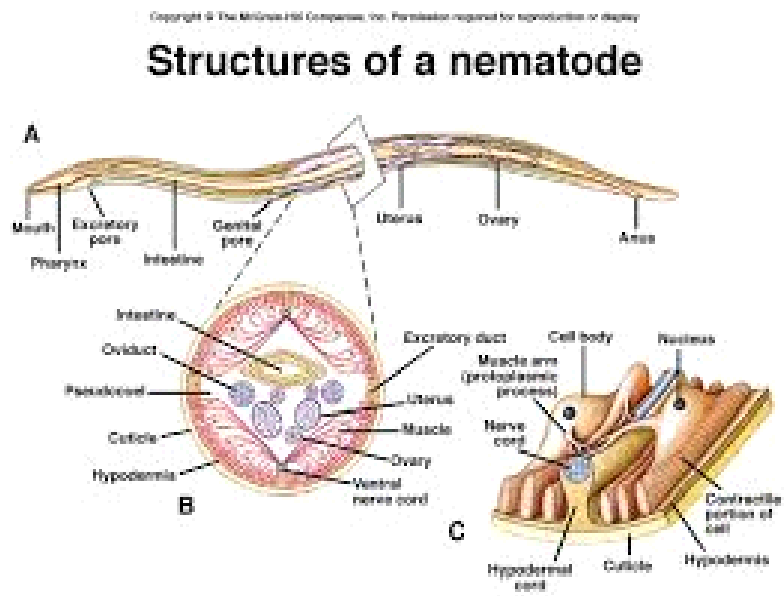


Longitudinal markings

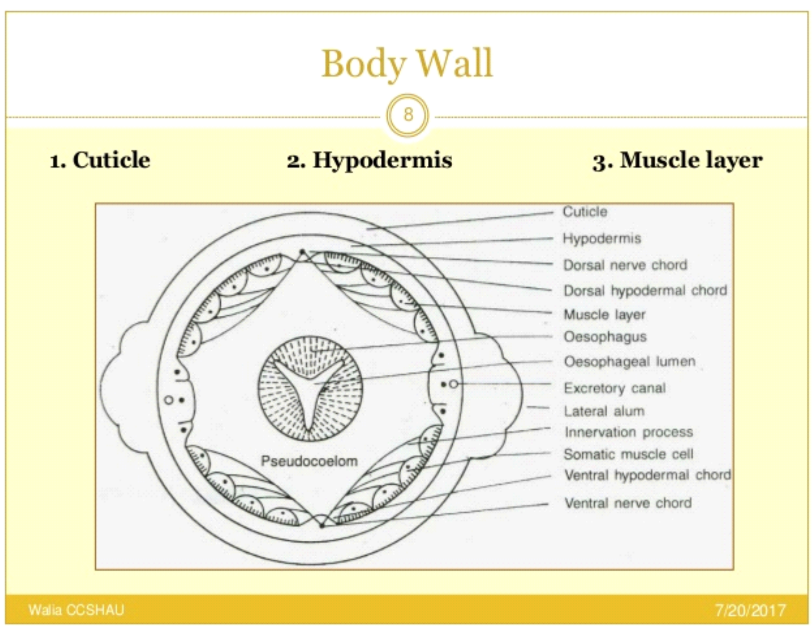


Transverse marking or Striations

Fig. 1: General morphology of plant parasitic nematode



Cuticle



Bodywall of nematode

Fig. 2: Structure of bodywall and cuticle of plant parasitic nematode

The outer body tube

The outer body tube or body wall includes the cuticle, hypodermis, and somatic muscles. The body wall protects the nematode from the harsh external environment, serves as the exoskeleton and provides the mechanism for movement of the organism through the soil and plant tissue.

The cuticle: The Cuticle is a non living, non cellular, triple – layered covering secreted by the underlying hypodermis. The cuticle is flexible. It covers the entire body and lines the oesophagus, vulva, anus, cloaca, excretory pore and sensory organs. The feeding stylet and copulatory spicules are formed from cuticle.

The composition and from of the cuticle is highly variable. In general the cuticle is composed of three primary zones viz., the cortical layer, median layer and basal layer.

The cuticle of may nematodes have markings on the surface. They are varied and complex and have been often used by taxonomists to assist in the identification of various species. The cuticular makings are categorized into different following types.

I. Punctuations

These are minute, round dots arranged in a pattern. They act as structures for strengthening the cuticle.

II. Transverse marking or Striations

There are transverse lines present on the surface of the cuticle. These markings exhibit distinct variations among the plant parasitic nematodes and often used by the taxonomists for identification. The transverse markings cause a pattern of ridges and furrows right from head to tail and theses markings gives the false appearance as if the nematode is segmented.

III. Longitudinal markings

These markings are the lines on the cuticle, which runs longitudinally throughout the length of the nematode body. These markings are divided into **a) lateral lines or incisures and b) longitudinal ridges.**

a) Lateral lines or Incisures

These are lines running longitudinal to the body axis of nematode but they are confined to the lateral field in area just on top of lateral hypodermal chords on either side of the nematode body running throughout the length.

b) Longitudinal ridges

Longitudinal ridges are raised lines present on cuticle running longitudinal to nematode body axis but are confined in the area other than lateral field.

Alae are thickening or projections of the cuticle which occur in the lateral or sublateral region. There are 3 types of alae I. Caudal alae II. Cervical alae and III. Longitudinal alae.

I. Caudal alae

These are found in the posterior region and restricted to males as copulatory bursa.

II Cervical alae

These are confined to the anterior part of the nematode body and are found in some species of marine nematodes.

III. Longitudinal alae

The longitudinal alae delimit the later fields and are known as lateral alae. Their form varies in different species. They are transverse by striations or furrow varying in number from 1 to 12. Functionally they probably assist in locomotion.

The functions of cuticle

Cuticle gives definite shape and size to the body, act as an exoskeleton, helps in movement it functions as a semipermeable membrane.

Somatic musculature

Platymyrian

A flat type of cell with contractile elements limited in places to the base lying close to the epidermis.

Coleomyarian

'U' shaped cells in which muscle fibre are adjacent and perpendicular to the hypodermis and extend along the sides of the muscle cell of varying distances.

Circomyarina

This type of muscle cells are almost round and the muscle fibres completely surround the cytoplasm.

The platymyarian muscle cell is considered primitive which might have modified into coelomyarian type of narrowing and upward elongation of the fibrillar zone. Muscle cells are connected to each other by means of cytoplasmic bridges and have nerve connections.

Mode of Reproduction

Bisexual species: Bisexual species usually have equal numbers of females and males. Insemination by a male and egg fertilization is necessary of the development of the eggs in such forms.

Hermaphroditic species: In hermaphroditic species, reproduction through self fertilization occurs. Hermaphroditic nematodes have the appearance of females. Hermaphroditism is common among the free-living *Rhabditida*.

Syngonic: Syngonic sperm and eggs are produced in the same gonad. In most cases, the gonad first produces sperm that are stored and later fertilize the eggs subsequently developed by the same gonad (protandry).

Parthenogenesis: In parthenogenesis, the eggs develop without fertilization. Parthenogenesis has been proved for a number of free-living nematodes. It is also known to occur in plant parasites of the genera *Meloidogyne* and *Heterodera*.

Intersexes: intersex is an individual that exhibits a blending of male and female characters. The possessed well-developed ovaries with uteri, vagina, and vulva. In addition they had developed to some extent male sexual openings, spicules, brusal muscles, and male genital papillae.

Above and Below Ground Symptoms Caused by Nematodes

A successful host parasite relationship results in appearance of symptoms on host plant. Symptoms are generally non-specific like poor growth, stunting, discoloration of foliage and patchiness of crop stand. Symptoms caused by plant parasitic nematodes are shown in Figures 3 and 4.

Symptoms of injuries caused by plant parasitic nematodes can be classified as

I. Above ground symptoms
II. Below ground symptoms

I. Above ground symptoms

Leaf discoloration: The leaf tip become white in rice due to rice white tip nematode *Aphelenchoides besseyi*, yellowing of leaves in Chrysantyhemum due to Chrysanthemus foliar nematodes, *A. ritzemabosi.*

Dead or devitalized buds: The nematodes affect the growing point and kill the buds and stopping growth of affected tissues as in case of strawberry infected by *A. fragariae.*

Seed galls: In wheat, *Anguina tritici* larva enter into the flower primordium and develop into a gall.

Twisting of leaves and stem: The basal leaves become twisted due to nematode infection as in onion infected with *Ditylenchus. angustus*.

Crinkled or distorted stem and foliage: The wheat seed gall nematode. A tritici infests the growing point as a result distortions in stem and leaves take place.

Necrosis and discoloration: Discoloration of foliage and stem may range from light to dark shades. Due to *Rahadinaphelenchus cocophilus* produces band of necrotic tissue on coconut.

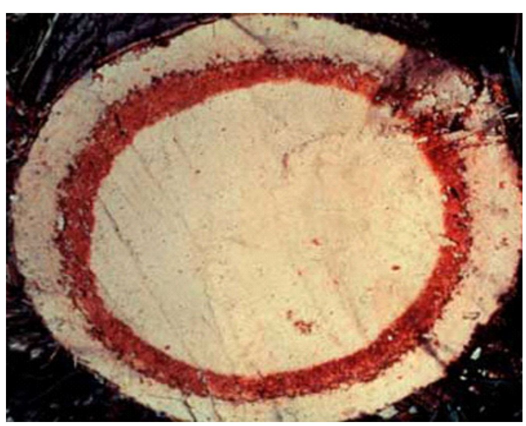
Lesions on leaves and stem: Small yellowish spots are produced on onion stem and leaves due D.dipsaci, and the leaf lesion caused by *A. ritzemabosi* on hrysanthemum.

A. ritzemabosi on Chrysanthemum

Aphelenchoides fragariae-infected-strawberry

Chrysanthemum foliar nematode

Ditylenchus destructor cause root rot



Rahadinaphelenchus cocophilus on coconut

Root galls or knots

Fig. 3: Symptoms caused by plant parasitic nematodes

II. Below ground symptoms

Nematode produces a wide range of symptom on underground parts of the plants which may be specific or non specific types.

Stunting: Plant growth is reduced and the plants are not able to withstand adverse conditions. Patches of stunted plants appears in the field. (eg.) in potato due to *Globodera rostochiensis*, in gingelly, due *to Heterodera cajani* and in wheat by *Heterodera avenae*.

Wilting: Day wilting due to *Meloidogyne* spp. i.e. In hot weather the root – knot infested plants tend to droop or wilt even in the presence of enough moisture in the soil. Severe damage to the root system due to nematode infestation leads to day wilting of plants.

Root galls or knots: The characteristic root galls are produced by root- knot nematode, *Meloidogyne* spp. The size and number of galls may vary with host crop and nematode sp.

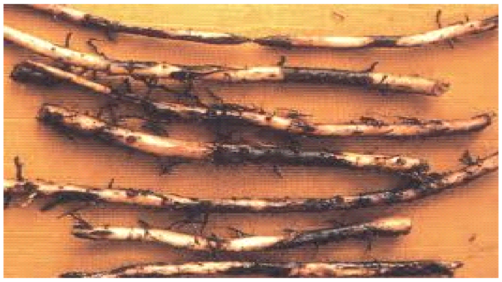
Root lesion: The penetration and movement of nematodes in the root causes typical root lesions eg. Necrotic lesions induced by *Pratylenchus* thornei on chickpea; the burrowing nematode, *Radopholus similes* in banana. *Helicotylenchus multicinctus* causes reddish brown lesion on banana roots. The rice root nematode produces brown lesions on rice root.

Curly tip: The nematode retards the elongation of roots and cause curling of roots known as "Fish book" symptom.

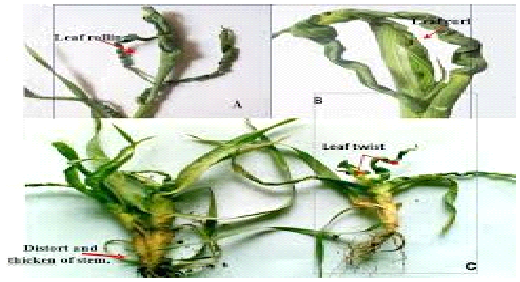
Root proliferation: Increase in the root growth or excessive branching due to nematode infestation. The infested plant root produced excessive root hairs at the point of nematode infestation. (eg.) *Heterodera* spp. *Meloidogyne hapla* and *Pratylenchus* spp. etc.

Root – rot: The nematode feeds on the fleshly structure of roots and resulting in rotting of tissues (eg.) *Ditylenchus destructor* cause root rot.

Root surface necrosis: Severe injury caused by nematodes lead to complete decortication of roots and result in root necrosis.



Radopholus similes in banana



Wheat seed gall nematode foliage

Wheat seed gall nematode

Wilting-and-drying-out-of-Bitter-Melon-caused-by-Meloidogyne-incognita

Fig. 4: Symptoms caused by plant parasitic nematodes

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L. 14

Dispersal and survival of the Plant pathogens

Shikha Sharma
agri.shikha2oct@gmail.com
JNKVV, College of Agriculture, Waraseoni

Definition of Dispersal: Transport of spores or infectious body acting as a inoculums from one host to another host at various distance resulting in the spread of disease or in other word we can say that displacement of a plant pathogen from its place of origin or production to a suitable host or place where it can grow and futher establish is called dispersal or dissemination of the pathogen.

It is of two type

1. **Active/Direct/Autonomous**: The dispersal of plant pathogen takes place through soil, seed and planting material during normal agronomic operation.

Mechanism of Dispersal of plant pathogen

Active Dispersal: spore require some structural mechanism or physiological response which enable them to be thrown out with some force.

a. Liberation due to bursting of turgid cell: spores of ascomycota are liberated by this mechanism as asci are turgid cell which burst in regular manner violently liberated the spore.
b. Liberation due to round off of turgid cell: Separation of spore from the parent hypae, then violent discharge of spore is due to change in shape of turgid cell.eg occur in Sclerospora and acecia of rust fungi.
c. Ballistospore discharge: this type of discharge occur in basidiospore of rust and smut fungi as point of contact of the spore with the sterigmata a gas filled bubble appear and grow in few second to a definite size, then the spore is shot away carrying the bubble.
d. Liberation due to hygroscopic movement: this movement is caused by a sudden fall in humidity which results in drying of sporophore bearing the spore eg.

Sporangia of *Phytophthora infestans* and also in Peronospora ospora in which collapse of sap filled turgid hyphae and their bursting responsible for violent discharge of spore.

2. **Passive/Indirect discharge :** The agency dislodging the spore is mainly the force from some outside source such as strong air current, raindrops, falling of spore mass, insect, workers etc.

1. Active/Direct/Autonomous:

(A)soil: it is of two type

(I)Dispersal in soil: soil borne pathogen *viz.,* facultative saprophytes or facultative parasite may be survive in soil or growth of pathogen in soil.The following are different stages

a)Contamination of soil: Introduction of the pathogen infested soil, plant debris, infested seed and planting material to a new area or contamination of the soil takes place by the spread of the pathogen from an infested area to new area.

b)Growth and spread of the pathogen in soil: Growth and spread of the pathogen depend on the virulent power of pathogen, high multiplication rate, adaptiblity to the soil environment including saprophytic survival ability and susceptibility of host and it is also depend on high growth rate, fast spore germination, good enzymatic activity, production of antibiotic and tolerance to antibiotic produce by soil microflora.The active saprophytic survival of Facultative saprophyte and facultative parasite in soilis affected by soil structure, moisture ,organic matter, pH, antagonism , however specialized facultative parasite survive in the ansence ofhost plant but they depend on the plant residue.the non specialized facultative parasite can whole life in the soil.eg. Pythium sp., and Phytopthora sp. Whereas., soil borne obligate parasite such as *Plasmodiophora brassicae* and *Synchytrichum endobioticum* require the presence of active host.

c)Persistence of the Pathogen: The pathogen persit in the soil as dormant structure like oospore as in *Pythium, Phytophthora,Sclerospora* and chlamydospore in *Fusarium .*

II) Dispersal by the soil : The pathogen enter the soil, grow, multiply and further spread in the soil. During the intercultural operation in the field,the propagule of fungal and bacterial structure present in soil spread takes place from one place to the other by tools, implements, feet of man and irrigation water.

(B)Seed and Seed Material: Dissemination of pathogen by seed and seed material is of great importance as it introduce the pathogen to new area where they may never existed before.The dormant structure of the pathogen viz., seed of Cuscuta, sclerotia of ergot fungus, smut sori are found mixed with seed lots and they are dispersed with seed lots and they are dispersed as seed contaminants. The fungal spores and bacterial cells are present on the seed coat and are transported to long distance and dormant mycelium of many fungi are also present in the seed is transmitted to long distances. Propagating material from infested nursery spread the pathogen to new area.

There are three types of dispersal by seeds:

i)Contaminated seed

ii)Externally seed borne

iii)Internally seed borne

i)Contaminated seed : Seed borne pathogens move in seed lot as separate contaminate without intimate contact with the viable crop seeds. The identity of the seeds of the host and parasite is difficult to separate eg smut of pearl millet *(Tolyposporium penicillariae*),ergot of rye and pearlmillet (*Claviceps purpurea* and *C. fusiformis* respectively. Smut sori and ergot mix easily with the seed lot during harvesting and threshing. Also in 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 (*Entyloma oryzae*) leaf pieces containing smut sori are mixed with the seed.

ii)Externally seed borne: Close contact between structure of the pathogen and seeds in established in diseases like covered smut and loose smut VI Daney, snoll smut of sorghum, stinking smut of wheat and bacterial blight of cotton where the pathogen gets lodged in the form of dormant 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.

iii)Internally seed-borne: The Internally seed-borne pathogen may penetrate into the ovary and cause infection of the embryo, while it is developing. Example of internally seed borne pathogens like *Ustilago nuda tritici* are viable for more than 15 years. Other example are of *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. *compestris* on *crufifers*, 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/Indirect

Passive dispersal of plant pathogens occurs through

1. **Animate agents**
   - b. Insects
   - c. Mites
   - d. Fungi
   - e. Nematodes
   - f. Human beings
   - g. Farm and wild animals
   - h. Birds
   - i. Phanerogamic parasites
2. **Inanimate agents**
   - a. Wind
   - b. Water

Insect: plant pathogens are carried by insect either externally (epizoic) or internally(endozoic). The external transmission of plant pathogens occur in those fungi, which produce their conidia, oidia and spermatia in sweet or honey secretions having attractive odours, the Sclerotinia brown rot of pear and apple, the honey dew stage in the 'sugary disease' of sorghum and pearl millet in part of India and the pycnial nectar in the cluster cup stage of rust. The spermatial oozing at the mouth of spermagonia in the ascomycetes attract various types of insects, flies, pollinating bees and wasps which play a dual role *viz.* pollination and transmission of pathogens. The fire blight organism (*Erwinia amylovara*) 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* in 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 However, Ingenious transmission of pathogens, of an internal nature (endozoic) is provided by the Dutch elm disease (*Ceratostomella ulmi*) and 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.

The cucumber wilt bacterium, *Erwinia tracheiphila* is spread by the striped cucumber beetles (*Acalymma vitata*) and the spotted cucumber beetle (*Diabrotica undecimpunctata*). Different types of insects spread more than 80 percent of the viral and phytoplasmal diseases.

Aphids

Aphids are the most important insect vectors of plant viruses and transmit the great majority of all stylet-borne viruses.. Aphids generally acquire the stylet-borne virus after feeding on a diseased plant for only a few second (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.Eg *Acyrthosiphon pisum non persistently transmitted* bean common mosaic virus and *Toxoptera citricida also transmitted nonpersistantly* Citrus tristeza virus.

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 mouth 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.

Mites

Mites belonging to the families eriophyidae (eriophid mite) and tetranychidae (spider mite) transmit plant viruses.

. Fungi

Some soil-borne fungal plant pathogens transmit plant viruses. *Olpidium brassicae, ploymyxa graminis* and spongospora subterranea are the fungi involved in transmission of virus disease. 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.

Nematodes

Nematodes act as agents for dissemination of pathogenic fungi, bacteria and viruses. Nematodes help these pathogenic fungi to enter into the host though punctures for their own entry into host 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 plant and then moving on roots of healthy plants. Larvae as well as adult nematodes can acquire and transmit virus, but the virus is not carried through the larval molts or though 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 For example *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. *Paratrichodorous* sp carry pea early browning Tobacco rattle virus, *Xiphinema index carry* Grape vine chrome virus (NEPO virus)

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.The means by which human beings help in dispersal are as follows.

i. Transportation of seeds

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. The disease 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 bunchy top of banana.

ii. Planting diseased seed materials (vegetatively propagated materials)

Planting diseased bulbs, corms, 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 form one country to another.

iii. By adopting farming practices

Human being (men and women) engaged in preparatory cultivation, planting, irrigation, weeding, pruning etc. help in dispersal of plant pathogens. The spores (*oospores, chlamydospores*), dormant structure like sclerotia are carried by worker's clothing, shoes, hand etc. from field to field.

iv. Through clothing

Through clothing of workers plant pathogen are also disseminate. eg.Palm workers engaged in cleaning coconut trees spread bud rot disease.

v. By use of contaminated implements

Pathogens are transferred from one area to another by implements used in various cultural operations (weeding, hoeing, thinning etc.) in the field. e.g. root rot of pulses and cotton *(Macrophomina phaseolina,* bacterial angular leaf spot of cucumber *(Pseudomonas /achrymans)*

and bacterial canker of tomato *(Corynebacterium michiganensis).* Cutting 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 is the most effective method of distribution of pathogens of horticultural crops (fruit trees, ornamental etc.) e.g. selection of infected stocks and scions in propagation of h.orticultural helps in the dissemination of pathogen.

f. Farm and wild animals

Farm animals (cattles) while feeding on diseased fodder ingest the viable fungal propagules (spores of oospores or sclerotia) in to their digestive system. Animals which feed on downy mildew affected pearl millet 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 incolum, 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.

Stem of dodder (*cuscuta* spp.) are carried by birds for building their nests. Thus the phanerogamic parasites are getting transported to new location.

h.Phanerogamic parasites

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. Example **Short distance dissemination** occur iby sporangia of downy mildew fungi, conidia of powdery mildew fungi and basidiospores of rust fungi. Where as long distance dessimination in Uredospores of rust fungi, Chlamydospores of smut fungi conidia of *Alternaria*, *Helminthosporium and pyricularia.* However, 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.

b. Water

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.

Survival of plant pathogen

The means of survival are the first link in the infection chain or the disease cycle. Any pathogen can cause disease under favorable conditions. The only important 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 come in contact to the host is called inoculum. The initial infection that occurs from these sources in the crop are called **primary infection** and the propagules are called **primary inoculum.**The pathogens find some alternates source of their survival to maintain the infection chain in the absence of their cultivated host. After initiation of the disease in the crop, the spores or cells or other structures of the pathogen are sources of secondary inoculums and cause secondary infection. The primary infection initiate the disease and secondary infection spread the disease Fungal pathogens are highly diversified, where the hyphae, Dormant mycelium either embedded in the embryo of seeds or other part of the plants, special reproductive structures viz., rhizomorphs, sclerotia, chlamydospores, various types of asexual spores like sporangia, soprangiospores, zoospores, conidia and sexual spores as oospores, zygospores, resting spores, ascospores, basidiospores, etc. , serve as inoculum. In case of viruses and plant pathogenic bacteria, the individuals are acting as inoculum, since they do not produce any special type of infective units like resting spoes or endospores, etc. however in *Streptomyces* sp. (Actinomycetes), fragments of filaments and spore-like cells serve as inoculum. In phanerogamic parasites, seeds are the potential inoculum.The existence of the pathogen between the two crop seasons is the vulnerable period in its life cycle. Hence knowledge of the survival of the pathogen in the off-season is useful for the plant pathologists to suggest suitable management practices.

These sources of survival of pathogens can be grouped as follows:

1. Survival by means infected plant parts.
2. Survival as saprophytes.
3. Survival by means of specialized resting structures
4. Survival in association with nematodes and fungi.
5. Survival in association with insects.

6. Survival in association with phanerogamic plant parasites
7. Survival on agricultural materials.
8. Survival on surface water.

1 Survival in Infected plant parts

plant pathogens structure, mycelium survive in infected crop plants part *viz,* leaves, stem, pod, seeds etc from few month to years as reservoir of primary inoculum eg. *Colletotrichum lindemuthinum*, the causative organism of bean anthracnose**.**

a. Alternate hosts: Pathogen having wide host-range and also tolerant to wide range of weather conditions, the alternate hosts become very important source of survival of the pathogen. Black rust of wheat caused by *Puccinia graminis tritici* require alternate host *Berberis vulgaris,* the barberry bush, grows side by side with wheat for the completion of the life cycle of heteroecious, rust pathogen in temperate In such areas this wild host belonging to different family is important for survival of the fungus. Where as *Thalictrum flavum* is alternate host for the brown rust of wheat caused by *Puccinia recondita* .

b. Collateral hosts: Collateral hosts are the wild host of same family, which are susceptible to the plant pathogens of crop plant and provide adequate facilities for their growth and reproduction of these pathogenring off-seseaon and help in the survival. For example, blast disease of paddy , *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.

c. Self sown crops : Self-sown plants, voluntary crops and early sown crops are reservoirs of many plant pathogens e.g. groundnut rust pathogen, *Puccinia arahidis* 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*.

d. Perennial crop : also play a 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 dominant. Example 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.

e. Ratoon Crops: 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.

g. Survival as residents : Plant pathogenic bacteria have the capacity to grow on the surface of host and non-host plant utilizing the small amount of nutrients that are secreted on the plant surface. Eg. Fire blight of apple and pear caused by Erwinia amylovora and bacterial blight of soybean caused by *Pseudomonas syringae* pv. *Glycinea*.

2- Survival as saprophytes : In the absence of the living host ,the facultative parasites are capable of surviving as saprophytes. Soil and plant debris serve as media for this saprophytic survival. Spp. of *Pythium, Sclerotium* etc. resting structure like oospores and sclerotia.In *Pythium aphanidermatum (*foot rot of papaya), the fungus rapidly forming oospores. *S. rolfsii*, Sclerotia are formed and these can germinate under decaying residues

3.Survival by means of specialized resting structures

Plant pathogens survive as dormant spores like conidia, perithesia etc and other dormant structure such as chlamydospores, oospore and sclerotia. 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 uredospores and teliospores of certain rust fungi also are important enduring structures.

4. Survival in association with nematodes and fungi

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*. *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.

5. Survival in association with insects

Insects are carriers of inoculum during growing season and plant pathogens survive between growing seasons within insects. Some bacterial plant pathogens may survive within the insect body and over winter therein. Example corn flea beetle, *Chaetocnema pulicaria* Melsh carries inside its body, the corn 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 *Erwinia tracheiphila* carry the pathogen inside their body, where it over winters.

5.Survival in association with phanerogamic plant parasites : *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.

Loranthus and striga also help in survival of pathogen. phanerogamic parasite also helps in the survival of plant pathogens during on and off-season.

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 15months 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.

L. 15

Parasitism and Variability in Plant Pathogens

Ashish Kumar Tripathi
aktjnkvv@gmail.com
Krishi Vigyan Kendra, Panna

Parasitism is a type of symbiotic relationship, or long-term relationship between two species, where one member, the parasite, gains benefits that come at the expense of the host member. The word parasite comes from the Latin form of the Greek word *parasitos*, meaning “one who eats at the table of another”.

An organism that lives on or in some other organism and obtains its food from the latter is called a parasite. The removal of food by a parasite from its host is called parasitism. A plant parasite is an organism that becomes intimately associated with a plant and multiplies or grows at the expense of the plant. The removal by the parasite of nutrients and water from the host plant usually reduces efficiency in the normal growth of the plant and becomes detrimental to the further development and reproduction of the plant.

In many cases, parasitism is intimately associated with pathogenicity, i.e., the ability of a pathogen to cause disease, as the ability of the parasite to invade and become established in the host generally results in the development of a diseased condition in the host. In some cases of parasitism, as with the root nodule bacteria of legume plants and the mycorrhizal infection of feeder roots of most flowering plants, both the plant and the microorganism benefit from the association. This phenomenon is known as symbiosis. In most plant diseases, however, the amount of damage caused to plants is often much greater than would be expected from the mere removal of nutrients by the parasite. This additional damage results from substances secreted by the parasite or produced by the host in response to stimuli originating in the parasite. Tissues affected by such substances may show increased respiration, disintegration or collapse of cells, wilting, abscission, abnormal cell division and enlargement, and degeneration of specific components such as chlorophyll. These conditions in themselves do not seem directly to improve the welfare of the parasite. It would appear, therefore, that the damage caused by a parasite is not always proportional to the nutrients removed by the parasite from its host. Pathogenicity, then, is the ability of the parasite to interfere with one or more of the essential functions of the plant, thereby causing disease. Parasitism frequently plays an important, but not always the most important, role in pathogenicity. Of the large number of groups of living organisms, only a few members of a few groups can parasitize plants: fungi, bacteria, mollicutes, parasitic higher plants, parasitic green algae, nematodes, protozoa, viruses, and viroids. These parasites are successful because they can invade a host plant, feed and proliferate in it, and withstand the conditions in which the host lives. Some parasites, including viruses, viroids, mollicutes, some fastidious bacteria, nematodes, protozoa, and fungi causing downy mildews, powdery mildews, and rusts, are biotrophs, i.e., they can grow and reproduce in nature only in living hosts, and they are called obligate parasites. Other parasites (most fungi and bacteria) can live on either living or dead hosts and on various nutrient media, and they are therefore called nonobligate parasites. Some nonobligate parasites live most of the time or most of their life cycles as parasites, but, under certain conditions, may grow saprophytically on dead organic matter; such parasites are semibiotrophs and are called facultative saprophytes. Others live most of the time and thrive well on dead organic matter (necrotrophs) but, under certain circumstances, may attack living plants and become parasitic; these parasites are called facultative parasites. he association of these pathogens with their host cells is an intimate one and results in continuous absorption or diversion of nutrients, which would normally be utilized by the host, into the body of the parasite. The depletion of nutrients, however, although it restricts the growth of the host and causes symptoms, does not always kill the host. In the case of obligate parasites, death of the host cells restricts the further development of the parasite and may result in its death. Parasitism of cultivated crops is a common phenomenon. About 2,500 species of higher plants are parasitic on other plants, only a few of them are serious parasites of crop plants. A single crop, e.g., the tomato, may be attacked by more than 40 species of fungi, 7 bacteria, 16 viruses, several mollicutes, and several nematodes. This number of diseases is average as corn has 100, wheat 80, and apple and potato each are susceptible to about 80–100 diseases. Fortunately, however, in any given location, only a fraction of the diseases affecting a crop are present and, in any given year, only a small number of these diseases become severe.

Types of Parasitism

There are many types of parasitism, and parasites can belong to multiple classifications based on their size, characteristics, and relationship with the host.

1) Symbiosis : Tow living organisms may live in association with one aother and in a sense, each may be Parasitic upon the other. However they are not only non-pathogenic to one another, but are also essential to each other's development or at least each is beneficial to the other's development. this phenomenon is known as symbiosis. Lichens are classical examples of symbiosis in which a fungus and an alga live in close association. the alga, through its photosynthetic activity, converts the kinetic energy of the sun's rays into the potential energy of carbohydrates which is useful for its own development and essential to the life of the fungus. The latter, through its property of producing hydrolytic enzymes, breaks down material in the substrate, and thus makes energy available and provides minerals and organic nutrients essential to itself and the alga. another case of symbiosis is that of the Rhizobium species forming root nodules in leguminous plants.

2) Obligate Parasites : There are various categories of parasitism. Parasites which are restricted tc living tissues (also known as biotrophs) are called obligate parasites. Obligate is also used to denote those parasites which have not been grown in axenic cultures, that is, free from any other organism.

3) Facultative Saprophytes: The term faculties is both cumbersome and confusing Comprehension of the phrase facultative saprophytic requires a mental pause for translation to strongly parasitic. Facultative saprophytic requires a mental pause for

translation to strongly parasitic. Facultative saprophytes ordinarily have a life cycles similar to that f obligate parasites, in that they pass most of the cycle in association with the host and do not subsist as saprophytes. They may, however, subsist as saprophytes for part of their life cycle, but do not complete their life cycle away from the host.

4) Facultative parasites: This term implies that they are ordinarily saprophytic but under certain conditions they may become parasitic. Many damping off fungi, such as pythium and Rhizoctonia are good examples of this.

5) Saprophytes: Saprophytes are those organisms which have no relation with the living cell and secure their nutrients from dead organic tissues or from available inorganic materials.

In fact, a number of fungi, once considered to be obligate parasites, have been cultured away from their hosts on artificial media. This makes the term obligate inappropriate. Luttrell (1970) recognizes three categories of parasitism which are as follows.

1) Biotrophs: There are those organisms which, regardless of the ease with which they can be cultured in nature, obtain their food from the living tissues on which they complete their life cycles. Some Typical examples are rusts, smuts and mildews.

2) Hemibiotrophs: These are organisms which attack living tissues in the same way as biotrophs but continue to develop and sporulate after the tissue is dead. Typical example of these is leaf-spotting fungi.

3) Perthotrophs: These are organisms which kill host tissues in advance of penetration and then live saprophytically. *Sclerotium rolfsii* is a typical fungus included in this category.

Variability in Plant Pathogens

Variability is the property of an organism to change its characters from one generation to the others. In nature, variability in organism may be due to hybridization and Mutation. In fungi, variability occurs through heterokaryosis, recombination, paraxesuality, mutation and cytoplasmic adaptation.

- Variation: when progeny of an individual show variation in characters from parents such a progeny is called a variant.
- Pathotype: A pathotype is a population of a parasite species in which all individuals have a stated pathosystem character (pathogenicity or parasitic ability) in common.
- Biotype: progeny developed by variant having similar heredity is called a biotype or a subgroup of individuals with in the species, usually characterized by the possession of single or few characters in common.

Stages of Variation in pathogens

• Certain common traits in organism make up- species e.g *Puccina graminis.* In species some individual attack only some host genera e.g. wheat, barley, oats, this give rise to group – f.sp. *Puccina graminis* f.sp. *tritici*, F. *oxysporum* f.sp. *pisi*. With in species or f.sp. There are further subgroups of individual that infect different varieties of the host– such subgroups are called races/ strains. These may further have individuals that attack some new variety in severe form than others are Biotypes

Variability in fungi

In fungi, variability occurs through parasexualism, Mutation, Herterokaryosis, Recombination, and Heteroploidy

1) Parasexualism:

It is a process by which genetic recombination can occur with fungal heterokaryon. Parasexuality firstly demonstrated by Pontecorvo (1956) in Aspergillus nidulans. In parasexualism, dissimilar nuclei to fuse and produce diploids known as mitotic recombination. There is no fine coordination between plasmogamy, karyogamy and haploidism. Parasexuality has produced new races of *Fusarium oxysporum* f. sp. pisi, Ascochyta, Verticillium albo-atrum etc. Sequence of events in Parasexuality is as follows:

i) Formation of dikaryotic mycelium

ii) Fusion between two nuclei

iii) Multiplication of diploid nuclei side by side the haploid nuclei

iv) Occasional mitotic crossing over during the multiplication of diploid nuclei

v) Sorting out of diploid nuclei

vi) Occasional haploidization of the diploid nuclei

vii) Sorting out of the new haploid strain.

2) Mutation:

This refers sudden heritable change in genetic material of an organism. Mutation is more or less an abrupt change in genetic material of an organism or a virus, which is then transmitted in a hereditary fashion to the progeny. Mutations are spontaneous and represent change in sequence of the bases of DNA either by-substitution or by deletion or addition. Mutation may occur due to improper cell division or abnormalities during division or physical radiations or Mutagenic chemicals.

- Mutations in nature are less frequent and are result of infrequent changes that take place during cell division and result in irregularities in replication or rearrangement of minute parts of genetic material of the cells.
- Mutation can be induced artificially with increased frequency by physical agents like ultra violet rays, X-rays, gamma-rays or by chemicals like alkaloids, phenols etc.
- Most mutations are recessive; therefore in diploid organisms mutation remains unexpressed until they are brought together in a homozygous condition.
- Although frequency of mutation is low, but given the great number of progeny produced by pathogen, it is possible that large number of mutants differ in virulence from their parents.
- Mutation has been reported in *Cladosporium fulvum* causing tomato leaf mould, *Phytophthora infestans*, *Puccinia graminis* and *Melampsora lini*, apart from the appearance of highly destructive race T of *Heliminthosporium maydis*.

3) Heterokaryosis:

Heterokaryosis is occurrence of dissimilar or genetically different nuclei in a vegetative cell or spore or hypha as in basidiomycetes. Heterokaryosis is certainly a way in which avirulent strains may acquire virulence, for example in *Thanatephorus cucumeris*.

- It provides haploid organisms the ability or somatic flexibility with changing environment.
- It increases diversity as genetic recombination is brought about by interchanges of whole chromosome or through mitotic crossing-over.
- It plays an important role in homothallic and imperfect fungi.
- Heterokaryosis can arise by gene mutation or fusion of vegetative mycelium or at the time of spore formation in many fungi such as Neurospora tetrasperma, Podospora sp.

4) Recombination: Most changes in the characteristics of pathogens are the result of recombination occurs during sexual processes. When two haploid nuclei (1N) containing different genetic material unite to form diploid (2N) nucleus called a Zygote, when undergo meiotic division produce new haploid . Recombination of genetic factor occurs during meiotic division of zygote as a result of cross over in which part of chromatid of one chromosome of a pair are expressed with that of the other • Recombination can also occur during mitotic division of cell in the course of growth of the individual and is important in fungi *Puccinia graminis*.

5) Heteroploidy : Heteroploidy is the existence of cells tissues or whole organisms with numbers of chromosomes per nucleus. Heteroploids may be haploids, diploid, triploid or tetraploids i.e. have one or more extra chromosomes from normal euploid number e.g.N+1. This represents a normal situation in eukaryotes

Variability in Bacteria:

Variability in Bacteria may be occurs due to conjugation or transformation or transduction. In conjugation, transfer of DNA from one bacterial cell to another donor cell (F+) transfers DNA to recipient cell (F-). In this process two compatible bacteria come in contact and exchange the portion of plasmid or chromosomes through Conjugation Bridge or pilus. In transformation, DNA taken up by the bacterial cell from external environment by absorption. In the process of transduction, bacterial genes transferred with a bacteriophage.

Variability in Viruses

Variability in viruses may be occurs due to recombination or results from mixed infection of two strains of the virus or during replication of viruses. Mutation also creates variability in viruses due to addition or deletion or replacement of nucleotide changes in the coding regions which ultimately leads to functional changes in the genes.

L. 16

Pathogenesis-role of enzyme, toxin, growth regulators in disease development

Pramod Kumar Gupta,
pkgtaxo@gmail.com
JNKVV, Jabalpur

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 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

Role of Enzymes in Disease development

Enzymes are generally large protein molecules that catalyze organic reactions in living cells and in solutions. Because most kinds of chemical reactions that occur in a cell are enzymatic, there are almost as many kinds of enzymes as there are chemical reactions. Each enzyme, being a protein, is coded for by a specific gene . 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.

Pectolytic Enzymes

Pectolytic enzymes are classified according to their catalytic activity and this is complicated by the fact that the substrate is heterogeneous. There are two mechanisms by which the linear chains of pectate or pectin are broken, hydrolysis and b -elimination, the latter giving rise to oligomers which are 4,5 unsaturated at the non-reducing end.

Plant Substances and Their Enzymatic Degradation

Aerial plant part surfaces consist primarily of cuticle and/or cellulose, whereas root cell wall surfaces consist only of cellulose. Cuticle consists of cutin, wax and covering of layer of wax. The lower part of cutin contains pectin, cellulose lamellae and a thin layer of pectic substances; below that there is a layer of cellulose (Acharya 1989).

Cuticular wax

Plant waxes are found as granular, blade, or rod-like projections or as continuous layers outside or within the cuticle of many aerial plant parts. The presence and condition of waxes at the leaf surface affect the degree of colonization of leaves and the effect varies with the plant species.

Cutin

The main component of the cuticle upper part is admixed with waxes. The lower part is admixed with pectin and cellulose. Cutin is insoluble polyester of 16- and 18-carbon hydroxy fatty acids. Many fungi and a few bacteria produce cutinases and/or nonspecific esterases, i.e., enzymes that can degrade cutin.

Pectic substances

Main components of the middle lamella, i.e., the intercellular cement that holds in place the cells of plant tissues. Also make up a large portion of the primary cell wall in which they form an amorphous gel filling the spaces between the cellulose microfibrils.

Pectic enzymes are regulated by diverse factors like the presence of pectin, growth phase, catabolite repression, plant extracts, temperature, anaerobiosis, iron limitation and nitrogen starvation.

Cellulose

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.

Cross-linking glycans (hemicelluloses)

The enzymatic breakdown of hemicelluloses requires the activity of many enzymes. Several hemicellulases seem to be produced by many plant pathogenic fungi. Since hemicelluloses are such a diverse group of polymers such as xyloglucans, glucomannans, glactomannans, arabinoglucans, etc.,

Suberin

Suberin is found in certain tissues of various underground organs, such as roots, tubers, and stolons, and in periderm layers, such as cork and bark tissues. Suberins are also formed in response to wounding and to pathogen-induced defenses of certain organs and cell types.

Lignin

Lignin found in the middle lamella, as well as in the secondary cell wall of xylem vessels and the fibres that strengthen plants. Also found in epidermal and occasionally hypodermal cell walls of some plants

Cell wall flavonoids

Flavonoids are a large class of phenolic compounds that occur in most plant tissues and, especially, in the vacuoles. Also occur as mixtures of single and polymeric components in various barks and heartwoods.

Cell wall structural proteins

Cell walls consist primarily of polysaccharides, i.e., cellulose fibres embedded in a matrix of hemicelluloses and pectin, but structural proteins, in the form of glycoproteins, may also form networks in the cell wall.

Enzymatic degradation of substances contained in plant cells

Most kinds of pathogens spend all or part of their lives in association with or inside the living protoplast. Some of the nutrients, e.g., sugars and amino acids are sufficiently small molecules to be absorbed by the pathogen directly.

Proteins

Plant cells contain innumerable different proteins, which play diverse roles as catalysts of cellular reactions (enzymes) or as structural material (in membranes and cell walls). The plant pathogenic enzymes involved in protein degradation are similar to those present in higher plants and animals

Starch

Starch is a glucose polymer and exists in two forms: **amylose**, an essentially linear molecule **amylopectin**, a highly branched molecule of various chain lengths .Most pathogens utilize starch and other reserve polysaccharides in their metabolic activities.

Lipids

Various types of lipids occur in all plant cells, with the most important being phospholipids and glycolipids, both of which, along with proteins, are the main constituents of all plant cell membranes. Several fungi, bacteria, and nematodes are known to be capable of degrading lipids. Lipolytic enzymes, called lipases, phospholipases, and hydrolyze the lipid molecules with liberation of the fatty acids.

Microbial Toxins in Plant Disease management

Toxins are extremely poisonous substances and are effective in very low concentrations. Fungi and bacteria may produce toxins in infected plants as well as in culture medium. Toxins injure host cells either by affecting the permeability of the cell membrane or by inactivating or inhibiting enzymes and subsequently interrupting the corresponding enzymatic reactions.

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*

Phaseolotoxin

Phaseolotoxin is produced by the bacterium *Pseudomonas syringae* pv. *phaseolicola*, the cause of halo blight of bean and some other legumes. Phaseolotoxin plays a major role in the virulence of the pathogen by interfering with or breaking the disease resistance of the host toward not only the halo blight bacterium, but also several other fungal, bacterial, and viral pathogens.

Tentoxin

Tentoxin is produced by the fungus *Alternaria alternata* (previously called *A. tenuis*), which causes spots and chlorosis in plants of many species.

Cercosporin

Cercosporin is produced by the fungus Cercospora and by several other fungi. It causes damaging leaf spot and blight diseases of many crop plants

Other non-host-specific toxins

Fumaric acid- produced by *Rhizopus* spp. in almond hull rot disease

Oxalic acid -*Sclerotium* and *Sclerotinia* spp. in various plants they infect and by *Cryphonectria parasitica*, the cause of chestnut blight

Alternaric acid, alternariol, and zinniol -*Alternaria* spp. in leaf spot diseases of various plants

Ceratoulmin- *Ophiostoma ulmi* in Dutch elm disease

Fusicoccin- *Fusicoccum amygdali* in the twig blight disease of almond and peach trees

Ophiobolin -several *Cochliobolus* spp. In diseases of grain crops

Pyricularin- *Pyricularia grisea* in rice blast disease

Fusaric acid and lycomarasmin -*Fusarium oxysporum* in tomato wilt

Victorin, or HV Toxin

Victorin, or HV-toxin is produced by the fungus *Cochliobolus* (*Helminthosporium*) *victoriae*, which causes Victoria blight of oats

Phytoalexins

Phytoalexins are toxic antimicrobial substances produced in appreciable amounts in plants only after stimulation by various types of phytopathogenic microorganisms or by chemical and mechanical injury. Phytoalexins are produced by healthy cells adjacent to localized damaged and necrotic cells in response to materials diffusing from the damaged cells.

Growth Regulators

The major groups of plant growth regulators are the auxins, gibberellins, kinins and ethylene.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.

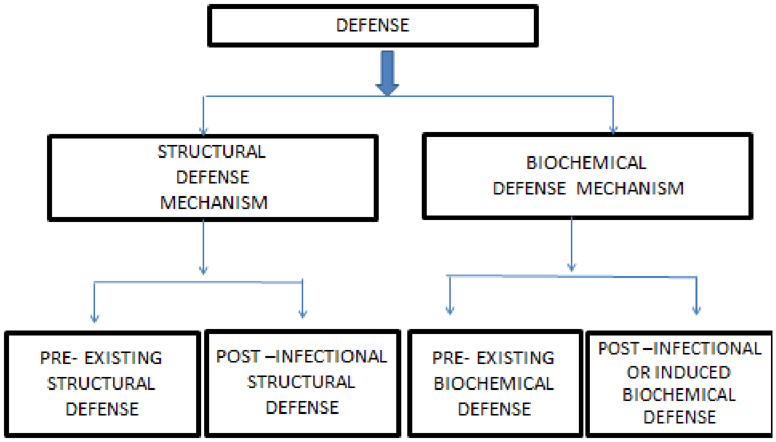
L. 17

Defense mechanism in plant

Dhananjay Kathal
dkathal@gmail.com
JNKVV, College of Aiculture, Waraseoni

Defense is action that is taken to protect someone or something against attack.

How a pathogen fails to infect the host plant? In general plants defend themselves either (i) By structural characteristics that act as physical barriers and inhibit the pathogen from gaining entrance and spreading through the plant, or (ii)by mean of biochemical reactions taking place in cell/ tissues to produce chemical substance that inhibit pathogen. Two thinks are relevant here. one, both structural and chemical defense may be used against pathogen at any stage of infection i.e. during prepenetration, or penetration or post penetration. Second, each of two lines of defense i.e. structural and chemical may be pre-existing (Passive) existing before infection or active i.e. originating in response in response to infection.



(I) Structural defense

1.) **Pre- existing defense structures.** The plant surface is the first line of defense. Such structures include (i) amount and quality of wax over the cuticle, (ii) thickness of the cuticle, (iii) structure of the epidermal cell walls,(IV) size, location and shapes of stomata and lenticels and (v) the presence of thick walled cells, trichomes and other such structures on plant surface that may hinder the pathogen's advance.

2.) **Post – inflectional structural defense .** Some physical barriers may develop in response to infection by the pathogen and these affect their entry into the host. Some of these actively formed structures are as follows:

a) Histological barriers. These include the following

i) Cork layers – Some bacteria, fungi, viruses and nematodes stimulate the host to form multilayered cork cells beyond the point of infection. These develop as a result of stimulation of host cells by substance secreted by the pathogen.

ii) Abscission layer – these develop on young active leaves of stone fruits infected by any of several fungi, bacteria or viruses. such layers developing at the point of infection ultimately help discarding the infected area along with a few healthy cells from the host part.

iii) **Tyloses-** These outgrowths of the protoplasts of adjacent live parenchyma cells protruding into xylem vessels through pits, are known to develop under stress and in response to invasion by vascular pathogen.

iv) **Gum deposition –** Plant produce variety of gummy substances around lesions in response to injury or infection. These are common in stone fruits. They are difficult to be invaded.

b) **Cellular structures-** These involve changes in the cell wall morphology, or other structures derived from the cell wall of the cell being invaded. these include (i) swelling of cell wall of epidermal and sub epidermal cells and (ii) sheathing of hyphae penetrating a cell wall by enveloping them in a sheath formed by extension of cell wall inward in a way surrounds and precedes the invading hypha.

c) **Cytoplasmic defense reaction** - Some such reactions include the appearance of some structures in the cytoplasm.

d) **Hypersensitivity -** In some host pathogen combinations, nucleus moves towards the invading point and soon disintegrates. Resins like granule develop in cytoplasm, resulting into death of plant cell. This leads to degeneration of the pathogen structure- a fungal hypha.

(II) Biochemical defense

Although structure barriers may protect plants from attack by their pathogens, the defense is less effective than the chemical substances produce in their cells before or after infection. This become apparent from the fact that a particular pathogen will not infect certain plant varieties even through no structural barriers of kind seem to be present or to form in these varieties.

1. **Pre- existing biochemical defense-** The various pre- existing lines of biochemical defense are as follows

a) **Inhibitors released by the plant in its environment –**Plant exudate a variety of substances through the surfaces of their aboveground (aerial) part in the phyllosphere as well as through the surfaces of their roots in the rhizosphere. Some of the compounds released by some kinds of plants are shown to have an inhibitory effect on certain pathogens (particularly during penetration phase). for instance fungitoxic exudates on the leaves of tomato and sugar beet inhibit the germination of the spores of their pathogen, Botrytis and Cercospora respectively.

b) **Defense through lack of essential factors-** A range of the factors must be available to the pathogen. Lack of some of these may result into protection of plant surface.

   (i) **Lack of recognition between host and pathogen-** Plant surfaces lacking specific recognition factors(specific molecules/structures) that can be recognized by the pathogen may not become infected. Pathogen fails to recognize the plant as one of its hosts, and thus not become attached to plant or may not produce structures/ chemicals (appressoria, infection peg, enzymes, toxins) record for infection.

   (ii) **Lack of host receptors and sensitive site for toxins-**This is important particularly where a host-specific toxin is involved in disease development. Only plants having sensitive receptors (binding sites) for the toxin would become diseased. Plants lacking them would remain resistant.

   (iii) **Lack of essential nutrients of the pathogen-** Plant species or varieties which do not produce one of the substances essential for the pathogen would be resistant. For instance, *Rhizoctonia* needs a substance necessary for the formation of hyphal cushion. Plants lacking this substance would not become infected. *Erwinacarotovora* var. *atroseptica* (bacterial soft rot of potatoes) is less severe on potatoes with low reducing sugar content than in potatoes high in reducing sugar**.**

c) **Inhibitors present in plant cell before infection –** Presence of several phenolics and tannins in high concentration in cells of young fruit or leaves affords them resistance to pathogens. As the tissue age, their inhibitor content decreases, lowering their resistance. Several other types of performed compounds, For example the saponins tomatine in tomato and avinacin in oats have antifungal activity. Plant cells may also contain hydrolytic enzymes like glucanase and chitinases that may breakdown the cell wall components of pathogens.

2. **Post- inflectional or induced biochemical defense-** These develop in response to invading pathogen. A range of biochemical inhibitors and a range of biochemical processes are induced in the plant by the attacking pathogen. These are as follows.

a.) **Defense through increased levels of phenolic compounds-** Some of the phenolics implicated in defense mechanisms are widespread in plant healthy as well as diseased. However, their synthesis or accumulation is accelerated following infection. Such compounds may be called common phenolics. Certain other phenolics, not present in healthy plants but are produced upon stimulation of plant by a pathogen or a mechanical or chemical injury. Such compounds are known as phytoalexins.

(i) **Common phenolics-** These include chlorogenic acid, caffeic acid and scopoletin etc.

(ii) **Phytoalexins-** These are general are not produced by healthy plants but are produced by plant following infection, injury, or at least stimulation by certain fungal but not bacterial secretions. Muller and Borger (1940)first used the term phytoalexins for fungistatic compounds produced by the plant in response to injury or infection.

Phytoalexins can be regarded as toxic substances which arise only after stimulation by pathogenic microbes or by chemical and mechanical injury and which are inhibitory to microorganisms attacking plants. Phytoalexins have be demonstrated in a number of plants as potato,pea, sweet potato, barely, carrot and other of more than 20 families

Phytoalexins

Phytoalexin	Host	Pathogen
Pisatin	*Pisumsativum*	*Sclerotiniafructicola*
Phaseollin, Kievitone	*Phaseolus vulgaris*	*S. fructicola*
Orchinol	*Orchismilitaris*	*Rhizoctonia repens*
Ipomeamarone	*Ipomoaeabatatas*	*Ceratocystisfimbriata*
Isocoumarin	*Daucascarota*	*C. fimbriata*
Gossypol	*Gossypiumhirsutum*	*Verticilliumalbo-atrum*
Rishitin	*Potato tuber*	*Phytophthora infestans*
Trifolirhizin	*Trifolium pretense*	*Helmenthosporiumturcicum*
Medicarpin	*Medicago sativa*	*H. turcicum*
Cicerin	*Cicerarietinum*	*Ascochytarabiei*

b) **Hypersensitive reaction-** This is one of the most important defense mechanisms in plants. It occurs only in incompatible combinations of host plants with fungi, bacteria, viruses and nematodes. The term Hypersensitivity was first used by stakman (1915) to denote increased sensitivity as in the rapid death of a host cell in immediate vicinity of the infection site of *Puccinia graminis.* The invading pathogen may thus find itself surrounded by a zone of dead host cells and if it is a biotroph its further growth may be prevented. Here, the resistance is due to extreme sensitivity of the plant tissue and characteristic necrotic lesions develop. This has got much significance in obligate parasites as rust and powdery mildews. The concept of hypersensitivity and resistance has been applied to a wide range of host –parasite interaction.

The hypothesis for precise sequence of events is suggested by Tomiyama(1963). A number of physiological changes occur in infected cells and in adjacent cells. Such changes in hypersensitive reactions include (i) loss of permeability of cell membranes. (ii) Increased respiration (iii) accumulation and oxidation of phenolic compounds, production of phytoalexins and others. The end result of all these is death and collapse of the infected and perhaps a few surrounding cells. Pathogens are isolated by necrotic tissue and quickly die. The reaction occurs in fungal, bacterial and viral pathogen.

c) Fungitoxic phenolics released from nontoxic phenolic complexes –Many plant contain nontoxic glycosides (sugar joined to another, often phenolic molecule). Several fungi and bacteria are known to produce or to liberate from plant tissues an enzyme, glycosidase that can hydrolyse such complex molecules and release the phenolic compound from the complex.

d) **Phenol- oxidising enzymes (phenoloxidases)-** The activity of several polyphenoloxidases is generally higher in the infected tissues of resistant varieties than in the infected susceptible ones or in uninfected plants. These enzyme oxidise phenols to quinones, which are often more toxic to microbes than original phenols. Another class of phenoloxidases, peroxidases, not only oxidase phenols but also increase their polymerization rate into lignin like substances.

e) **Induced synthesis of enzymes-**Pathogen attack may induce alterations in enzyme synthesis in plant that may provide resistance around infection sites. An important enzyme, whose activity increases or synthesis accelerated in disease tissues is (PAL) phenylalanine ammonia lyase, a key enzyme in producing basic molecules used for biosynthesis of most phenolics.

f) Formation of substrates resisting the enzymes – Some substance that are not easily degraded by pathogen enzymes may appear in plant after attack. These compounds are usually complexes between pectin's, proteins and polyvalent cations such as calcium and magnesium.

g) **Inactivation of pathogen enzymes –**Several phenolsor their oxidation products inhibit the pectolytic and other enzymes of the pathogen. The resistance of many young immature fruit to fungal infection, as apple to *monilinia* and grape to *Botrytis* seems to be due to their high content of such enzyme – inhibitors.

h) **Release of fungitoxic cyanides from nontoxic complexes–**Some plants like flax, sorghum, cassava etc. Contain cyanogenic glycosides or esters that are nontoxic as long as in the cell (i.e. kept separate from hydrolytic enzymes). When cells are physically damaged, or stressed to the point where their membranes are disrupted and their cellular constituents are decompartmentalized, the hydrolytic enzymes are mixed with the cyanogenic complexes and release the toxic cyanide (HCN). Pathogenic fungi that can infect cyanogenic plants appear capable of either detoxifying HCN by converting it into a nontoxic metabolite or perhaps, of switching to an alternate mitochondrial respiration that is insensitive to cyanide. One of the enzymes that detoxifies HCN is formamide hydro-lyase which converts HCN to nontoxic formamide ($HCONH_2$).

i) **Detoxification of pathogen toxins-**In those cases where pathogen produces a toxin, this line may provide resistance. Detoxification of same toxins such as fusaric acid and pyricularin is known to occur in plants. Some toxins may be metabolized more rapidly by resistant varieties of plant.

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Epidemiology: Factor affecting disease development

Ashish Shrivastava

Ashishshrivastava.1971@gmail.com

JNKVV, College of Agriculture, Ganjabasoda

Epidemiology is primarily concerned with epidemics but the term has wide meaning and has come to include most field aspects of plant diseases. It is the interaction of crop, pathogen and environment. Epidemiology covers the effect of environmental factor prevalence, incidence and severity. A proper understanding of epidemiology is necessary for prediction of plant diseases and formulation of effective control measures.

Concept: The word epidemic consists from the Greek words epi (on) and demons (people). An epidemic has been defined as any increase of disease in a population. A similar definition of an epidemic is the dynamics of change in plant disease in time and space. The Term epidemiology has come to have broad meaning within plant pathology. The term has been defined as the study of epidemics and of the factors that influence them is called epidemiology. Epidemiology is concerned simultaneously with population that occur is an environment.

Epidemiology is also concerned with population genetics of their host resistance and with the evolutionary potential of the pathogen populations to produce pathogen races that may be more virulent to host varieties or more resistant to pesticides. Epidemiology, however must also take into account other biotic factors, such as environment strongly influenced by human activity as it relates to disease management.

Plant disease epidemic, sometimes called epiphytotics, most epidemics are more or less localized and cause minor to moderate losses, some epidemics are kept in check by chemical sprays and other control measures. Some plant disease epidemics e.g. Wheat rust, late blight of potato, downy mildew of grape and brown spot of paddy have caused tremendous losses of produce over other large areas.

Element of an epidemic: Plant disease epidemics develop as a result of the timely combination of the element in plant disease: Susceptible host plant, a virulent pathogen and favourable environmental conditions over a relatively long period of time. Humans may un willingly help initiate and develop epidemics. Thus, the chance of an epidemic increases when the susceptibility of the host and virulence of the pathogen are greater, as the environmental conditions approach the optimum level for pathogen growth, reproduction and spread and as the duration of all favourable conditions.

The interaction of the three components of disease has been visualized as triangle generally referred to as the disease triangle. Each side of the triangle represents one of three components. The length of each side is proportional to the sum total of the characteristics of each component that favour the disease development. The interaction of the components of plant disease, can be expressed to include time and human. Indeed, the amount of each of the three components of plants disease and their interactions in the development of disease are affected by a fourth component time must be added to a disease triangle to give a disease pyramid. The interaction of the four components can be visualized as a tetrahedron or pyramid.

Disease development in cultivated plants is also influenced greatly by a fifth component human : Humans affect the kind of plants grown in a given area, the degree of plant resistance and time of planting. By their cultural practices and by the chemical and biological control they may use, human affect the amount of primary and secondary inoculums available to attack the plants. The human component has some time been used in place of the component "time" in the disease tetrahedron but it should be considered a distinct fifth component that influences the development of plant disease directly and indirectly.

Factor affecting the disease development:

Host: Several internal and external factors of particular host plants play an important

role in the development of epidemics involving those hosts.

- Level of genetic resistance or susceptibility of the host (Highly resistance, moderately resistance and susceptible)
- Degree of genetic uniformity of host plant
- Type of crop (Annual & perennial)
- Age of the host plants
- Distance of susceptible host from the source of the primary inoculums
- Abundance and distribution of susceptible host
- Availability of alternate or collateral host etc

Are the factor which play important role in the development of epidemics involving host.

The host plant having high level of resistance do not allow some races or biotypes of a pathogen to become establishment and no epidemic unless and until there is evolution of new races that can attack that resistance and thus making the host susceptible. On the other hand susceptible host plant lacking genes for resistance against existing races of the pathogen provide suitable and adequate subtract of establishment and development of new infections.

The disease in an area is initiated by primary inoculums surviving at some sources. Longer the distance from the source of primary inoculums, longer time will be required for build up of epidemic in a susceptible crop. Continuous cultivation of a susceptible variety in a given area, large areas under a similar susceptible variety and distribution of the variety over large continuous areas help in build up of inoculums and improve the chance of epidemic. Under these conditions, the pathogen is able to use maximum number of its propagules effectively increase the rate of multiplication many times and report the disease cycle quickly.

Plant change in their susceptibility to disease with age for example in root rots, downy mildew, smuts and rusts etc. The hosts are susceptible only during the growth period and become resistant during the adult period. In some other diseases such as flower and fruit blight caused by fungal pathogen is able to post harvest infections, plant parts are resistant during growth and early adult period but become susceptible near ripening presence of alternate host is necessary for providing primary inoculums. The amount of inoculums thus available will determine the intensity of primary infection and subsequent period. Presence of collateral hosts plays the same role for pathogen of homogenous infection chain. In annual or seasonal crops such as maize, wheat, vegetables, chickpea and cotton etc., the epidemic generally develops much faster than fruits and woody trees.

Pathogen:

- Levels of virulence

- Quantity of inoculums near the host
- Type of reproduction of the pathogen (sexual : oospores, accospores) & (asexual: conidia & zoospores)
- Ecology of the pathogen (ectoparasites and endoparasites)
- Mode of spread of the pathogen (active and passive dispersal) etc.

are the factor which play important role in the development of epidemics involving pathogen :

virulent pathogens capable of infecting the host rapidly ensure a faster production of larger amounts of inoculums and there by disease, than pathogen of lessor virulence. The number of pathogen propgules (fungi, bacteria. Virus infected plants etc.) within or near fields of host plants the more inoculums reaches the host and at an earlier time thereby increasing the chance of an epidemic greatly. All pathogen produce many offspring, while a few fungi, all nematodes and all parasitic plants produce relatively small numbers of offspring. Some plant pathogenic fungi, bacteria and viruses have short reproduction cycles and therefore polycyclic i.e. they can produce many generations in a single growing season. Polycyclic pathogens include fungi that cause rusts, mildews and leaf spots are responsible for most of plant disease epidemics in the world. Several pathogens, such as smuts and several short cycle rusts, require an entire year to complete a life cycle (Monocyclic pathogen)and can therefore cause only one series of infection per year. In such monocyclic diseases, the inoculums builds up from one year the next and the epidemic is usually polyetic its develop over several years.

Most of the pathogens such as vascular fungi, bacteria, virus and protozoa reproduce inside the plant and spared the spore with the help of vector. Therefore, such pathogens can cause epidemics only when vector are active and plentiful, still other pathogens as soil borne fungi, bacteria and nematodes, produce their inoculums on infected plant parts in the soil within which the inoculums disperses slowely and present little danger for sudden or widespread epidemics.

The spore of many plants pathogenic fungi, such as those causing rusts, mildews and leaf spots, spores are released into the air can be dispersed by air over distance varying from a few centimeters up to several kilometers. These kind of fungi are responsible for the most frequent and widespread epidemic. Many of the viruses are transmitted by aphids, whitefly and other insects, mollicutes and fastidious bacteria are transmitted by leaf hopper and plant hopper, pathogens carried with the seed or other vegetative propagetive organs (such as tuber and bulbs) are often placed into midst of susceptible plants, but their ability to cause epidemic depends on the effectiveness of their transmission to new plants.

Environmental factors: The majority of plant disease occurs wherever the host is grown but usually do not develop into severe and widespread epidemics. This factor dramatizes the controlling influence of the environment on the. Development of an epidemic. The most important environmental factor that affects the development of plant disease epidemic are moisture, temperature and light are necessary for activities of biotic pathogens. A particular fungal pathogen meets all the conditions for causing epidemic, high reproductive cycle, high aggressiveness, effective dispersal and susceptible host even then development of epidemic may not occur if weather is not favorable for germination of spore or in the absence of light stomata have not opened to permit entry of the infection. The weather also affects the activity of the pathogen on the host surface. It may not permit sporulation on the host surface thus reducing amount of inoculums for secondary spread.

Activities of Human: many activities of human have direct or indirect effect on plant disease epidemic such as selection of sites, propagetive materials and various diseases management practices including cultural practices have a direct or indirect effect of disease epidemics. Low-lying and poorly drained field, especially if near other infected fields tend to favor the appearance and development of epidemic. The use of infected seeds, nursery stocks and other propagetive materials, increase the amount of primary inoculums within the crop and thus, greatly favor the development of epidemics continuous monoculture, large acreage planted to the same variety of the crop, high level of nitrogen fertilizers, dance planting and poor sanitation all increase the possibility and severity of epidemics. Chemicals sprays, cultural operations and biological control they may use human effects the amount of primary and secondary inoculums available to attack plants.

New Tools in epidemiology:

The study of plant disease epidemiology has been facilitated greatly by new methods and new equipment that make possible studies of aspect of plant diseases that more possible. Some of the method and other equipment & that have been used to great advantage in the plant disease epidemiology..

I **Molecular tools** : The most important tools of these are development and use of genetic (DNA) probe that allow the definite detection and identification of a plant pathogen within or on the surface of a plant tissue that include following tools 1. Polymerase chain reaction (PCR), Random amplified polymorphic DNA (RAPD).

II **Geographic Information system (GIS)**: GIS Is a computer system that can be installed or any model desktop computer and is capable of assembling, Storing, manipulating and displaying data that are referenced by Geographic coordinates. GIS is adaptable to operation of any size and data can be used at any scale from single field to an agriculture region.

III **Global positioning system (GPS)**: It consists of a hand held device that is coordinate with a global system of manmade satellites and depending on the accuracy and co-ordination, provide quite accurate reading of the coordinate of the position of the device.GPS enables a specific area of the field that are affected by the pathogen, which can be visited and examined again periodically for incremental advance of the symptom.

IV **Geostatistics:** Geostatistics consists of various “geostatical” techniques that are applied in plant disease epidemiology to characterize quantitatively spited patterns at disease development or the development of pathogen populations in space and our time. These techniques have the capability to take into account the characteristics of spastically distributed variables whether they are random or systematic.

V Remote sensing: Remote sensing usually refers to the use of instruments for measuring electromagnetic radiation reflected or emitted from an object. The various remote sensing instruments store data obtained from field situations and data are then printed out are analyzed.

VI **Image Analysis**: Image analysis refers to photography and electronic image analysis usually of large areas of fields or of mountains. The image or photographs are taken through aerial photography, ground based sensor data and satellite-borne and air borne sensor. Air borne multispectral scanning is studied and used widely for the surveillance of plant disease, pests and environmental stresses in agriculture.

VII **Information Technology :_** This technology involves primarily the use of computers alone or in combination with other electronic devices. They help to collect data on plant diseases at various levels and various locations in a continuous manner electronic information technology can above all, describe and display spatial pattern of characteristics of different pathogenic

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PRINCIPLES AND METODS OF PLANT DISEASE MANAGEMENT

D. S.Tomar
Tomar_sd@rediffmail.com
JNKVV, College of Agriculture, Tikamgarh

The principles of plant disease management are generally based on identity of the disease to minimizing the damage or loss below economic injury level. Methods for the control of disease are classified as: Exclusion, Eradication, Protection and Resistance, and later two more methods were included, Avoidance and Therapy .

Principles of Plant disease management are as under:

1. Avoidance of the pathogen
2. Exclusion of the pathogen
3. Eradication of the pathogen
4. Protective measures
5. Development of resistance in host
6. Therapy of diseased plant

1. Avoidance of the pathogen

It involves tactics that prevent the contact of the pathogen on susceptible stage of the plant and favorable conditions for the pathogen. This is achieved by

i). Selection of Geographic area
ii). Selection of field
iii). Choice of time of sowing
iv). Disease escaping varieties
v). Selection of seed
vi). Modification of cultural practice

i). Selection of Geographic area

Several bacterial and fungal diseases are more severely infect the crop in wet areas than in dry areas. smut (*Tolyposporium penicillariae*) and ergot of pearl millet (*Cleviceps microsphala*) are serious in wet areas. Growing of pearl millet in dry areas with irrigation facilities can be avoided from smut and ergot diseases.

ii). Selection of field

Selection of field will help in the management of several soil borne diseases. Cultivation of same crop year after year in the same field then survivality of soil borne pathogen is long and makes the soil sick., Ex: Red rot of sugar cane, , late blight of potato, wilt diseases of arhar, green ear of bajra, root knot nematodes, bacterial wilt of vegetables.

iii). Choice of time of sowing

Generally pathogens are able to infect the susceptible plants under certain environmental conditions. Alteration of date of sowing can help in avoidance of favourable conditions for pathogen. Ex. Pea and Gram planted soon after rain, when soil temp and moisture level are high, shows high incidence of root rot, blight and wilt. Delayed sowing will help in reducing the incidence of disease.

iv). Disease escaping varieties

The disease escaping quality of crop varieties due to characteristics of growth and time of maturity e.g. early maturing varieties of Pea and wheat which matures early (by January) usually escape damage from powdery mildew and rust.

v). Selection of seed

Selection of seed and planting material from healthy sources will effectively manage the diseases such as loose smut of wheat caused by *Ustilago nuda tritici*, bunchy top of banana (*Banana virus-1*), *Fusarium* wilt of banana (Panama wilt), whip smut and red rot of sugarcane and virus free potato tubers through tuber indexing.

vi). Modification of cultural practice

Modification in various cultural practices like method of sowing, choice of crop, crop rotation, irrigation time/method, application of fertilizers and soil amendment will help in management of plant diseases.

a). Sanitation: Field sanitation including removing the host debris is effective in significantly reducing the incidence of late blight, ring rot and leaf roll diseases of potato and *phomopsis* spp. in soybean. Eradication of host and pathogen or rouging and elimination of over summering or over wintering host or control of weeds also help for elimination of viral and soil borne pathogens.

b). Tillage: Tillage help in loosening of soil hence provide aeration which is effective in preventing/ against soil borne pathogen like *Fusarium* root rot of beans and *Sclerotium rolfsii*.

c). Crop rotation: Crop rotation refers to the practice of growing different type of crops in a piece of land and this practice play an important role in increasing soil fertility and crop production, maintaining the soil health and controlling seed borne pathogens.

d). **Mixed cropping:** Fusarium wilt of pigeon pea is reduced when pigeon pea is grown along with sorghum due to secretion of Hydrogen cyanide (HCN) by sorghum root and this compound harm to wilt pathogen.

e) **Inter cropping:** Intercropping is a practice of growing two or more crops within a field in order to derive the benefits of unutilized inter-row spaces, complementation, and competition among the crops .Intercropping watermelon with upland rice suppressed *Fusarium* wilt in rice.

e). Spacing: Sowing with optimum distance play an important role in disease management. When sowing with close spacing results in high humidity among plants which can be conducive for heavy seed borne infections. Disease caused by *Cercospora spp.* on pulses spread very fast under crowdy conditions.

f). Method of sowing: Planting method is effective in increasing and reducing disease severity, deep sowing of wheat seed increased bunt and flag smut diseases. When ginger planted in raised bed, then incidence of *Pythium myriotylum* infection is less.

g). Selection of healthy seed: Planting seeds should be free of the pathogen and come from a carefully maintained, generally pure block and selected from production fields and should be cleaned commercially and treated chemically or non- chemically to avoid or eradication of seed borne inoculums .

h). Adjustment of planting time: Choice the planting time when requirements of the host and pathogen do not correspond and so the plant may escape infection. If winter wheat sown early in autumn may escape infection of *Tilletia caries* and *T. foetida* due to plants pass the susceptible stage before optimum condition for bunt spore germination. Similarly early sowing of oat seeds in spring reduces the disease incidence of *Ustilago avenae.*

Exclusion of the pathogen

It means preventing the entrance and establishment of pathogens in uninfected crops in a particular area. Objective of the exclusion is to prevent spread of the disease and this can be achieved by:

i). Seed treatment
ii). Inspection and certification
iii). Plant quarantine
iv). Eradication of insect vector

i). Seed treatment

Eternal and external seed borne inoculums can be prevented through heat, gas or chemical treatment of seed, tuber, bulbs and propagative plant part. The seed treatments increase the seed germination and reduce disease development in the field.

ii). Inspection and certification

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

iii). Plant quarantine

Plant quarantine prevent the import and spread of plant pathogens into the country or individual states by legal restriction, certain federal and state laws regulate the conditions under which certain crops may be grown and distributed between states and countries.

Types of Plant quarantine:

1. Domestic quarantine: When rules and regulations issued for prohibiting the movement of insects, pest and diseases and their hosts from one state to another state of India is called domestic quarantine. For example, *Bunchy top of banana* present in Kerala, Assam, Bihar, West Bengal and Orissa, *Banana mosaic* present in Maharashtra and Gujarat and *Wart of potato* present in Darjeeling area of West Bengal.

2.* Regulatory quarantine or foreign *quarantine: In this type of quarantine rules and regulations issued prohibiting the import of plants, plant materials, insects and fungi into India from foreign countries by air, sea and land.

3. **Exclusive quarantine or Embargo**: Total restriction on import and export of agricultural commodities.

2.Eradication of the pathogen

i). Biological control of plant pathogen

In the current intensive agricultural practices where the adverse side effects of mismanaged chemical agriculture are weighing more than their benefits, biological control is assuming an important component of the modern agriculture for enhancing the productivity without affecting the ecosystem.

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iii). Removal and destruction of diseased plants or plant organs

The presence of diseased plant, alternate and collateral host in the field is a source for maintain of infection chain of pathogen. The removal of crop residue and other survival substitute of inoculums will help in eradication of pathogen.

a). Rouging of diseased plants

b). Eradication of alternate and collateral host

c). Sanitation

iv). Heat and chemical treatment of diseased plant

Heat and chemical treatments of diseased plant eradicate the pathogen present in the plant or on plant organs. Root dip of vegetables crop like bringal, tomato and chilli in chemical fungicide or nematicide is a method of sanitizing the seedlings before transplanting.

v). Soil treatment

In this method, the soil treatment with chemicals, heat and some cultural practices as summer deep ploughing, mulching, flooding and fallowing will help to inactivate or eradicate the pathogens present in the soil.

a). Summer deep ploughing: Deep ploughing of field during summer months expose soil to hot weather which will eradicate heat sensitive soil borne pathogens.

b). Soil solarization: Soil solarization or slow soil pasteurization is the hydro/thermal soil heating accomplished by covering moist soil with polyethylene sheets as soil mulch during summer months for 4-6 weeks.

c). Flooding of field: If flooded the field up to 30cm deep for 8-10 weeks will help in eradicating several soil borne pathogens due to creations of anaerobic and low oxygen conditions in the soil.

***d).* Soil amendments**: Amendments of soil with organic materials like oil cake, saw dust, straw, and and karanj cake will effectively manage the several soil borne diseases caused by *Fusarium*, *Pythium, Phytophthora, Macrophomina, Aphanomyces* and *Verticillium*. Beneficial micro-organisms increases in soil and helps in suppression of pathogenic microbes.

e). Application of Soil fungicides: Spray or drench the fungicide in soil before sowing of seed for eradication of soil borne pathogen like, Bordeaux mixture, copper oxy chloride, Carbendazim and Formaldehyde etc.

2. **Protective measures :**

If provided some protective cover for plant to face infectious pathogens

For prevents infection by means of a toxicant or some other barrier to infection.

i). Chemical treatment

The prevention of the pathogen from entering the host or checking the further development after infection by the application of chemicals as foliar spray and seed treatment. Ex. Seed treatments with Thiram + Carbendazim 2:1 ratio protect the seed from soil borne diseases and spray Mancozeb @ 0.25% protect the crop from devaral air bone diseases.

ii). Chemical control of insect vector

Biting and mostly sucking insects may cause severe irritation and transmit causal agents of various plant diseases especially viral diseases from infected crop to uninfected susceptible plants. Spray of crop with systemic insecticide Imidacloprid 17.8% SL @ 0.5ml/lit of water minimized the population of white fly vector of leaf curl of chilli and yellow mosaic of urd, moong and soybean.

iii). Modification of environments

The environment can be modified so that it is suitable for plant growth but not for disease development. For example if aeration is increased in crop canopy then humidity decrease on aerial plant parts, and become unfavourable for growth of pathogen. Similarly improving soil drainage, changing the time of sowing, proper irrigation practices can all produce conditions unfavourable to diseases development.

iv). Modification of host nutrition

Nutrient application affects the development of plant diseases under field conditions directly through the nutritional status of the plant and indirectly by affecting the conditions which can influence the development of the disease . The root rot disease of wheat and barley (take-all) caused by *Gaeumannomyces graminis* can be effectively controlled by nutrition of the host plant

3. Development of resistance in host

Development and utilization of host plant resistance remains the most viable, environmentally safe, ecologically sound and also less expensive technique for the management of diseases.

i). Selection and hybridization for disease resistance

ii). Resistance through chemotherapy

iii).Resistance through host nutrition

4. Therapy of diseased plant

Generally cure of diseased plant or plant parts in most crops is not possible, but some crops and fruit trees have been successfully therapy by chemical and physical treatment.

i). Chemotherapy

ii). Heat therapy

iii). Tree surgery

i). Chemotherapy

In chemotherapy, chemical treatments applied to eliminate the pathogen from the infected part of the diseased plant. The using chemicals are mostly systemic fungicides and antibiotics. These chemicals toxic to pathogen and provide temporary resistance in host plant and they known as chemotherapeutants.

ii). Heat therapy

It is an important component of healthy seed and plant propagative material production as it has proved most effective in eliminating the pathogen associated with seed, tubers, bulbs and graft and also many virus diseases.

a). Hot water treatment: The seed and propagative plant part like cane set is treated at 50^0 C for 10 to 15 minutes (grain seed) and 2 to 3 hours (can set). The method is effective against loose smut of wheat, smut of barley, sorghum and smut, wilt, leaf scald, ratoon stunting, grassy shoot, mosaic and chlorotic streak pathogens of sugarcane.

b). Hot air treatment: The hot air treatment has been proved as eradication of plant pathogen. If seed cane treated by hot air treatment at 54^0 C for 8 hours is effective against grassy shoot and ratoon stunting causing pathogens.

c). Aerated stem therapy: Several fungal and viral pathogens eliminated through specially designed aerated stem therapy (AST). The eradication of grassy shoot, ratoon stunting and smut pathogens is recommended the treatment of sugarcane set by aerated stem therapy at 50^0C for 1-3 hours.

d). Moist hot air treatment: This method is successfully practices in management of smut, grassy shoot, leaf scald and ratoon stunting diseases of sugarcane with the seed can treated by moist hot air treatment at 54^0 C for 2.5 hours at 95-99 % RH.

iii).Tree surgery

After removal diseased parts and pruning and cutting practice covering the wound with fungicidal paste is helping in avoid pathogen infection. Basically this method employed on horticultural plants.

Biological methods for disease management:

Practically using microorganisms against plant pathogens started with the control of crown gall with *Agrobacterium radiobacter* and seedling blights caused by *Pythium* and *Rhizoctonia* with *Trichoderma harizanum, Gliocaladium virens* and *Streptomycesgriseus.*

Mechanisms of biological control (Antagonism)

1. Antibiosis or Amensalism

Antibiosis or amensalism is microbial activities, in which one organism produce antibiotics and toxins, which are volatile or nonvolatile in nature, and have a direct effect on other organisms.

a). **Antibiotics**: Antibiotics are microbial toxins that can, at low concentrations, poison or kill other microorganisms. Most microbes produce and secrete one or more compounds with antibiotic activity. For example the strong antagonists *Trichoderma harzianum* and *T. viride* secrete cell wall lysing enzymes, 6-1, 3-glucanase . Similarly *Gliocladium virens* produces **gliotoxin** which is responsible for the death of *Rhizoctonia solani* on potato tubers. Some strains of *Pseudomonas fluorescens* produce a range of compounds, viz., 2,4- diacetyl phloroglucinol (DAPG), phenazines, pyocyanin, which have broad spectrum activity against many plant pathogenic bacteria and fungi.

b). **Bacteriocins**: These are antibiotic like compounds with bactericidal specificity closely related to the bacteriocin producer. Ex: crown gall (*Agrobacterium tumefaciens*) can be control by the use of related *Agrobacterium radiobacter*

c). **Volatile compounds**: Antibiosis mediated by volatile compounds has been observed in the management of soil borne pathogens, viz., *Pythium ultimum,* *Rhizoctonia solani* and *Verticillium dahlia*, by *Enterobacter cloacae*. The volatile fraction responsible for inhibition was identified as ammonia.

2. Competition: The majority of the biocontrol agents are fast growing and they compete with plant pathogens for space, nutrients and minerals including oxygen. During this process, the antagonist may suppress the growth of the pathogen population in the rhizosphere and thus reduce disease development.The bacterial bioagent *Pseudomonas fluorescens* produce extracellular, low molecular weight iron transport agents, known as **siderophores** which chelate with iron in the soil, and make it difficult for the pathogens to proliferate.

3. Mycoparasitism: Mycoparasitism or hyper parasitism occurs when the antagonist invades the pathogens by secreting enzymes such as chitinases, celluloses, glucanases and other lytic enzymes. The mechanism covers different stages of interactions. First stage: Chemical stimulus of pathogenic fungi attracts the antagonist fungi and induces a chemotropic response of the antagonist. Second stage: Recognition between the pathogen and the antagonist is due to the lectins. Third stage: It is followed by the interactions between hyphae of the pathogen and the antagonist. Examples of such interactions are T. *harzianum* acting against *Fusarium oxyporum, F. roseum, F. solani, Phytophthara colocaciae* and *Sclerotium rolfsii.*

List some biocontrol agents for the management of plant diseases

S. No.	**Name of bioagent**	**Trade name**	**Target pathoge**
1.	*Trichoderma spp.* *T. viride*	Bio-fungus Ecofit, Bioderma	soil borne diseases causing pathogens *viz., Sclerotinia, phytopthora, Rhizoctonia solani, Pythium spp., Fusarium Verticillium,*
2.	*Paecilomyces lilacinus*	Paecil or Bioact	Egg parasite of *Meloidogyne incognita*

3.	*Pythium oligandrum*	Polygandron	*Pythium altimum*
4.	*Ampelomyces quisqualis*		Powdery mildew disease
5.	*Pseudomonas florescence*		*Sclerotium rolfsii, Xanthomonas axonopodis, Fusarium moniliformae*
6.	*Pseudomonas syringae*	Bio save 100	*Botritis cinerea,Penicitllium spp*.
7.	*Bacillus subtilis*	Companion	*Ralstonia, Rhizoctonia, Pythium, Fusarium and Phytopthora*
8.	*Agrobactertitum radio bactor* strain	Galltrol-A	*Agrobacterium tumefaciens*
9.	*Pasteuria penetrans*		parasite on juvenile of root knot nematode

Plant Growth Promoting Rhizobacteria (PGPR):

Bio control agents also produce growth hormones like, auxins, cytokinin, gibberellins etc. These hormones suppress the harmful pathogens and promote the growth of plants and simultaneously increase the yield. A group of bacteria that enhance the growth of plant through nitrogen fixation, phosphorus solubilization or production of plant growth promoting metabolites are known as Plant Growth Promoting Rhizobacteria (PGPR). Many PGPR strains specially *Bacillus subtilis and Pseudomonas fluorescens* have a potential to be used as microbial inoculants to enhance crop productivity due to their ability to produce phytohormones

Cross protection: The phenomenon in which plant tissues infected with mild strain of a pathogen are protected from infection by other severe strains of the pathogen. In wilt disease of mint caused by *Verticillium dahlia* inoculation of roots at least 2 days earlier with *Verticillium nigresces* reduce the incidence of wilt. This strategy also used in the management of severe strains of *Citrus Tristeza virus.*

Systemic Induced or Acquired Resistance Various biotic inducers (e.g., fungi, bacteria, viruses, phytoplasma, insects, etc.) and abiotic stresses (e.g., chemical and physical inducers) developed resistance due to the formation of structural barriers such as lignification, induction of pathogenesis-related proteins, and conditioning of the plants

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Fungicides nature, chemical combinations and formulations

S. K .Tripathi
Sanat62tripathi@rediffmail.com
JNVVV, College of Agriculture, Rewa

FUNGICIDES

The word 'fungicide' originated from two latin words, viz., 'fungus' and 'caedo'. The word 'caedo' means 'to kill.' Thus ,the fungicide is a chemical which has the ability to kill the fungus.

Fungistat

The chemicals which may arrest the growth of the fungus temporarily. called fungistat and the phenomenon of temporarily inhibiting the fungal growth is termed as fungistatis.

Antisporulant

Chemicals may inhibit the spore production without affecting the growth of vegetative hyphas called as 'Antisporulant'. The fungicide has been defined as a chemical agent which has the ability to reduce or prevent the damage called Fungitoxicant'.

Fungicides can be broadly grouped based on their (i) mode of action (ii) general use and (iii) chemical composition.

Protectant

Protectant fungicides are prophylactic in their behavior. 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 and antibiotics like Aureofungin.

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.

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 chloride (for growing plants), Capton, PCNB, thiram etc.
4. Foliage and blossom protectants : Eg. Capton, ferbam, zineb, mancozeb, chlorothalonil etc.
5. Fruit protectants : Eg. Captan, carbendazim,mancozeb
6. Eradicants : Eg. Organomercurials, lime sulphur, etc.
7. Tree wound dressers : Eg. Boreaux paste, chaubattia paste, etc.
8. Antibiotics : Eg. Actidione, Griseofulvin, Streptomycin, Streptocycline,

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, quinones 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

Fungicides formulations:

Fungicides are formulated in various ways and most commonly available formulations are Emulsifiable Concentrates (EC) Wettable Powders (WP), Dusts (D), etc.

Commercially available fungicides usually consist of a mixture of active ingredient (a.i.) and other substances including diluents, wetting agents, stickers, emulsifiers, etc. Formulations containing mixtures of different active ingredients (especially mixtures of protectant and systemic fungicides) are also widely used nowadays. Different formulations incorporating the same active ingredient may be used for distinct purposes like seed treatment, foilar application etc.

Emulsifiable Concentrates (EC)

These are liquid formulations which can be diluted with water before application. The active ingredient is dissolved in a solvent. When these emulsifiable concentrate is added to water, a milky mixture is formed which is a suspension of active ingredient and emulsified solvent in the water.

Wettable Powders (WP)

Wettable powder is a very common formulation for most of the fungicides, which is used for spray mixtures. The modern wettable powders are water-dispersible which have the quality to wet easily and disperse well in water. They are also called as Water-Dispersible Powders (WDP). The active ingredient is incorporated, usually at the rate of 30-80%, with a finely ground inert dust (filler) such as Kaolin, a wetting agent and a suspending agent. The commonly used suspending agents are sodium lignin sulphonate (Sulphite dye), methyl celluloses, polyvinyl acetate and aluminium silicate. In addition, spreader-sticker is sometimes desirable, especially on plants with glossy or waxy leaves.

Dusts (D)

Dust formulations usually contain 1-10% active ingredient for direct application in dry forms. They are manufactured in such a way that they are light enough to be carried by a slight breeze for a considerable distance. The finely divided particle of active ingredient is carried on a carrier particle. The commonly used carriers (diluents) are kaolin, talc, pyrophylite, bentonite, calcium silicate, hydrated silica, calcium carbonate, magnesium carbonate, gypsum, lime etc.

Granules

Granules are the formulations of the fungicide with inert materials formed into particles about the size of coarse sugar. The granules normally contain 3-10% of the active ingredient. Due to their size, the granules do not drift but have limited application being confined to soil and seed treatments.

Suspension or slurries

Formulation in which a dry form of the active ingredient is mixed with a liquid. Such formulations usually contain a high percentage of active ingredient which is similar to wettable powders. They are mixed with water for final use and require agitation. These are mostly used as seed dressers in seed processing companies.

Solutions True solutions are formulations in which active ingredient or a combination of active ingredients and a solvent is dissolved in water Solutions have the advantage of requiring no agitation after formulation is added in water. At present, the manufacturers are concentrating to develop new formulations to increase the efficacy of the chemicals. Some new formulations developed are: Soluble Liquid (SL), Soluble Powder (SP), Water Soluble Concentrate (WSC), Suspension Concentrate (SC) and Aqua Flow (AF).

Adjuvants

The fungicides can be commonly applied either as spraying or dusting. In spraying method, the toxicant is made into a suspension in water. In order to increase the efficacy of the water mixed sprays, certain substances like wetting agents, dispersing agents, spreaders, stickers, etc. are added during the formulation of fungicides.The various adjuvants are grouped as follows.

Dispersing agents (Deflocculating agents)

These are the substances which keep fine particles away from each other to prevent deflocculation. These materials, when added to formulations, ensure uniform suspension and retard sedimentation of particles in the spray suspension. These are also called as deflocculating agents. Eg. Gelatin, plant gums and milk products.

Emulsifying agents

Powders (WDP). The active ingredient is incorporated, usually at the rate of 30-80%, with a finely ground inert dust (filler) such as Kaolin, a wetting agent and a suspending agent. The commonly used suspending agents are sodium lignin sulphonate (Sulphite dye), methyl celluloses, polyvinyl acetate and aluminium silicate. In addition, spreader-sticker is sometimes desirable, especially on plants with glossy or waxy leaves. Agitation is generally necessary to keep uniform suspension.

Wetting agent (Wetters)

These are the materials which are added to ensure that there will be no layer of air between a solid and a liquid as they reduce the surface tension of the particles. Wetting agents, when added to aqueous fungicidal preparation, help in easy deposition on leaves. Eg. Polyethylene oxide condensat, esters of fatty acids and flour.

Spreading agent (Spreaders) Spreaders are the materials added to establish improved contact between the spray materials and plant surface and thus ensuring a good coverage of fungicide. Wetting must precede spreading and this is the only distinction between wetting and spreading. Spreaders also reduce the surface tension and thus improve contact. Eg. Soap, flour, sulphated amines, soapamines, mineral oils, glyceride oil, terpene oil, resinates and petroleum sulphonic acids.

Stickers (Adhesives)

The materials which are added to spray or dust to improve the adherence to plant surfaces are called as stickers. They increase the tenacity of the fungicidal preparations, thus increasing the residual action. Eg. Polyvinyl acetate, polybutanes, fish oil, linseed oil, milk casein,gelatin, dextrines, polyethylene polysulphide, starch, gum arabic, hydrocarbon oils and bentonite clays; Milk casein, gelatin also act as good spreading and wetting agents besides acting as stickers.

Safeners

A Chemical which reduces the phytotoxicity of another chemical is called safener. For example copper sulphate is phytotoxic to plants, but with addition of lime its toxicity is reduced. Lime is, therefore, a safener. Lime is used universally with chemicals to prevent the formation of, or to neutralise arsenic, which is phytotoxic to plants. Glycerine oils are also used as safeners.

L. 21

FUNGICIDES CLASSIFICATION AND THEIR MODE OF ACTION

A.R.WASNIKAR

JNKVV , Jabalpur

Fungicides can be mainly classified based on their (i) mode of action (ii) general use and (iii) chemical composition.

Classification on the basis of Chemical Composition

. 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 broadly grouped as follows and discussed in detail.

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.

I. Copper sulphate preparations

Bordeaux Mixture

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:

$$CuSO_4 + Ca(OH)_2 \; Cu(OH)_2 + CaSO_4$$

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.

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 preparation

Cuprous oxide Preparation	Fungimar, Perenox, Copper Sandoz, opper 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.

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.

Dithio –Carbamates:

Monoalkyl Dithiocarbamates Eg. Zineb, Maneb, Eg. Thiram, Ziram, Mancozeb, Nabam, Vapam Ferbam	Dialkyl Dithiocarbamates	
Trade Name	**Diseases Controlled**	
Inorganic Sulphur 1. Elemental Sulphur (i) Sulphur dust	Sulphur dust Cosan, Wetsulf, Microsul	Sulphur is a contact and protective fungicide, 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 (Dithiocarbamates) a. Monoalkyl	Hexathane 75% WP, Dithane Z-78, Funjeb, Lonocol, Parzate C,	It is used to protect foliage and fruits of a wide range of crops
dithiocarbamate 1. Zineb (Zinc ethylene bisdithiocarbamate)	Du Pont Fungicide A, Polyram.	against diseases such as early and late blight of potato and tomato, downy mildews and rusts of cereals, blast of rice, fruit rot 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.	Foliar spray for leaf spot disease
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 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 sensitive 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	Thiride 75 WDP, Thiride 750, Thiram 75% WDP, Hexathir,	It is used for seed treatment both as dry powder or as a

thiram disulphide)	Normerson, Panoram 75, Thiram, TMTD, Arasan, Tersan 75, Thylate, Pomarsol, Thiuram.	slurry. It is a protective fungicide also suitable for application to foliage to control *Botrytis spp.* On lettuces, ornamental, soft fruits and vegetables, rust on ornamentals and *Venturia pirina* on pears. It is also effective against soil borne 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.

Common Name	Trade Name	Diseases Controlled
I. Inorganic Mercury 1. Mercuric chloride	Merfusan, Mersil	It is used for treating potato tubers and propagative materials of other root crops
2. Mercurous chloride	Cyclosan, M-C Turf fungicide.	Mercurous chloride is limited to soil application in crop protection use because of its phytotoxicity.These are used mainly for treatment of seeds and planting materials.
II. Organomercurials Methoxy ethyl mercury Chloride Phenyl mercury chloride	Agallol, Aretan, Emisan, Ceresan wet (India) Ceresan Dry (India), Ceresol, Leytosan. Ceresan (USA)	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

Ethyl Mercury Chloride Tolyl mercury acetate	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, widely used to control foliage and fruit diseases of tomatoes, coffee potato.
3. Glyodin	Glyoxaliadine, Glyoxide, Glyodin, Glyoxide Dry, Glyodex 30% liquid and 70% WP.	It has a narrow spectrum of 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 soilborne 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 are resent 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 rotectant. This is also used as a foliage fungicide, particularly against apple scab and peach leaf curl.
Organo – Phosphorous fungicide Ediphenphos (Edifenphos) (O-ethyl-SSdiphenyldithiophosphate)	Hinosan 50% EC and 2% D.	It has a specific action against *Pyricularia oryzae* (Rice blast). It is also effective against *Corticium sesakii* and *Cochliobolus miyabeanus* in rice.

Systemic Fungicides:

Any compound capable of being freely translocated after penetrating the plant is called systemic. Several systemic fungicides have been used as seed dressing to eliminate seed infection. 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 fungicideused for seed treatment of cereals against bunts and smuts, especially loose smut of wheat
2. Oxycarboxin (5,6-	Plantvax 5G, Plantvax	It is a systemic fungicide used

dihydro-2-methyl- 1,4- oxathin-3-carboxianilid- 4,4- dioxide)	5% liq. Plantvax 1.5 EC, 10% dust, 75 WP.	for the treatment ofrust 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) 2. Carbendazim (MBC) (Methyl -2- Benzimidazole carbamate)	Benlate 50 WP, Benomyl. Bavistin 50 WP, MBC, Dersol, B.Sten 50, Zoom, Tagstin, Agrozim, Jkenstin.	It is a protective and eradicative fungicide with systemic activity, effective against a wide range of fungi 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.
3. Thiabendazole (TBZ)	Thiabendazole, Mertect,	It is a broad spectrum

(2,4-thiazoyl benzimidazole)	Tecto, Storite.	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 *Venturia* spp., on apple and pear crops, powdery mildews, *Botrytis* and *Sclerotinia* spp.
2. Thiophanate - methyl (1,2 bis (3 methoxycarbonyl- 2-thioureido) benzene.)	Topsin-M70 WP, Cercobin-M 70 WP, Envovit-methyl,	It is effective against a wide range of fungal pathogens, including *Venturia spp.* on apples and pears,

	Mildothane.	*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 foliage 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-imethyl-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	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*

4. Etridiazole (5-ethaoxy-3-trichloromethyl, 1,2-4-thiadiazole)	Terrazole 30% WP, Terrazole 95% WP, Terrazole 25% EC, Koban, Pansol EG, Pansol 4% DP, Turban WP, Terracoat Aaterra.	leafspots of groundnut and banana. It is very effective against *Phytophthora* and *Pythium* spp. and seeding diseases of cotton, groundnut, vegetables, fruits and ornamentals

IX. Organo phosphorous compounds:

Common Name	Trade Name	Diseases Controlled
1. Pyrazophos (2-0-0-Diethylthionophosphoryl) -5- methyl-6-carbethoxy pyrazolo-(1- 5a)pyrimidine)	Afugan, Curamil, WP, Missile EC.	It is used to control 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 *ythium* 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)	It is a systemic fungicide and highly effective for specific use as seed dressing against fungal pathogens of the order Peronosporales.
2. Metalaxyl + Mancozeb	Beam, Alliette 80 WP	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*

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Antibiotics

Sanjeev Kumar
Department of Plant Pathology,
JNKVV, Jabalpur-482004 (M.P.), India
sanjeevcoa@gmail.com

Definition :

"Antibiotic is defined as a chemical substance produced by one microorganism, which in low concentration can inhibit or even kill other microorganism".

Brief History

Sl.no	Name of scientist	Year	Contribution
1	Alexander Fleming	1928	Discovered first antibiotic 'Penicillin' in Scotland from the fungus *Penicillium notatum.*
2	Windling	1932	Isolated first antibiotic 'Gliotoxin' from *Gliocladium fimbriatum* to be used in plant protection
3	Dr. S. A.Waksman	1942	Coined term Antibiotics
4	W. Waksman	1944	Isolated non-toxic broad- spectrum antibiotic Streptomycin from *Streptomyces griseus*
5	M.J. Thirumalachar and Gopalkrishnan	1962	Developed Aureofungin a antifungal antibiotic from *Streptomyces cinnamoneus var terricola* in India

Character of good antibiotics

- It should be broad spectrum.
- It should be safe to plants
- It is fairly harmless to human beings and animals.
- It should be active on or inside of the plant.
- It tolerates oxidation, UV irradiation, rainfall, and high temperature.

Advantages in using antibiotics

- Easy to produce antibiotics at cheaper rate.
- Cure incurable diseases.
- Less number of sprays required.
- Less leaching effect.
- Acts as eradicant.
- Manage MLO's and bacterial diseases.

Disadvantages in using antibiotics

- Shelf life very short.
- Less stable in storage.
- Narrow site of action.
- Risk of development of resistance.

Classification of antibiotics

I. Based on Their Activity

a) **Broad-spectrum antibiotic:** Antibiotic which destroy or inhibit the growth of a wide range of gram positive and gram negative bacteria.
E. g. Tetracylines, Chloromycetin etc.
b) **Narrow-spectrum antibiotic:** Antibiotic which mainly attack gram positive bacteria or gram negative bacteria.
E. g. Penicillin.

II.Based on Chemical Group

1.β- Lacta antibiotics

Ex: a. penicillins
b. cephlosporins

2. Tetracyclins

Ex: a. Tetracyclins
b. Chlorotetracycline
c. Oxytetracyclins

3. Rifamycins

Ex: Rifamycin A to E

4. Amino glycosidic antibiotics

Ex: Streptomycin, Gentamycin

5. Macrolide antibiotics

a. Erythromycin
b. Spyramycine
c. Olendomycine

6. Polypeptide group antibiotics

Bacitracine, Capriomycine, Polymixin, Viomycine

7. Miscellaneous group

Vancomycine, Chloromphenical, Fusidic acid, Lincomycine

8. Synthetic antibiotics

Ex: Nitrofuron compounds

a. Furazolidin - Stomach
b. Nitrofurantoin - Urinary track infection
c. Nitrofurozone - Ear infection

III. Based on how they work on the stopping the infection of the bacteria

- **Bactericidal**

  They kill the bacteria present in the body which causes disease.
  Eg.:- Penicillin and polymyxin.

- **Bacteriostatic**

  The medicines which are used to inhibit the growth of microbes are known as bacteriostatic.
  Eg.:- Tetracycline, Chloramphenicol.

Mode of Action

Sl.No	mechanism	Examples
1	Cell wall synthesis inhibitors	Penicillins, Cephalosporins, Bacitracins
2	Inhibitors of protein synthesis	Streptomycin, tetracyclins
3	Inhibitors of nucleic acid synthesis	Sulphanomides
4	Disorganises the cytoplasmic membrane	Amphitericin- B

Antibiotics for plant disease management

Antibiotics are substances which are produced by micro- organisms and which act against micro-organisms. Most antibiotics known uptill now are products of actinomycetes and some are from fungi and bacteria. Some of the important antibiotics are mentioned here.

Sl. no	Name of Antibiotic	Source	Disease managment
1	**Streptomycin**	Streptomyces griseus	Citrus canker, bacterial leaf spot of tomato and pepper, hollow blight of french bean, fire blight of apples and pears. Bacterial diseases of tubers, beans, cotton, crucifers, cereals, etc.
2	**Cycloheximide**		Mildew of beans, covered smut of oats, brown rot of peach, yeasts but is inactive against bacteria.

3	**Griseofulvin**	*Penicillium griseofulvwn* *P. patulum,*	Downy mildew of cucurbits, Powdery mildew of rose, Powdery mildew of beans, Early blight of tomato and Brown rot of apple.
4	**Blasticidins**	*Streptomyces griseochromogen es*	Both bacteria and fungi
5	**Aureofungin**	*Streptomyces cinnamomens*.	Downy mildew, powdery mildew and anthrancnose of grapes, rice controls *Helminthosprium oryzae*. *Pyricularia oryzae* of rice. *Diplodia* of mango, *Alternaria* rot of tomato, *Sclerotinia* rot of peach, *Pythium* rot of cucurbits etc
6	**Tetra cyclones**	*Streptomyces*	Crown gall, fire blight of apples etc.
7	**Agrimycin-l00 & 500**		Halo blight, citrus canker, seedling blight, leaf spot, black arm disease of cotton, soft rot and black leg of potato.
8	**Antimycin**	*Streptomyces kitasawensis* *S.griseus*	Early blight of tomato, seedling blight of oat, rice blast etc.
9	**Thiolutin**	*Streptomyces albus*	Late blight of potato and downy mildew of broccoli
10	**Mystatin**	*Streptomyces noursei*	Anthracnose of beans and downy mildew of cucumber
11	**Bulbifonnin**	*Bacilus subtiles*	Wilt of pigeon pea.