K. K. WAGH COLLEGE OF AGRICULTURE, NASHIK

DEPARTMENT OF PLANT PATHOLOGY

THEORY NOTES

Course No.: - PATH -121

Course Title: - Fundamentals of Plant Pathology

Credits: - 3 (2+1)

Compiled By

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Teaching Schedule

a) Theory

Lecture	Topic	Weightage (%)
1	Importance of plant diseases, scope and objectives of Plant Pathology.....	3
2	History of Plant Pathology with special reference to Indian work	3
3,4	Terms and concepts in Plant Pathology, Pathogenesis	6
5	classification of plant diseases	5
6,7, 8	Causes of Plant Disease Biotic (fungi, bacteria, fastidious vesicular bacteria, Phytoplasmas, spiroplasmas, viruses, viroids, algae, protozoa, and nematodes) and abiotic causes with examples of diseases caused by them	10
9	Study of phanerogamic plant parasites.	3
10, 11	Symptoms of plant diseases	6
12,13, 14	Fungi: general characters, definition of fungus, somatic structures, types of fungal thalli, fungal tissues, modifications of thallus,	7
15	Reproduction in fungi (asexual and sexual).	4
16, 17	Nomenclature, Binomial system of nomenclature, rules of nomenclature,	6
18, 19	Classification of fungi. Key to divisions, sub-divisions, orders and classes.	6
20, 21, 22	Bacteria and mollicutes: general morphological characters. Basic methods of classification and reproduction in bacteria	8
23,24, 25	Viruses: nature, architecture, multiplication and transmission	7
26, 27	Nematodes: General morphology and reproduction, classification of nematode Symptoms and nature of damage caused by plant nematodes (Heterodera, Meloidogyne, *Anguina* etc.)	6
28, 29, 30	Principles and methods of plant disease management.	6
31, 32, 33	Nature, chemical combination, classification of fungicides and antibiotics.	7
34, 35, 36	Mode of action and formulations of fungicides and antibiotics.	7
	Total	**100**

Suggested Readings

1) Pathak, V. N. Essentials of Plant Pathology. Prakash Pub., Jaipur
2) Agrios, GN. 2010. *Plant Pathology*. Acad. Press.
3) Kamat, M. N. Introductory Plant Pathology. Prakash Pub, Jaipur
4) Singh RS. 2008. *Plant Diseases.* 8th Ed. Oxford & IBH. Pub. Co.
5) Singh RS. 2013. *Introduction to Principles of Plant Pathology.* Oxford and IBH Pub. Co.
6) Alexopoulos, Mims and Blackwel. Introductory Mycology
7) Mehrotra RS & Aggarwal A. 2007. Plant Pathology. 7th Ed. Tata Mc Graw Hill Publ. Co. Ltd.
8) Gibbs A & Harrison B. 1976. *Plant Virology - The Principles*. Edward Arnold, London.

9) Hull R. 2002. *Mathew.s Plant Virology*. 4th Ed. Academic Press, New York.

10) Verma JP. 1998. *The Bacteria*. Malhotra Publ. House, New Delhi.

11) Goto M. 1990. *Fundamentals of Plant Bacteriology*. Academic Press, New York.

12) Dhingra OD & Sinclair JB. 1986. *Basic Plant Pathology Methods*. CRC Press, London, Tokyo.

13) Nene YL & Thapliyal PN. 1993. *Fungicides in Plant Disease Control.* 3rd Ed. Oxford & IBH, New Delhi.

14) Vyas SC. 1993. *Handbook of Systemic Fungicides*. Vols. I-III. Tata McGraw Hill, New Delhi.

15) Rajeev K & Mukherjee RC. 1996. Role of Plant Quarantine in IPM. Aditya Books.

16) Rhower GG. 1991. Regulatory Plant Pest Management. In: Handbook of Pest Management in Agriculture. 2nd Ed. Vol. II. (Ed. David Pimental). CRC Press.

Importance of plant diseases, scope and objectives of Plant Pathology

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). Such epidemics had left their effect on the economy of the affected countries.

Objectives of Plant Pathology

Plant Pathology (Phytopathology) deals with the cause, etiology, resulting losses and control or management of the plant diseases. The objectives of the Plant Pathology are the study on:

i. the living entities that cause diseases in plants;

ii. the non-living entities and the environmental conditions that cause disorders in plants;

iii. the mechanisms by which the disease causing agents produce diseases;

iv. the interactions between the disease causing agents and host plant in relation to overall environment; and

v. the method of preventing or management the diseases and reducing the losses/damages caused by diseases.

Scope of Plant Pathology

Plant pathology comprises with the basic knowledge and technologies of Botany, Plant Anatomy, Plant Physiology, Mycology, Bacteriology, Virology, Nematology, Genetics, Molecular Biology, Genetic Engineering, Biochemistry, Horticulture, Tissue Culture, Soil Science, Forestry, Physics, Chemistry, Meteorology, Statistics and many other branches of applied science.

History of Plant Pathology with special reference to Indian work

Historical perspectives show that the attention of man to plant diseases and the science of plant pathology were drawn first only in the European countries. Greek philosopher Theophrastus (about 286 BC) recorded some plant diseases about 2400 years ago. This branch of science could maintain a proper record on the plant disease and their causal organisms only after development of compound microscope by the Dutch worker Antony von Leeuwenhoek in 1675. He first visualized bacteria in 1683 under his microscope. Robert Hook (1635-1703) also developed simple microscope which was used to study of minute structure of fungi. The Italian botanist Pier' Antonio Micheli (1679-1737) first made detail study of fungi in 1729. With the contribution of many other scientists' viz., Mathieu Tillet (1755), Christian Hendrik Persoon (1801) and Elias Magnus Fries (1821), the foundation of modern plant pathology was built and was further strengthened by Anton de Bary (1831-1888), who is regarded as the Father of Plant Pathology.

Historically, plant pathology of India is quite ancient as the Indian agriculture, which is nearly 4000 years old. This confirms that mention about plant diseases was made much before the time of Theophrastus. The events of the development of plant pathology in India are chronologically recorded as follows:

(i) Plant diseases, other enemies of plants and methods of their control had been recorded in the ancient books viz., *Rigveda*, *Atharva Veda* (1500-500 BC), *Artha Shastra* of Kautilya (321-186 BC), *Sushruta Samhita* (200-500AD), *Vishnu Purana* (500 AD), *Agnipurana* (500-700 AD), *Vishnudharmottara* (500-700 AD) etc.

(ii) During 11th century, Surapal wrote *Vraksha Ayurveda*, which is the first book in India where he gave detail account on plant diseases and their control. Plant diseases were grouped into two-internal and external. Tree surgery, hygiene protective covering with paste, use of honey, plant extracts, oil cakes of mustard, castor, sesamum etc. are some of the disease management practices recorded in the book.

(iii) Symptoms of plant diseases are cited in other ancient Indian literatures viz. *Jataka* of Buddhism, *Raghuvamsha* of Kalidas etc.

(iv) The Europeans started systemic study of fungi in India during 19th century. They collected the fungi and sent to the laboratory in Europe for identification. D.D. Cunningham and A. Barclay, during 1850-1875, started identification of fungi in India itself. Cunningham specially studied on rusts and smuts. K.R. Kirtikar was credited as the first Indian scientist for collection and identification of fungi in India.

(v) Edwin John Butler started the systemic study on Indian fungi and the diseases caused by them. This Imperial Mycologist came to India in 1901 and initiated the works on fungi at Imperial Agricultural Research Institute established by the British Government of Pusa (Bihar). The first and most classic book in the field of plant pathology of India i.e. *Fungi and Diseases in Plants* was written by him based on the exhaustive study on Indian fungi. He left India in 1920 and joined as the first Director of Imperial Mycological Institute in England. He is regarded as the Father of Indian PlantPathology.

(vi) Jahangir Ferdunji Dastur (1886-1971), a colleague of Butler, was the first Indian plant pathologists to made detail study of fungi and plant diseases. He specially studied the diseases of potato and castor caused by genus *Phytophthora* and established the species *P. parasitica* from castor in 1913. In recognition of his command in Plant Pathology, he was promoted to the Imperial Agricultural Science in 1919.

(vii) G.S. Kulkarni, a student of Butler, generated detail information on downy mildew and smut of jowar and bajra. Another student S.L. Ajrekar studied wilt disease of cotton, sugarcane smut and ergot of jowar.

(viii) Karam Chand Mehta (1894-1950) of Agra had contributed a lot to Plant Pathology of India. He first joined Agricultural College as a demonstrator at Kanpur. His outstanding contribution in the discovery of the life cycle of stem rust of wheat in India and reported that barberry, an alternate host, does not play any role in perpetuation of the rust fungus in India. He published two monographs entitled “Further Studies on Cereal Rust in India” Part I (1940) and Part II (1952) and also established three laboratories for rust works at Agra, Almora and Shimla.

(ix) Raghubir Prasad (1907-1992) trained under K.C. Mehta, contributed to the identification of physiological races of cereal rusts and life cycle of linseed rust. Subsequently, L.M. Joshi at IARI conclusively studied various aspects of wheat rusts viz., chief foci of infection of rusts, dissemination of rust pathogens in India. Later on S. Nagarajan and L.M. Joshi developed most useful mathematical models in 1978 to predict appearance of stem and leaf rust of wheat.

(x) Manoranjan Mitra was considered as one of the most critical plant pathologist worked on *Helminthosporium*. He first reported Karnal bunt of wheat in 1931 from Karnal in Haryana.

(xi) B.B. Mundkur was the second mycologist trained under Butler and worked with Mehta and Mitra. He worked on control of cotton wilt by using resistant varieties and became successful in reducing yield loss in Maharashtra. His significant contribution is the establishment of Indian Phytopathological Society (IPS) in 1948 with its journal *Indian Phytopathology*. In the same year, he published a text book *Fungi and Plant Diseases* which was the second book of Plant Pathology after the classic book of Butler.

(xii) S.R. Bose was taxonomist, mainly worked on the classification of Polyporaceae and isolated “polyporin” from *Polyporus*.

(xiii) Notable contribution in the field of Mycology was made by M.J. Thirumalachar (1914-1999). He created 20 new genera and 300 new species of fungi, monographed genera of Uredinales of the world and Ustilaginales of India. Similarly many Hyphomycetes particularly *Fusarium* were elaborated by C.V. Subramanian in 1971.

(xiv) Works on fundamental plant pathology, especially the biochemistry of host-parasite relationship were started at Lucknow and Madras (Chennai) lead by Sachindra Nath Dasgupta (1904-1990) and T.S. Sadasivan (1913-2001), respectively. Dr. Dasgupta initiated the works on leather mycology, paper pulp mycology and predacious fungi. Dr. Sadasivan's school developed the concept of vivotoxin and reported the production of fusaric acid by *Fusarium vasinfectum* that causes wilt diseases in cotton.

(xv) T.S. Ramakrishnan, a mycologist to Madras Government cultivated ergot diseased rye for toxin production. He published two books entitled *Diseases of Millets* (1963) and *Diseases of Rice* (1971). Renowned plant pathologists viz., G Rangaswami and R. Ramakrishnan were his students.

(xvi) Plant Bacteriology in India got a shape with the effort of Makanj Kalyanji Patel (1899-1967). He established a school of Plant Bacteriology at College of Agriculture, Pune and first described a new species *Xanthomonas campestris* pv. *uppali* in 1948 from the host *Ipomea muricota*. He described more than 30 bacterial diseases from India. Other scientists viz., V.P. Bhide and G. Rangaswami also contributed their pioneering works to the phytobacteriology of India. D.N. Srivastava (1925-2000) is mostly remembered for his tremendous contribution on bacterial blight of rice. M.K. Hingorani reported about the complex nature of *tundu* disease of wheat caused by a bacterium and a nematode in 1952 and also he confirmed the causal agent of ring disease of potato as *Pseudomonas* (=*Ralstonia*) *solanacerarum*. J.P. Verma (1939-2005) contributed many valuable findings on bacterial blight disease of cotton.
(xvii) Plant virus research in India was started particularly at IARI, New Delhi under the leadership of R.S. Vasudeva (1905-1987), S.P. Raychaudhury (1916-2005) and Anupam Varma. Considering the importance of plant viral diseases, IARI established

some Regional Research Stations at Shimla for temperate fruits (1952), at Pune for fruits and vegetables (1952) and at Kalimpong (West Bengal) for large cadamom, citrus and other crops in north-eastern sub-Himalayan mountain (1956). Y.L. Nene's contributions have been well remembered particularly the viral diseases of pulses and the 'Khaira' disease of rice caused by Zinc deficiency. He wrote the book "Fungicides in Plant Disease Control".

(xviii) Teaching of plant pathology as a course was started at University of Calcutta, Bombay and Madras in 1857 where only fungal taxonomy was emphasized. But plant pathology as a university science was started in 1930 at University of Allahabad, Lucknow and Madras. Of which, perhaps University of Madras was first to introduce plant pathology as a course. Agra University had introduced one post-graduate programme in plant pathology in Govt. Agricultural College, Kanpur in 1945. The organized teaching in Mycology and Plant Pathology was began as a part of agricultural science under the banner of Indian Agricultural Research Institute. The subject received due importance and teaching of its supporting courses viz. mycology, bacteriology, virology and nematology in both under- and post-graduate programmes of Agriculture was taken up regularly after the establishment of Agricultural Universities in different states of India in 1960. At present, most of the courses related to plant pathology have been revised and added molecular plant pathology by keeping pace with the advancement in the science.

Terms and concepts in Plant Pathology, Pathogenesis

Definition and terms

1. **Parasite**: An organism living upon or in another living organism (the host) and obtaining the food from the invading host.
2. **Pathogen**: An entity, usually a micro-organism that can cause the disease.
3. **Biotroph**: A plant pathogenic fungus that requires living host cells i.e. an obligate parasite.
4. **Hemibiotroph**: A plant pathogenic fungus that initially requires living host cells but after killing the host cell grows on the dead and dying cells.
5. **Necrotroph**: A pathogenic fungus that kills the host and survives on the dying and dead cells.
6. **Pathogenicity**: The relative capability of a pathogen to cause disease.
7. **Pathogenesis**: It is a process caused by an infectious agent (pathogen) when it comes in contact with a susceptible host.
8. **Virulence**: The degree of infectivity of a given pathogen.
9. **Infection**: The initiation and establishment of a parasite within a host plant.
10. **Primary infection**: The first infection of a plant by the over wintering or over summering of the pathogen.
11. **Inoculum**: That portion of pathogen which is transferred to plant and cause disease.
12. **Invasion**: The penetration and spread of a pathogen in the host.
13. **Colonization**: The growth of a pathogen, particularly a fungus, in the host after infection is called colonization.
14. **Inoculum potential**: The growth or threshold of fungus available for colonization at substratum (host).
15. **Symptoms**: The external and internal reaction or alterations of a plant as a result of disease.
16. **Incubation period**: The period of time between penetration of a pathogen to the host and the first appearance of symptoms on the plant.
17. **Disease cycle**: The chain of events involved in disease development.
18. **Disease syndrome**: The set of varying symptoms characterizing a disease are collectively called a syndrome.
19. **Single cycle disease** (Monocyclic): This type of disease is referred to those caused by the pathogen (fungi) that can complete only one life cycle in one crop season of the host plant. e.g.

downy mildew of rapeseed, club root of crucifers, sclerotinia blight of brinjal etc.

20. **Multiple cycle disease** (Polycyclic): Some pathogens specially a fungus, can complete a number of life cycles within one crop season of the host plant and the disease caused by such pathogens is called multiple cycle disease e.g. wheat rust, rice blast, late blight of potato etc.

21. **Alternate host**: Plants not related to the main host of parasitic fungus, where it produces its different stages to complete one cycle (heteroecious).

22. **Collateral host**: The wild host of same families of a pathogen is called as collateral host.

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23. **Predisposition**: The effect of one or more environmental factors which makes a plant vulnerable to attack by a pathogen.

24. **Physiologic race**: One or a group of microorganisms similar in morphology but dissimilar in certain cultural, physiological or pathological characters.

25. **Biotype**: The smallest morphological unit within a species, the members of which are usually genetically identical.

26. **Symbiosis**: A mutually beneficial association of two or more different kinds of organisms.

27. **Mutualism**: Symbiosis of two organisms that are mutually helpful or that mutually support one another.

28. **Antagonism**: The counteraction between organisms or groups of organisms.

29. **Mutation**: An abrupt appearance of a new characteristic in an individual as a result of an accidental change in genes present in chromosomes.

30. **Disease**: Any deviation in the general health, or physiology or function of plant or plant parts, is recognized as a disease.

31. **Cop Damage**: It is defined as any reduction in the quality or quantity of yield or loss of revenue resulting from crop injury.

32. **Deficiency:** Abnormality or disease caused by the lack or subnormal level of availability of one or more essential nutrient elements.

Concept of Plant Disease

The normal physiological functions of plants are disturbed when they are affected by pathogenic living organisms or by some environmental factors. Initially plants react to the disease causing agents, particularly in the site of infection. Later, the reaction becomes more widespread and histological changes take place. Such changes are expressed as different types of symptoms of the disease which can be visualized macroscopically. As a result of the disease, plant growth in reduced, deformed or even the plant dies.

When a plant is suffering, we call it diseased, i.e. it is at ‘dis-ease’. Disease is a condition that occurs in consequence of abnormal changes in the form, physiology, integrity or behaviour of the plant.

According to American Phytopathological Society (*Phytopathology* 30:361-368, 1940), disease is a deviation from normal functioning of physiological processes of sufficient duration or intensity to cause disturbance or cessation of vital activities. The British Mycological Society (*Trans. Brit. Mycol. Soc*. 33:154-160, 1950) defined the disease as a harmful deviation from the normal functioning of process. Recently, Encyclopedia Britannica (2002) forwarded a simplified definition of plant disease. A plant is diseased when it is continuously disturbed by some causal agent that results in abnormal physiological process that disrupts the plants normal structure, growth, function or other activities. This interference with one or more plant’s essential physiological or biochemical systems elicites characteristic pathological conditions or symptoms.

Parasitism and Pathogenesis

An organism which lives in or on other living organisms and derives its nutrients from the latter is called *parasite*. The relationship between a parasite and its hosts is known as parasitism. Many fungi and most bacteria grow on a non-living substrate within a living plant. The organism of this type of mode of nutrition is called *saprophyte*. Based on the different types of modes or nature of nutrition, the relationship between the host and parasite or saprophyte is termed in many ways viz., obligate parasite (biotroph), obligate saprophyte, facultative parasite, facultative saprophyte, hemibiotroph and necrotroph (perthotrophs or perthophyte). Parasitism in cultivated crops is common phenomenon. Any agent that can cause suffering or damage or disease is called a *pathogen*. In plant pathology, the term ‘pathogen’ is usually used to the living or infectious organisms. The ability of a pathogen or parasite to cause disease is known as *pathogenicity*.

It is obvious that a plant becomes diseased when it is attacked by a pathogen or parasite. The ultimate condition i.e. disease occurs by passing through some distinct events. Thus, the genesis or chain of events or stages of disease development are called *pathogenesis*. This is also called as *disease cycle*. The events that occur in specific order are namely inoculation, penetration, establishment of infection, invasion or colonization, growth and reproduction, dissemination and survival of the pathogen (over wintering or over summering in absence of the host). The events will continue to repeat in the same order in presence of both the host and pathogen/parasite that may lead to severe disease condition.

Classification of plant diseases

To facilitate the study of plant diseases they are needed to be grouped in some orderly fashion. Plant diseases can be grouped in various ways based on the symptoms or signs (rust, smut, blight etc.), nature of infection (systemic or localized), habitat of the pathogens, mode of perpetuation and spread (soil-, seed- and air-borne etc.), affected parts of the host (aerial, root disease etc.), types of the plants (cereals, pulses, oilseed, ornamental, vegetable, forest diseases etc.). But the most useful classification has been made based on the type of pathogens that cause plant diseases. Since this type of classification indicates not only the cause of the disease, but also the knowledge and information that suggest the probable development and spread of disease alongwith their possible control measures. The classification is as follows:

1. Infectious plant diseases:

a. Disease caused by parasitic organisms: The organisms included in animate or biotic causes can incite diseases in plants.

b. Diseases caused by viruses and viroids.

2. Non-infectious or non-parasitic or physiological diseases: The factors included in inanimate or abiotic causes can incite such diseases in plants under a set of suitable environmental conditions.

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. Further, the word “pathogen” can be broadly defined as any agent or factor that incites 'pathos or disease in an organism or host. 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 (v) Algae

(ii) Bacteria (vi) Phanerogams

(iii) Phytoplasma (vii) Protozoa

(iv) Rickettsia-like organisms (viii) Nematodes

2. Mesobiotic causes : These disease incitants are neither living or non-living, e.g.

(i) Viruses

(ii) Viroides

3. Inanimate 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 (e.g. 'Khaira' disease of rice due to Zn deficiency)

(ii) Light

(iii) Moisture

(iv) Temperature

(v) Air pollutants (e.g. black tip of mango)

(vi) Lack of oxygen (e.g. hollow and black heart of potato)

(vii) Toxicity of pesticides

(viii) Improper cultural practices

(ix) Abnormality in soil conditions (acidity, alkalinity)

Flowering Plant Parasites (Phanerogams)

Most of the diseases are caused by fungi bacteria and viruses. There are few seeds plants called flowering parasites (Phanerogams) which are parasitic on living plants. Some of these attack roots of the host, while some parasites on stem. Some are devoid of chlorophyll and entirely dependent on their host for food supply, while other have chlorophyll and obtain only mineral constituents of food from host by drawing nutrition and water they are called as Holoparasites or complete or total parasite. They have haustoria as absorbing organs, which are sent deep into the vascular bundle of the host to draw nutrients, water and minerals.

Flowering Plant Parasites: There are two types of parasites.

1) Root Parasites:

i) Striga (Partial root parasite)

ii) Orobanche (Complete root parasite)

2) Stem Parasites:

i) Dodder (Cuscuta) (Complete stem parasite)

ii) Loranthus (Partial Stem parasite)

A. Root Parasites:

1. Total or Complete or Holoparasite:

Orobanche (Broom rape or Tokra)

It is annual flashy flowering plant growing to height of about 15-50 cm long, yellow or brownish colour and covered by small thin scaly leaves. Flowers appears in the axil of leaves are white or tubular. Fruits appears in the axil of leaves are white or tubular. Fruits are capsule containing and seeds are very small, black in colour remain viable for several years. The hausteria of parasite penetrates into the roots of hosts and draw its nourishment. The growth of the plant is retarded, may die some times. It attacks tobacco, tomato, brinjal, cabbage, cauliflower.

2. Hemi Partial or Semi Root Parasite:

Striga (Witch Weed or Turfula or Talop)
Family Scrophulariaceae

It is a small plant with bright green leaves grows upto height 20-60 cm leaves beers chlorophylls and developed in clusters of 10-20 % host plant. They are obligate parasites therefore, do not obtain all their nutrient from their host root. Flowers are pink in colour, seed are very minute and produce in grate number 5000 to 100000 seeds plant per years. One flower contain 1200-1500 seeds and remains viable upto 12-40 years. Dissemination takes place with rain water, flood, wind and irrigation water. It cause yellowing and wilting of host leaves. It attacks sugarcane jowar, Maize, cereals and millets.

B. Stem Parasites:

1. Total or Complete or Holoparasite:

Cuscuta or dodder (Amarvel, Lovevine) Family cuscutaceae.
Genus – Cuscuta
It is non chlorophyllous, leaf less parasitic seed plant.

It is yellow pink or orange in colour and attached to the host. They do not bear leaves but bear minute function less scale leaves is produces flower and fruits. Flower are white, pink or yellowish in colour and found in clusters. Seed are form in capsules. A single plant may be produce 3000 seeds.

The first appearances of parasites is noticed as thread like leaf less stem which devoid of green pigment and twine around the stem or leaves of the host. When stem of parasitic plant comes in contact with host, the minute root like organs. i.e. hausteria penetrates into the host and absorbs. When the relation ship of the host is firmly established, the dodder plant looses the contact from soil.

These affect plant get weakened and yield poorly the seeds spread by animals, water and implements and remain viable when condition are unfavorable.

It attacks berseem alfalfa, clover, flax, onion, potato, ornamental and hedge plants.

2. Partial, Semi or Hemi Stem Parasites:

Loranthus
Family- Loranthaceae.
It is a partial parasite of tree trunks and branches with brown stem, dark green leaves but no roots.

1. Stem is thick and flattened of the node, appear in clusters at the point of attack which can be easily spotted on the trees.

2. At the point of attachment with the tree, it shows swellings or tumourous growth where the haustoria are produced. It produces flowers which are long, tabular, greenish, white or red colour and found in clusters. It produces fleshy berries with single seed.

3. The affected host plant becomes stunted in growth and dispersal of seed is mostly through the birds and animals. It attacks mango, citrus, apple, guava.

Phanerogamic Plant Parasites

Some flower and seed bearing higher plants (phanerogams) live parasitically on other living plants and can cause important diseases on agricultural crops and also in forest trees. They are classified in the following botanical families and genera,
1. Cuscutaceae (stem parasite)
Genus: *Cuscuta*, the dodders
2. Viscaceae (stem parasites)
Genus: *Arceuthobium*, the dwarf mistletoes of conifers
Phoradendron, the American true mistletoes of broad leaved trees
Viscum, the European tree mistletoes
Dendrophthoe, the giant mistletoes
3. Orobanchaceae (root parasite)
Genus: *Orobanche*, the broomrapes

4. Scrophulariaceae (root parasite)

Genus: *Striga*, the witchweeds

Identifying characters, reproduction and life cycle

1. **Dodder (Love-vine, Amarbel)**: Dodder is slender, twining plant. The stem is tough, succulent, threadlike, curling, leafless and bearing minute scales in place of leaves. Stem is usually yellowish or orange in colour. They grow and climb in abundance on the wild and cultivated plants. Their haustoria penetrate the stem or leave of the host plant and absorb foodstuffs and water. Growth of the infected plants is suppressed and finally dies. Tiny whitish flowers arise in clusters from the stem and they produce numerous grey to reddish-brown seeds within few weeks of bloom. The seeds fall on the ground where they either germinate immediately or remain dormant until next season. The seeds may be spread to new areas by animals, water, equipments and by mixing with crop seeds.

2. **Giant mistletoe (Loranthus)** : Mistletoes are semi-parasites of thee-trunks and branches. They have green leaves and many branches and hence grown like a small bush on the host. They do not have true roots and hence develop haustoria to draw nutrients from the vascular system of the host plant. Flowers are long, tubular, greenish white to red in colour and borne in clusters. Seed is fleshy, contains one seed, sweet in taste and usually eaten by birds and animals. The parasite is spread mostly through birds. Droppings of bird containing seeds get deposited on the other trees, mainly at the junction of a branch and main trunk. These seeds germinate, develop haustoria and established on the host plant.

3. **Broomrape**: Broomrape is a complete root parasite. It affects tobacco mostly and many other Solanaceous and Cruciferous plants. The parasite has a stout, fleshy stem of 10-15 cm long. The stem is pale yellow or brownish red in colour and is covered by small, thin, browny, scaly leaves. Flowers are white and tubular and appear in the axil of leaves. Seeds are very small, black in colour and can remain viable in soil for several years. Roots are haustoria-like, can penetrate the roots of the host for nutrition. The affected plants become stunted and may die.

4. **Witchweed**: It is a semi root parasite but obligate in nature. Commonly affected plants by this parasitic plant are sugarcane, cereals, maize and millets. *Striga* is a small plant

with bright green, slightly hairy stem and leaves. The weed grows 15-60 cm high in clusters. Leaves are long and narrow in opposite pairs. Flowers are small, brick red or yellowish or almost white with yellow centers, appear throughout the season. Tiny brown seeds are produced in each capsule and thus a single plant can produce 50,000-500,000 seeds. The seeds can remain viable for 12-40 years. Roots are watery white in colour without root hairs and hence obtain nutrients by haustoria from the host plant. The life cycle from seed germination to first seed setting on the developed plant needs 90-120 days.

Symptoms of Plant Diseases

A visible or detectable abnormality expressed on the plant as a result of disease or disorder is called *symptom*. The totality of symptoms is collectively called as *syndrome* while the pathogen or its parts or products seen on the affected parts of a host plant is called *sign*. Different types of diseasesymptoms are cited below:

Necrosis: It indicates the death of cells, tissues and organs resulting from infection by pathogen. Necrotic symptoms include spots, blights, burn, canker, streaks, stripes, damping-off, rot etc.

Wilt: Withering and drooping of a plant starting from some leaves to growing tip occurs suddenly or gradually. Wilting takes place due to blockage in the translocation system caused by the pathogen.

Die-back: Drying of plant organs such as stem or branches which starts from the tip and progresses gradually towards the main stem or trunk is called die-back or wither tip.

Mildew: White, grey or brown coloured superficial growth of the pathogen on the host surface is called mildew.

Rusts: Numerous small pustules growing out through host epidermis which gives rusty (rust formation on iron) appearance of the affected parts.

Smuts: Charcoal-like and black or purplish-black dust like masses developed on the affected plant parts, mostly on floral organs and inflorescens are called smut.

Blotch: A large area of discolouration of a leaf, fruit etc. giving a blotchy appearance.

White blisters: Numerous white coloured blister-like ruptures are surfaced on the host epidermis that forms powdery masses of spores of fungi. They are called white blisters or white rust.

Colour change: It denotes conversion of green pigment of leaves into other colours mostly to yellow colour, in patches or covering the entire leaves. (i) *Etioliation*: Yellowing due to lack of light, (ii) *Chlorosis*: Yellowing due to infection viruses, bacteria, fungi, low temperature lack of iron etc. (iii) *Albino*: Lack of any pigment and turned into white or bleached (iv) *Chromosis*: Red, purple or orange pigmentation due to physiological orders etc.

Exudation: Such symptom is commonly found in bacterial diseases when masses of bacterial cells ooze out to the surface of affected plant parts and form some drops or smear, it is called exudation. This exudation forms a crust on the host surface after drying.

Overgrowth: Excessive growth of the plant parts due to infection by pathogens. Overgrowth takes place by two processes (i) *Hyperplasia*: abnormal increase in size due to excessively more cell division (ii) *Hypertrophy*: abnormal increase in size or shape due to excessive enlargement of the size of cell of a particular tissue.

Atrophy: It is known as hypoplasia or dwarfing which is resulted from the inhibition of growth due to reduction in cell division or cell size.

Sclerotia: These are dark and hard structures of various shaped composed of dormant mycelia of some fungi. Sometimes, sclerotia are developed on the affected parts of the plant. Presence of sclerotia on the host surface is specifically called a sign of disease rather than symptom.

General characteristics of fungi

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

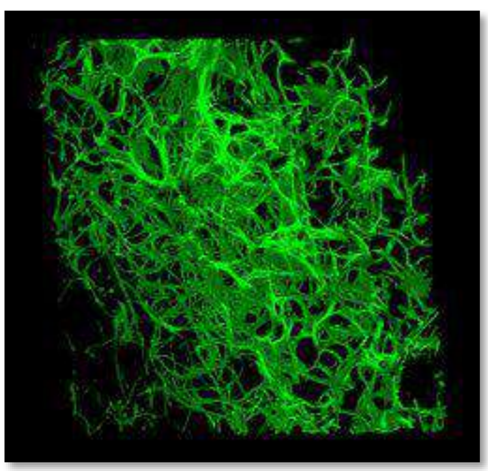
Somatic structures:

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

Hypha (hypha=web) (pl. hyphae) : Hypha is a thin, transparent, tubular filament filled with protoplasm.It is the unit of a filamentous thallus and grows by apical elongation.

Mycelium(pl. mycelia): A net work of hyphae (aggregation of hyphae) constituting the filamentous thallus of a fungus.It may be colourless i.e., hyaline or coloured due to presence of pigments in cell wall.The mycelium may be ectophytic or endophytic.

image of fungal mycelia

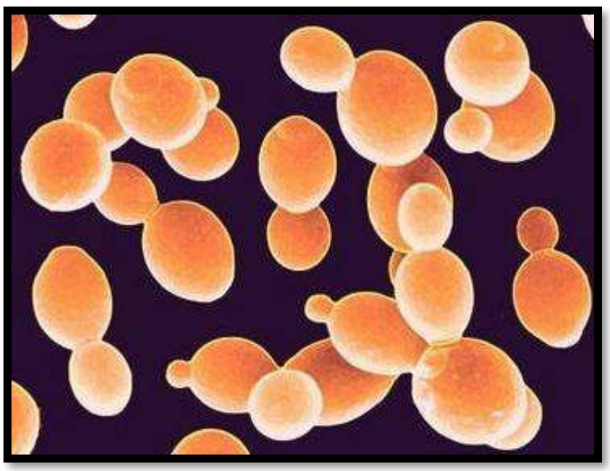


Types of fungal thalli:

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

Plasmodiophora brassicae in host cell

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



3.Multi cellular or filamentous thallus: Majority of fungi i.e., a true fungi are filamentous, consisting of a number of branched, thread like filaments called hyphae.Eg.Many fungi,*Alternaria.*

Fungi based on reproductive structures:

Holocarpic (holos=whole+karpos=fruit): If the thallus is entirely converted into one or more reproductive structures, such thallus is called holocarpic thallus. Eg.*Synchytrium*

Eucarpic(Eu=good+karpos=fruit): If the thallus is differentiated into a vegetative part which absorbs nutrients and a reproductive part which forms reproductive structures, such thallus is called eucarpic thallus**.** Eg.*Pythium*

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

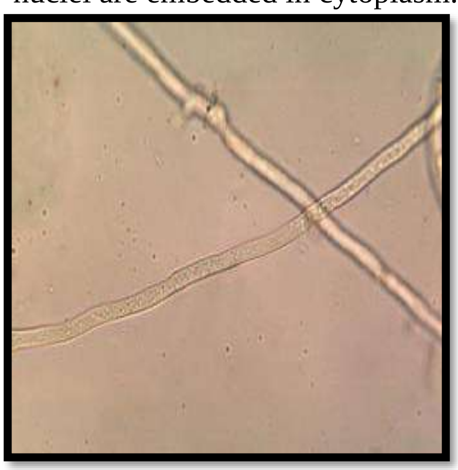
Endophytic fungus: If the fungus penetrates into the host cell / present inside the host, it is called endophytic.Eg. *Puccinia*. Endophytic fungus may be **intercellular** (hypha grows in between the cells), or **intra cellular** (hypha penetrates into host cell).Eg.Ustilago, or **vascular** (xylem vessels) Eg. *Fusarium oxysporum*

Inter cellular hyphae produce special organs called haustoria which penetrate the host cell and absorb food. These are absent in intracellular hyphae. Endophytic intra cellular mycelium absorb food directly from protoplasm with out any specialized structures.

In ectophytic mycelium, haustoria are produced in epidermal cells.

Septation in Fungi :(septum=hedge/partition) (pl.septa)

Some fungal hyphae are provided with partitions or cross walls which divide the fungus into a number of compartments /cells. These cross walls are called septa. **Aseptate hypha/coenocytic hypha:** (Koinos=common,kytos=hollow vessel) A hypha with out septa is called aseptate /non-septate/ coenocytic hypha wherein the nuclei are embedded in cytoplasm.Eg. lower fungi like Oomycetes and Zygomycetes.



Eg.common in higher fungi like Ascomycotina, Basidiomycotina and Deuteromycotina

General types of septa:

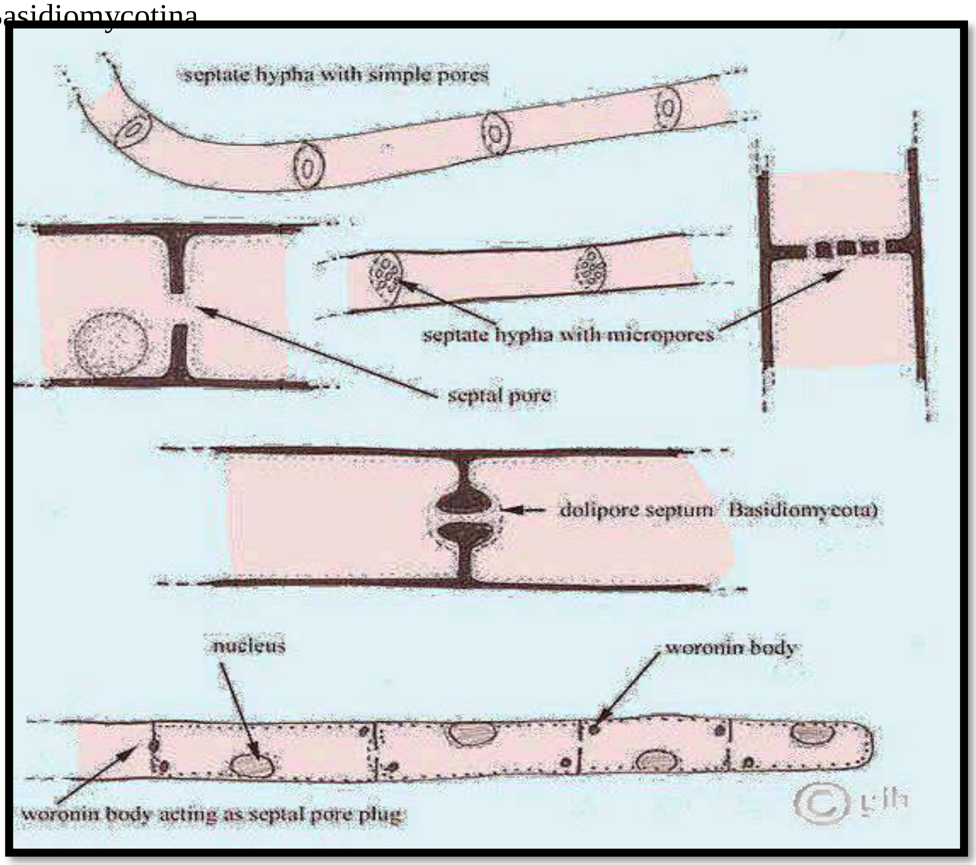
1.Based on formation:

a)Primary septa : These are formed in direct association with nuclear division (mitotic or meiotic) and are laid down between daughter nuclei separating the nuclei /cells. Eg. Higher fungi like Ascomycotina and Basidiomycotina. **b)Adventitious septa:** These are formed independent of nuclear division and these are produced to delimit the reproductive structures. Eg. lower fungi like Oomycetes and Zygomycetes in which septa are produced below gametangia (sex organs) which separate them from rest of the cells.

2. Based on construction:

a)Simple septa: It is most common which is a plate like, with or without perforation.

b)Complex septa: A septum with a central pore surrounded by a barrel shaped swelling of the septal wall and covered on both sides by a perforated membrane termed the septal pore cap or parenthosome. Eg. Dolipore septum in Basidiomycotina.



3.Based on perforation:

a)Complete septa: A Septum is a solid plate without any pore or perforations.

Eg. Adventitious septa in lower fungi.

b)Incomplete septa: A septum with a central pore.

Fungal tissues: Plectenchyma :(plekein=to weave+enchyma=infusion**)**

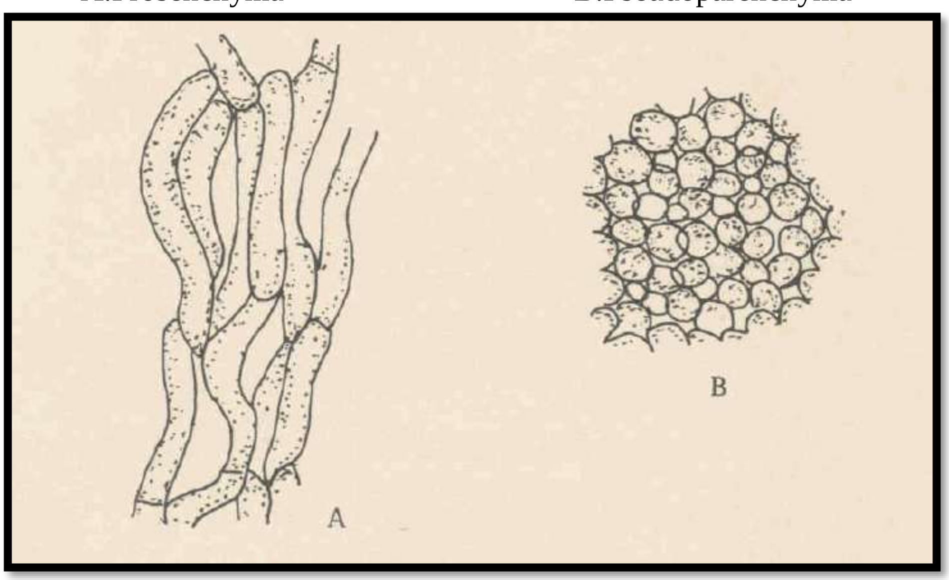
Fungal tissues are called plectenchyma i.e., mycelium becomes organized into loosely or compactly woven tissue. This tissue compose various types of vegetative and reproductive structures.

T ypes of plectenchyma:

1.Prosenchyma: It is a loosely woven tissue. The component hyphae retain their individuality which can be easily distinguishable as hyphae and lie parallel to one another.Eg. Trauma in *Agaricus.*

2. Pseudoparenchyma:It is compactly woven tissue. It consists of closely packed cells which are isodiametric or oval in shape resembling parenchymatous cells of plants and hence the name. The component hyphae loose their individuality and are not distinguishable as hyphae. Eg. Sclerotial bodies of *Sclerotium* and rhizomorph of *Armillariella.*

A.Prosenchyma B.Pseudoparenchyma



MODIFICATION OF MYCELIUM/ SPECIALISED SOMATIC STRUCTURES

Purpose :

1. to obtain nourishment i. e., for nutrition .
2. to resist or tolerate unfavourable conditions for their survival i.e., over wintering, over summering.
3. for reproduction.

1.Rhizomorphs: (rhiza=root, morph=shape) Thick strands of somatic hyphae in which the hyphae loose their individuality and form complex tissues that are resistant to adverse conditions and remain dormant until favourable conditions return. The structure of growing tip of rhizomorphs res emble that of a root tip, hence the name rhizomorph. Eg. *Armillariella mellea*

2.Sclerotium: (skleron=hard) pl.sclerotia: It is a hard, round (looks like mustard seed)/ cylindrical or elongated (*Claviceps*) dark coloured (black or brown)resting body formed due to aggregation of mycelium, the component hyphae loose their individuality , resistant to unfavourable conditions and remain dormant for a longer period of time and germinate on the return of favourable conditions.

Eg. *Sclerotium, Rhizoctonia* .

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

a. Sub stomatal stroma: cushion like structure formed below epidermis in sub stomatal region from which sporophores are produced. Eg. *Cercospora personata.*

b. Perithecial stroma: When reproductive bodies like perithecia of some fungi are embedded characteristically throughout periphery of stroma, such stroma are called perithecial stroma. Eg.*Claviceps, Xylaria.*

4. Haustorium: (hauster=drinker) pl.haustoria.It is a outgrowth of somatic hyphae regarded as special absorbing organ produced on certain hyphae by parasitic fungi for obtaining nourishment by piercing into living cells of host. They may be knob like(*Albugo),* elongated *(Erysiphe, Uncinula),* finger like (*Peronospora).*

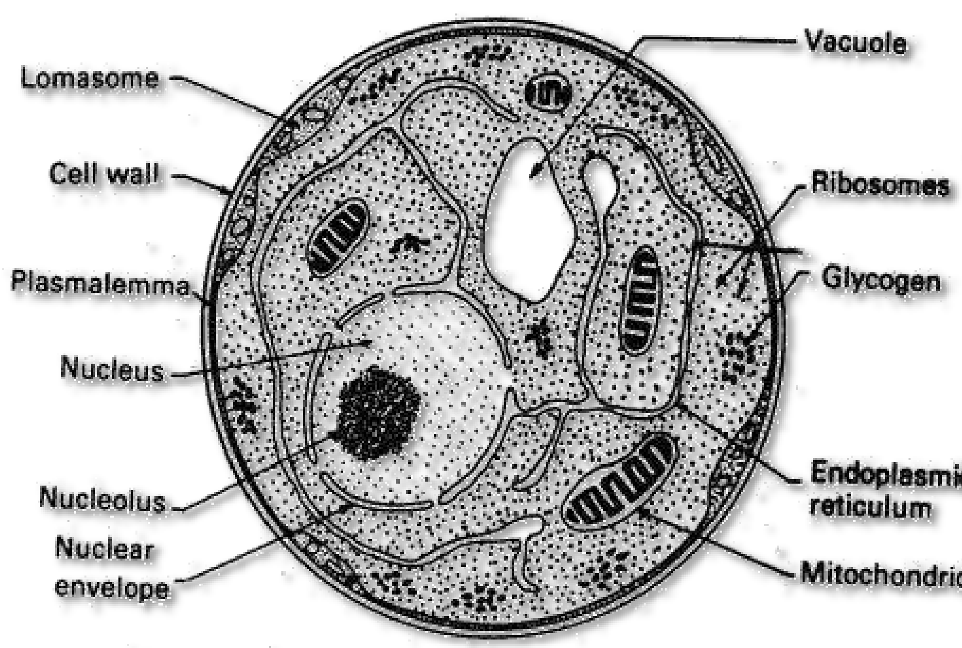
5.Rhizoids: (rhiza=root, oeides=like) These are slender root like branched structures found in the substratum produced by some fungi which are useful for anchoring the thallus to substratum and for obtaining nourishment from the substrate.Eg. *Rhizopus stolonifer.*

6. Appresorium: (apprimere=to press against) pl.appressoria A flattened tip of hyphae or germ tube acting as pressing organ by attaching to the host surface and gives rise to a minute infection peg which usually grows and penetrates the epidermal cells of the host. Eg. *Puccinia, Colletotrichum, Erysiphe.*

Fungal cell :

Fungal cells are typically eukaryotic and lack chloroplasts.

Cell is bounded by cell wall, which provides rigidity and shape to the cell is the outermost membrane of cell consisting of more than one layer with fibrous structure and made up of chitin or cellulose or both.



Diagrammatic representation of the ultrastructure of a cross section of a typical fungus cell.

The layer surrounding the cytoplasm is called cytoplasmic membrane or plasmalemma. Protoplasm contains a true nucleus surrounded by two layered membrane with nucleolus, cytoplasm and other inclusions.

Endoplasmic reticulum is not well developed, and it may be rough atudded with ribosomes or smooth with out ribosomes.

Vacuoles in which metabolic products are accumulated are bounded by a membrane called tonoplast .

Ribosomes are protenaceous bodies scattered all over cytoplasm, play a role in protein synthesis.

Mitochondria are the sites of respiratory activities.

Lomasomes are the swollen membranous structures of plasmalemma.

Cytoplasm also contains fat particles, calcium oxalate crystals, resins, glycogen.

Fungal nutrition:

Fungi are heterotrophic with holophytic nutrition(absorptive type). The essential elements for fungi are, C, H, O, N, P, K, S, Zn, Fe, Mg, Mn, Mo, Cu and Ca. Reserve food material in the c ell may be either fat or carbohydrates. Fats may be present in the form of oil drops and carbohydrates in the form of glycogen or sugars. Starch is never present in the fungal cell.

Groups of fungi based on mode of nutrition:

1. Saprophytes: (sapros=rotten, phytos=plant) Organisms which obtain nutrition on from dead organic matter either completely or for a part of their life. A large number of fungi fall under this category.

Eg. *Saprolegnia, Rhizopus, Mucor, Alternaria.*

a. **Obligate saprophytes:** (obligare =to bind it self) Organisms which can never grow on living organisms or can never obtain their food from living source. They get their food only from dead organic matter.

Eg. *Mucor, Agaricus* .

. **b. Facultative parasite:** (facultas=ability) Organisms which are usually saprophytic but have ability to become as parasites.

Eg. *Pythium aphanidermatum, Fusarium solani, Rhizoctonia solani.*

2.Parasites: Organisms which live within or out side another organisms for their nutrition either completely or for a part of their life .

Pathogen : If a parasite damages the host then they are called as pathogens..

All pathogens are not parasites and all parasites need not be pathogens .

a.Obligate parasites: (Organisms which obtain food only from living organisms (living protoplasm) and can never derive their food from dead organic matter or artificial medium. Eg. *Puccinia graminis* , *Plasmopara viticola* .

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

Reproduction in fungi :

Reproduction is the formation of new individuals having all the characteristics of the species.

T ypes of reproduction: 1. Asexual /non-sexual / vegetative / somatic reproduction 2. Sexual reproduction.

1.**Asexual reproduction :**

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

Asexual spores are formed after mitosis, hence also called mito spores.

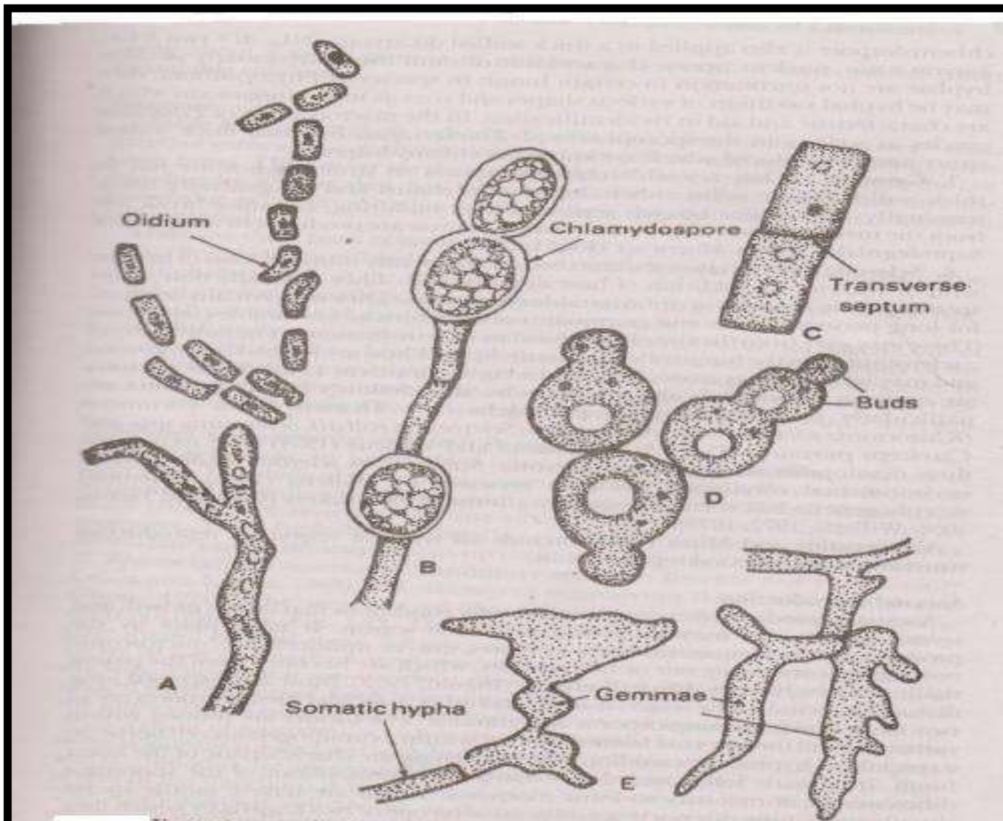
Methods of asexual reproduction :

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

1. Fragmentation : It is the most common method. Hypha of fungus breaks into small pieces, each broken piece is called a fragment, which function as a propagating unit and grows into a new mycelium.The spores produced by fragmentation are called **arthrospores** (arthron=joint) (spora=seed) or oidia..

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

2. Fission / Transverse fission: The parent cell elongates,nucleus under go mitotic division and forms two nuclei, then the contents divide into equal halves by the formation of a transverse septum and separates into two daughter cells.Eg.*Saccharomyces cerevisiae.*



Vegetative reproduction. (A) Fragmentation of hypha to form oidia. (B) Chlamydospores. (C) Fission. (D) Budding. (E) Gemmae formation.

3.Budding: The spores formed through budding are called **blastospores**. The parent cell puts out initially a small out growth called bud / blastos ie.,sprout or out growth which increases in size and nucleus divides, one daughter nucleus accompanied by a portion of cytoplasm migrates into bud and the other nucleus remains in the parent cell. Later, the bud increases in size and a constriction is formed at the base of bud, cutting off completely from parent cell . Bud, when separated from parent cell, can function as an independent propagating unit.Sometimes multiple buds are also seen i.e., bud over bud and looks like pseudomycelium. Eg. *Saccharomyces cerevisiae.*

4. Sporulation (spores): The process of production of spores is called sporulation.

Spore: It is a minute, simple propagating unit of the fungi, functioning as a seed but differs from it in lacking a preformed embryo that serves in the reproduction of same species.

Spores vary in colour,size,number of cells and the way in which they are borne.

There are 2 main types of spores.

1. Sporangiospores **2. Conidia**

1.Sporangiospores: When the asexual spores are produced internally, within the sporangia,such spores are called sporangiospores.The sac like structure which produces sporangiospores is called sporangium. The special hypha bearing sporangium is called sporangiophore which may or may not be distinguishable from hypha. A small sporangium with or without columella containing a few or single spore is called as sporangiolum.

Eg. *Choanephora trispora* .

Sporangium which is cylindrical in shape is called as merosporangium.

Eg. *Syncephalastrum racemosum.*

Sporangium with columella is called as columellate sporangium.

Eg.*Rhizopus stolonifer*

Sporangiospores are of 2 types.

a. Zoospores /planospores **b.Aplanospores**

a.Zoospores / planospores: sporangiospores which are motile by flagella are called zoospores.Also known as planospores.Eg. *Pythium, Phytophthora.* **b.Aplanospores**:

Flagellation in fungi:

Flagella : (sing.flagellum)Flagella are thin, hair like delicate structures attached to a basal granule called blepharoplast in cytoplasm and these are the organs of motility in lower fungi and aquatic fungi.

T ypes of flagella : Flagella of zoospores are of **2** types**.**

a.Whiplash **b.Tinsel**

a)Whiplash : A flagellum with long, thick, rigid basal portion and with a short, narrow, flexible, upper portion .It gives a whip like appearance to flagellum.

b)Tinsel : It is a feathery structure consisting of a long rachis with lateral hair like projections called mastigonemes or flimmers on all sides along its entire length.

The number, position and nature of flagella play an important role in the classification of lower fungi.

Uniflagellate zoospore : A zoospore with a single flagellum, may be placed at anterior or posterior end of spore.

Biflagellate zoospore:A zoospore with two flagella, situated laterally or anteriorly on zoospore.

One whiplash,one tinsel type flagella and equal in size.Eg. *Pythium aphanidermatum, Phytophthora infestans*

Both whiplash flagella,unequal in size (heterokont).Eg .*Plasmodiophora brassicae.*

2. Conidia / Conidiospores: (konis=dust; oides=like) Conidia are non- motile asexual spores which may arise directly from somatic hyphae or from specialized conidiogenous cells (a cell from which conidia are produced) or on conidiophore (hypha which bear conidia).Conidia are produced freely on conidiophore ie.,at the tips or sides of conidiophore or may be produced in specialized asexual fruiting bodies viz., pycnidium, acervulus, sporodochium and synnemata.

Asexual fruiting bodies :

(a) Pycnidium: (pl.pycnidia) It is a globose or flask shaped fruiting body lined inside with conidiophores which produce conidia. It may be completely closed or may have an opening called ostiole.

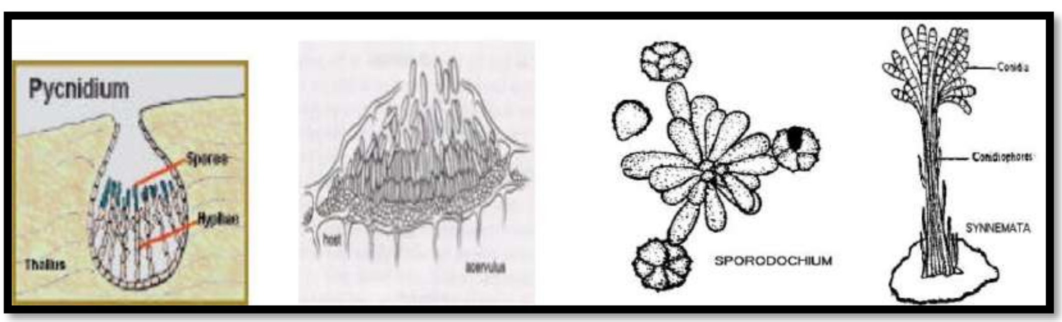
Pycnidium may be provided with small papillum or long neck. Eg.*Phomopsis.*

(b) Acervulus: (pl.acervuli) A flat or saucer shaped fruiting body with a stromatic mat of hyphae producing conidia on short conidiophores.

An acervulus lacks a definite wall structure and not having an ostiole or definite line of dehiscence. Eg.*Colletotrichum,Pestalotiopsis.*

(c) Sporodochium : (pl.sporodochia**)** A cushion shaped asexual fruiting body. Conidiophores arise from a central stroma and they are woven together on a mass of hyphae and produce conidia.Eg.*Fusarium.*

(d) Synnemata: (pl.synnema) A group of conidiophores often united at the base and free at the top. Conidia may be formed at its tip or along the length of synnema, resembling a long handled feather duster.Eg.*Graphium.*



Pycnidium **Acervulus** **Sporodochium** **Synnemata**

SEXUAL REPRODUCTION

Sexual reproduction involves union of two compatible nuclei or sex cells or sex organs or somatic cells or somatic hyphae for the formation of new individuls. Sexual stage is perfect stage and technically called as teleomorphic stage. Sexual cycle normally occurs once in the life span of the fungus. Sexual spores or sexual structures which contain sexual spores are thick walled, resistant to unfavourable conditions and are viable for longer period and thus these spores help the fungus to perpetuate from one season to another , hence these are called as resting spores.Sexual spores are definite in number.

Sex organs of fungi :

Gametangia: Sex organs of fungi are called gametangia containing gametes or gamete nuclei.

Gametes: Sex cells are called as gametes .

Antheridium: (pl.antheridia) Male gametangium is called as antheridium. Male gametangium is small and club shaped.

Oogonium / Ascogonium:(pl.oogonia/ascogonia):The female gametangium is called Oogonium (oomycetes) or ascogonium (ascomycotina).Female gametangium is large and globose shaped.

Male gametes are called antherozoids or sperm or spermatozoids .

Female gametes are called egg or oosphere.

Planogametes: If gametes are motile, they are called planogametes.

Isogametangia: If gametangia are morphologically similar or identical i.e.,indistinguishable as male and female , they are called as isogametangia.

Isogametes: If gametes are similar morphologically, they are called as isogametes.

Heterogametangia: If gametangia differ morphologically in size and structure, they are called as heterogametangia.

Heterogametes: If gametes differ morphologically, they are called heterogametes.

+ **or – signs:** In some sexually undifferentiated fungi, male and female are symbolically designated as ' + ' (male) and ' – ' (female).

Classification of fungi based on sex :

1. Monoecious fungi / hermaphroditic fungi: (mono=single,oikos=home)
The fungi which produce distinguishable male and female sex organs on the same thallus, which may or may not be compatible are called monoecious/ hermaphroditic fungi. Eg. *Pythium aphanidermatum*.

2. Dioecious fungi: (di=two, oikos=home) The fungi which produce distinguishable male and female sex organs on two different thalli ie., there will be separate male and female thalli . Eg. *Phytophthora infestans.*

Classification of fungi based on compatibility ;

Homothallic fungi: Fungi in which both sexes occur on same thallus, which can reproduce sexually by it self with out the aid of another thallus ie., self compatible / self fertile are called homothallic fungi. Eg. *Pythium aphanidermatum.*

Heterothallic fungi: A fungal species consisting of self sterile (self incompatible) thallus requiring the union of two compatible thalli for sexual reproduction, regardless of the possible presence of both male and female organs on the same thallus. Heterothallic fungi are dioecious Eg. *Phytophthora infestans..*

Phases in Sexual reproduction:. There are 3 phases in sexual reproduction.

1. **Plasmogamy**: union of two protoplasts takes place.As a result of it the two nuclei come together within the same cell.
2. **Karyogamy**: union of 2 sexually compatible nuclei brought together by plasmogamy to form a diploid nucleus (2n) i.e., zygote.

3. **Meiosis**: This is reduction division . The number of chromosomes is reduced to haploid (n) i.e., diploid nucleus results into haploid nucleus..

In lower fungi (Phycomycetes -Mastigomycotina and Zygomycotina) plasmogamy, karyogamy and meiosis occurs at regular intervals / sequence i.e.,karyogamy follows immediately after plasmogamy. In higher fungi (Ascomycotina, Basidiomycotina), karyogamy is delayed, as a result the nuclei remain in pairs (dikaryotic phase- n+ n condition), which may be brief or prolonged.

Dikaryon : A pair of genetically different nuclei, lying side by side with out fusion for a considerable period of time is called dikaryon.A cell containing dikaryon is called **dikaryotic cell**. And the process is known as **dikaryogamy**.

Methods of sexual reproduction : 5 methods.

1. Planogametic copulation. 2. Gametangial contact 3. Gametangial copulation
4. Spermatisation 5. Somatogamy .

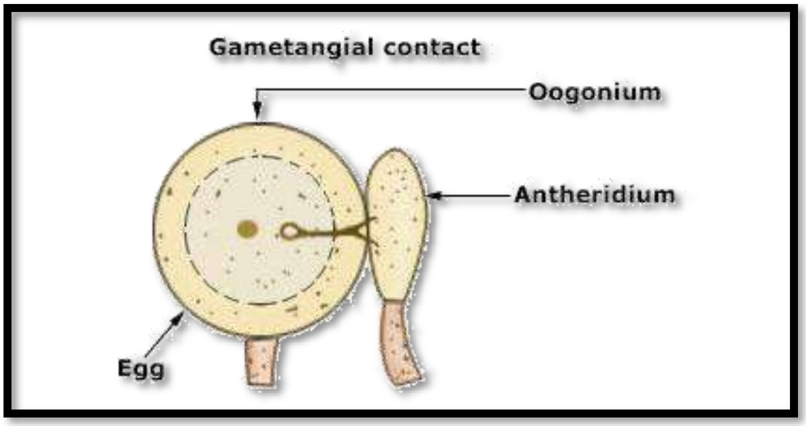
1.Planogametic copulation (gametogamy): This involves the union of 2 naked gametes one or both of which are motile.

a.Isogamy (Isogamous planogametic copulation) : If both gametes are motile and similar.Eg. *Plasmodiophora brassicae.*

b.Anisogamy (Anisogamous planogametic copula tion) : If both gametes are motile but dissimilar.E g. *Allomyces macrogynus*

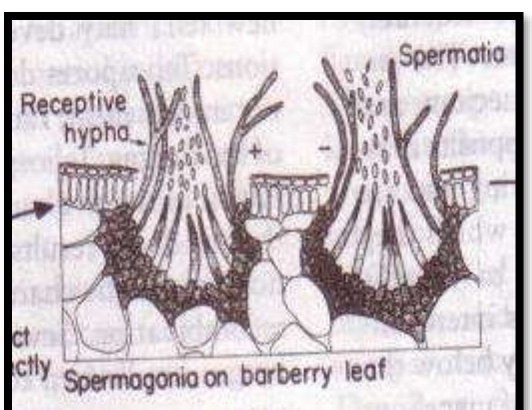
c.Heterogamy: If gametes are dissimilar, one motile, another is non motile. Eg. *Monoblepharis polymorpha.*

2.Gametangial contact (gametangy / oogamy): Male and female gametangia come in contact . At the place of contact, dissolution of wall occurs and a fertilization tube is formed. The conte nts of male gametangium migrate into female gametangium through a pore or fertilization tube developed at the point of contact. The gametangia do not loose their identity. E g. *Pythium aphanidermatum.*



3.Gametangial copulation (gametangiogamy): The isogametangia come ni contact, their intervening wall dissolves leading to fusion of entire contents of two contacting gametangia to form a single unit.Gametangia loose their identity.The protoplasts fuse and the unit increases in size. Eg. *Rhizopus stolonifer*.

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



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

Parasexual cycle / Parasexuality :Parasexual cycle is a process in which plasmogamy, karyogamy and haploidisation (non meiotic process) takes place in a sequence but not at specified points in the life cycle of a fungus. It was first discovered in 1952 by Pontecorvo and Roper in *Aspergillus nidulans*, the imperfect stage of *Emericella nidulans*.It is of importance in heterokaryotic fungi(a fungi in which genetically different nuclei are associated in the same protoplast or mycelium) .This is one of the methods of producing variability of fungal pathogens. In majority of Deuteromycotina,true sexual cycle is absent but derive many of the benefits of sexuality through this cycle.

Different types of sexual spores : Sexual spores are formed after meiosis,hence also called meiospores.

1.Oospores 2.Zygospores 3.Ascospores 4.Basidiospores

1**.Oospore:** A thick walled sexual resting spore produced by the union of two morphologically different gametangia.

Eg.*Pythium, Phytophthora* , members of class Oomycetes.

2. Zygospore: A thick walled sexual resting spore produced by the fusion of two morphologically similar gametangia.

Eg.*Rhizopus* , members of sub-division Zygomycotina

3. Ascospore:Sexual spore produced in a specialized sac like like structure known as ascus. Generally 8 ascospores are formed.

Eg.*Erysiphe*,members of sub-division Ascomycotina.

4.**Basidiospore:**Sexual spore produced on a club shaped structure known as basidium.Generally 4 basidiospores are formed.

Eg.*Puccinia*, members of sub-division Basidiomycotina.

Various Life cycle patterns displayed by fungi:

1. Haplobiontic life cycle 2. Diplobiontic life cycle

1. **Haplobiontic life cycle**: If there is only one free living thallus, which is haploid or diploid in life cycle of a fungus, it is called as haplobiontic life cycle.

(long haploid somatic phase and short diploid phase confined to zygote cell, which undergoes meiosis immediately after karyogamy and develop ascospores) Eg. *Schizosaccharomyces octosporus.*

2. **Diplobiontic life cycle:** If haploid thallus alternates with a diploid thallus, the life cycle is called diplobiontic life cycle, which has a long diploid somatic phase and a very short haplo Id phase. Eg. *Saccharomyces ludwigii.*

Nomenclature, Binomial system of nomenclature, rules of nomenclature

Taxonomy : The science of classification. It is concerned with pricnciples of classification.

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

Nomenclature : Art of naming living organisms.

Importance of taxonomy and nomenclature;

1. for study of fungi
2. for scientific communication between mycologists and plant pathologists throughout the world.

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

Some important rules of nomenclature :

1.According to International code of Botanical Nomenclature, the names of organisms should be binomial i.e., 2 parts.The first part is noun designating genus and the first letter of the genus name should be in capital. The second name is often an adjective, describing the noun which denotes the species, and the first letter should be in small letter. Eg. *Puccinia graminis.*

2.Binomials are usually derived from Greek or Latin.

3.Binomials when hand written should be underlined and when printed italicised. Eg.. Puccinia graminis (hand written)

Puccinia graminis (printed)

4. Citation of authors name: The full name or abbrevation name of scientist who described fungus first, follows the species name.Eg. *Puccinia graminis* Persoon or Pers.

5. Citation of two authors names: If name of species is transferred to another genus from original (*Botrytis infestans*), the name of first author who first described species must be kept in parenthesis followed by name of second author

who gave present status of species. *i.e., Phytophthora infestans.* Eg. *Phytophthora infestans* (Mont.) de Bary.

6. The taxa (groups) used in classification are Kingdom, Division, Class, Order, Family, Genus and Species.Each category may be sub divided into sub groups like Sub- Division,Sub- Class, Sub- Order.

7. Species is the unit of classification or basic taxonomic category (taxon).

8. Species some times broken into variety / formae speciales (f.sp.) and varieties into races and races into biotypes.

Standard endings of TAXA:

Division ends with **mycota**

Sub- Division ends with **mycotina**

Class with **mycetes**

Sub- class with **mycetidae**

Order with **ales**

Family with **aceae**

No special ending for genus and species.

TAXA:

Kingdom

Division

Sub-division

Class

Sub-class

Order

Sub-order

Family

Genera

Species

Eg. *Puccinia graminis tritici*race 1

Kingdom :Fungi

Division : Eumycota

Sub-division : Basidiomycotina

Class : Teliomycetes

Order : Uredinales

Family : Pucciniaceae

Genus : Puccinia

Species : graminis

Variety : tritici

Race : 1

Classification of fungi. Key to divisions, sub-divisions, orders and classes.

CLASSIFICATION OF FUNGI

(CLASSIFICATION BY AINSWORTH, 1973)

KINGDOM: MYCOTA

DIVISIONS

MYXOMYCOTA	EUMYCOTA
CLASS	**SUB DIVISIONS**
PLASMODIOPHOROMYCETES	1. MASTIGOMYCOTINA
ORDER : PLASMODIOPHORALES	2. ZYGOMYCOTINA
FAMILY:PLASMODIOPHORACEAE	3. ASCOMYCOTINA
Eg.*Plasmodiophora*	4. BASIDIOMYCOTINA
	5.DEUTEROMYCOTINA

S.D : 1. MASTIGOMYCOTINA
CLASSES

1.CHYTRIDIOMYCETES
ORDER: CHYTRIDIALES
FAMILY: SYNCHYTRIACEAE
Eg. *Synchytrium*
2.OOMYCETES
ORDER: PERONOSPORALES
FAMILY: PYTHIACEAE
Eg: *Pythium, P hytophthora*

FAMILY: ALBUGINACEAE
Eg. *Albugo*
FAMILY: PERONOSPORACEAE
Eg : *Sclerospora . Peronospora,Peronosclerospora*

Plasmopara , Pseudoperonospora, Bremia
S.D :2**.** ZYGOMYCOTINA
CLASS :ZYGOMYCETES

ORDER: MUCORALES
FAMILY: MUCORACEAE
Eg. *Rhizopus, Mucor*
S.D 3. ASCOMYCOTINA
CLASSES

1 .HEMIASCOMYCETES
ORDER:
PROTOMYCETALES
FAMILY: PROTOMYCETACEAE
Eg. *Eurotium, Talaromyces*

2 .PLECTOMYCETES
ORDER:
EUROTIALES

FAMILY: EUROTIACEAE

ORDER : ERYSIPHALES

FAMILY:ERYSIPHACEAE

Eg. *Erysiphe, Leveillula, Phyllactinia, Uncinula, Sphaerotheca,Podosphaera, Microsphaera*

3.PYRENOMYCETES

ORDER: HYPOCREALES

FAMILY: CLAVICIPITACEAE

Eg. *Claviceps*

4.DISCOMYCETES

ORDER: TUBERALES

FAMILY: TUBERACEAE

Eg. *Tuber*

ORDER: PEZIZALES

FAMILY: MORCHELLACEAE

Eg. *Morchella*

5.LOCULOASCOMYCETES

ORDER: PLEOSPORALES

FAMILY: VENTURIACEAE

Eg. *Venturia*

FAMILY: PLEOSPORACEAE

Eg. *Cochliobolus*

ORDER: MYRIANGIALES

FAMILY: MYRIANGIACEAE

Eg. *Elsinoe*

ORDER: DOTHIDIALES

FAMILY: DOTHIDIACEAE

Eg. *Mycosphaerella*

S.D 4. BASIDIOMYCOTINA

CLASSES

1.TELIOMYCETES

ORDER: UREDINALES

FAMILY: PUCCINIACEAE

Eg.*Puccinia, Uromyces, Hemileia*

FAMILY: MELAMPSORACEAE

Eg. *Melampsora*

ORDER: USTILAGINALES

FAMILY: USTILAGINACEAE

Eg. *Ustilago, Sphaecelotheca,Tolyposporium*

FAMILY: TILLETIACEAE

Eg. *Tilletia, Neovossia, Urocystis*

FAMILY: GRAPHIOLACEAE

Eg. *Graphiola*

2.HYMENOMYCETES

SUB CLASS: HOLOBASIDIOMYCETIDAE

ORDER : AGARICALES

FAMILY: AGARICACEAE

Eg. *Agaricus, Volvariella, Pleurotus*

ORDER: APHYLLOPHORALES

FAMILY: POLYPORACEAE

Eg. *Polyporus, Fomes, Peria*

FAMILY: GANODERMATACEAE

Eg. *Ganoderma*

S.D 5 DEUTEROMYCOTINA

CLASSES

1.COELOMYCETES

ORDER: SPHAEROPSIDALES

FAMILY: SPHAEROPSIDACEAE

Eg. *Phoma, Phomopsis, M acrophomina,*

Phyllosticta, Diplodia,Botryodiplodia

FAMILY:EXCIPULACEAE

Eg. *Ephelis*

FAMILY: NECTRIOIDACEAE

Eg. *Zythia*

FAMILY: LEPTOSTROMATACEAE

Eg. Leptostroma

ORDER: MELANCONIALES

FAMILY: MELANCONIACEAE

Eg. *Colletotrichum, Gloeosporium,*

Pestalotiopsis, Pestalotia

2.HYPHOMYCETES

ORDER: HYPHOMYCETALES / MONILIALES

FAMILY: MONILIACEAE

Eg. *Pyricularia, BotrytIs, Verticillium,*

FAMILY: DEMATIACEAE

Eg. *Alternaria ,Bipolaris, Cercospora, Phaeosariopsis*

ORDER: STILBELLALES

FAMILY: STILBELLACEAE

Eg. *Graphium*

ORDER : TUBERCULARIALES

FAMILY: TUBERCULARIACEAE

Eg. *Fusarium, Myrothecium*

ORDER : AGONOMYCETALES

FAMILY: AGONOMYCETACEAE

Eg. *Sclerotium,Rhizoctoni*

IMPORTANT CHARACTERISTICS OF DIVISIONS AND SUB-DIVISIONS

DIVISIONS :

1. **MYXOMYCOTA:** Plasmodial forms with out cell wall. Plasmodium is a naked multinucleate mass of protoplasm which moves and feeds in an amoeboid direction.Also calledcas slime molds.

   EUMYCOTA: True fungi. Thallus is typically filamentous with cell wall. Plasmodium absent

SUB DIVISIONS OF EUMYCOTA :

1. **MASTIGOMYCOTINA** :

Thallus is unicellular or aseptate mycelium.Asexual spores are zoospores (motile spores).Sexual spores are oospores. Sexual reproduction by gametangial contact.

2. **ZYGOMYCOTINA** :

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

3. **ASCOMYCOTINA :**

Thallus is septate mycelium. Rarely unicellular. Motile spores are absent. Asexual spores are conidia.Sexual spores are ascospores produced endogenously in an ascus.Sexual reproduction mainly by gametangial contact .

4. **BASIDIOMYCOTINA:**

Thallus is septate mycelium.Motile spores are absent.Clamp connections and dolipore septum are present.Sexual spores are basidiospores produced exogenously on basidium.Sexual reproduction is by spermatization and somatogamy.

5. **DEUTEROMYCOTINA:**

Thallus: septate mycelium . Motile spores are absent. Sexu al spores are absent. Asexual spores called conidia are present.

DIVISION - MYXOMYCOTA

CLASS :PLASMODIOPHOROMYCETES,ORDER:PLASMODIOPHORALES

FAMILY:PLASMODIOPHORACEAE

1. These are obligate endoparasites.Commonly called as endoparasitic slime molds . Thallus is a plasmodium,
2. There are 2 types of plasmodia.

a. **Sporangiogenous plasmodium** - formed asexually containing many thin walled zoosporangia and each zoosporangium produce a single or many secondary zoospores or sporangial zoospores.

b. **Cystogenous plasmodium** - formed sexually consisting of thick walled cysts and each cyst gives rise to a single primary zoospore / cyst zoospore. Cysts may be free or united.Cysts act as resting spores.

Zoospores are anteriorly biflagellte, whiplash type,unequal in size which are called as Heterokont zoospores. After swimming for some time, the zoospore encysts on the root hair of the host. A cylindrical sharp pointed body, called **satchel**, is formed in a specialized pouch or sheath called **Rohr**.

4.Nuclear division is by cruciform division.

5. Sexual reproduction is by isogamous planogametic copulation.
6. Members cause abnormal enlargement and multiplication of host cells i.e., hypertrophy and hyperplasia. Eg: *Plasmodiophora ,Spongospora*

Differences between *Plasmodiophora* and *Spongospora* :

***Plasmodiophora* :** Resting spores / cysts lie freely with in the host cell, but not in cystosorus.

Spongospora : Resting spores form balls and appear like sponge.

Diseases :*Plasmodiophora brassicae* : club root / finger & toe disease of cabbage / crucifers.

Spongospora subterranea : powdery scab of potato

DIVISION :EUMYCOTA

SUB - DIVISION: MASTIGOMYCOTINA

IMPORTANT CHARACTERISTICS OF CLASS CHYTRIDIOMYCETES:

1. Thallus (a) primitive members - unicellular, advanced members with coenocytic mycelium.

(b) endobiotic (fungus which lives with in the cells of host) or epibiotic (reproductive organs of the fungus on surface of the host, part or entire thallus with in the host cell).

(c) holocarpic or eucarpic.

2 .Zoospores are posteriorly uniflagellate whiplash type. Inside the zoospore, around the nucleus cell ribosomes cluster together to form a nuclear cap.

3. Asexual reproduction is by zoospores produced in zoosporangia.

4.Sexual reproduction is by (a) planogametic copulation (isogamy, anisogamy, heterogamy) . (b)gametangial copulation.

5. Zygote is converted into resting sporangium / resting spore. Zoospores produced from this resting spore infect host cell and produces prosorus
which is thick with golden-brown chitinous wall. Prosorus eventually gives rise to sorus. Eg.*Synchytrium.*

Important characteristics of Order: Chytridiales

1.Thallus is epibiotic or endobiotic, monocentric or polycentric, vegetative parts are rhizoidal .
2.Zoosporangium is operculate or inoperculate (operculum present or absent).
3.Zoospore germination is unipolar.
4.Resting spore on germination functions as a sporangium or prosporangium

Important characteristics of Family: Synchytriaceae :

Includes only single genus - *Synchytrium*, species - *endobioticum*.
Thallus is unicellular, endobiotic and holocarpic . Warts contain resting sporangia .
Thallus behaves as a prosorus.

Disease: Causes black wart of potato. It is prominent in hilly regions like Darjeeling.

Epidermal cells of tubers are infected by the fungus. Hypertrophy and hyperplasia takes place, as a result, out growths appear on tubers.

Diseases transmitted : *Synchytrium endobioticum* transmits potato virus - x .

IMPORTANT CHARACTERISTICS OF CLASS OOMYCETES

1. Members may be aquatic or terrestrial ,saprophytes or obligate parasites.
2. Thallus - mostly eucarpic ,coenocytic
3. Cell wall consists of cellulose. Chitin is absent.
4. Asexual reproduction is by zoospores produced in zoosporangia. Zoospores are biflagelte (whiplash and tinsel), anteriorly or laterally positioned, equal in size.
5. Sexual reproduction is oogamous type ie.,gametangial contact/ gametangy.. Heterogametangia come in contact, contents of antheridium (male gametangium) passes into oogonium(female gametangium) containing oosphere (egg) through fertilization tube.
6. Zygote resulting from sexual reproduction is called oospore.
7. Oospore is the sexual resting spore which is the characteristic of oomycetes.
8. This zygote/ oospore is diploid.Oospore which gives rise to mycelium/ gametangia is also diploid.
9. Meiosis o ccurs in gametangia instead of zygote.

IMPORTANTCHARACTERISTICS ORDER PERONOSPORALES:

1.Many species are destructive pathogens causing very serious diseases in some important crop plants.The diseases caused by these members include white rusts, downy mildews, damping off, leaf blights and seedling blights.

2.Members are mostly terrestrial.

3.Mycelium is coenocytic, produce inter and intra cellular hyphae.If inter – cellular produce haustoria.

4.Sporangia are produced on well developed, distinct sporangiophores and sporangia are deciduous (fall off at maturity).

5.Sporangiophores may be indeterminate / indefinite type (sporangiophores continue to grow indefinitely producing sporangia at the tip as they grow.ie.,sporangia of different ages are seen on sporangiophores) or determinate/definite type (sporangia are not produced until sporangiophores complete their development and maturity and all the sporangia are produced at one time.ie.,single crop of sporangia are produced.)

6.Zoospores are monomorphic (producing morphologically one type of zoospores i.e., reniform zoospores) and monoplanetic (only one swarming period.).

7.Zoospores are reniform ie., kidney shaped and biflagellate.

Some species exhibit highly specialized parasitism i.e., obligate parasites.

8.Oogonium produces a single oosphere / egg surrounded by conspicuous periplasm except in Family: Pythiaceae in which periplasm is inconspicuous. Periplasm serves as a source of nutrients to oosphere.

ORDER PERONOSPORALES :

Families: 1.Pythiaceae 2.Albuginaceae 3.Peronosporaceae

These three families are distinguished based on characteristics of sporangiophores and sporangia.

IMPORTANT CHARACTERISTICS OF FAMILY
1. PYTHIACEAE :

1.Species may be saprophytes or facultative parasites.Commonly called water molds.

2.May be inter or intra cellular mycelium.If inter cellular,produce haustoria, if intra cellular, no haustoria are produced.

3.Sporangiophores generally not distinguished from somatic hyphae unless sporangia are present.

4.Sporangiophores are indefinite or indeterminate type .

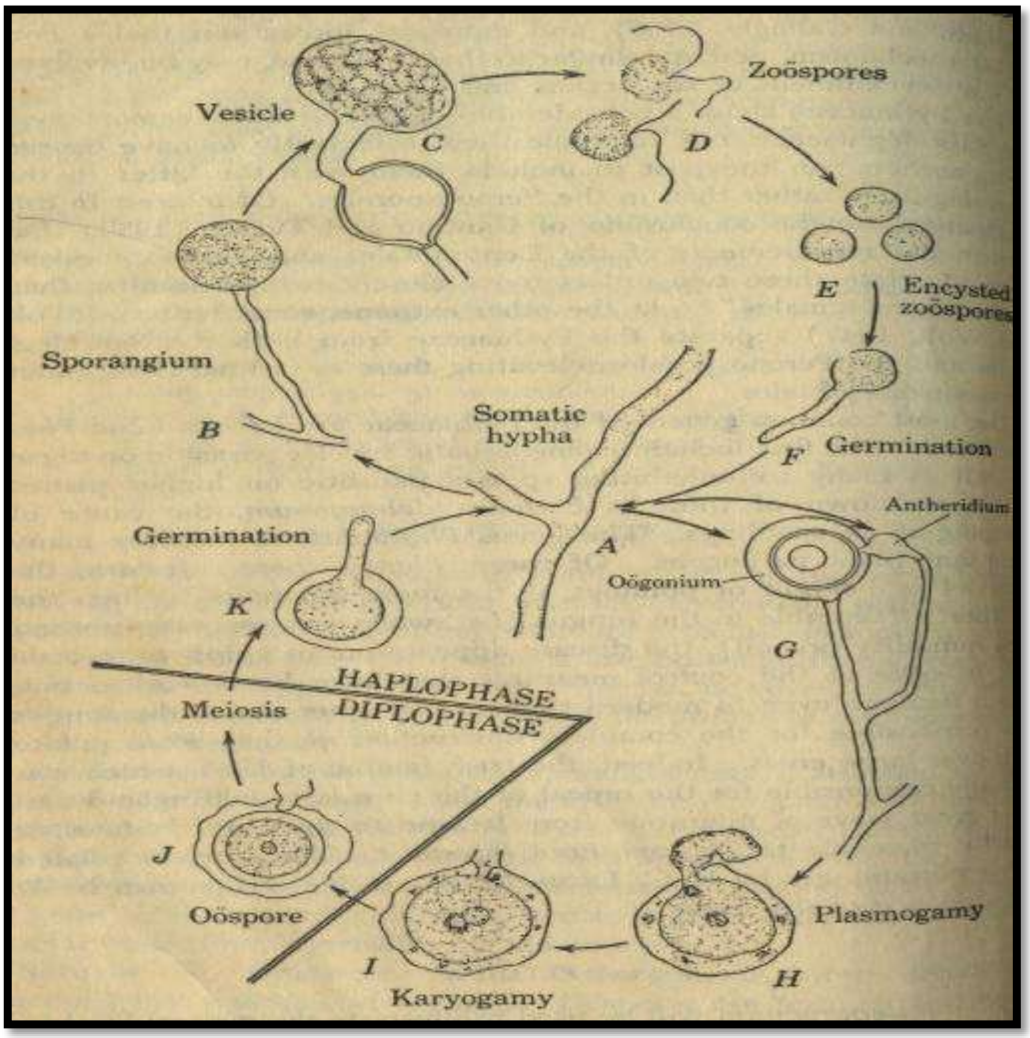
5.In oogonium ,Periplasm is inconspicuous (not visible).

Eg. *Pythium* and *Phytophthora*

Genus **PYTHIUM :**Fungus is facultative parasite and lives in soil on dead organic matter or parasitically on young seedlings of crop plants .Mycelium well developed,branched,coenocytic,hyaline,intracellular mycelium without haustoria. Thallus is homothallic.Asexual reproduction is through zoospores produced in zoosporangia . Sporangia are large globose(*P. debaryanum*) or irregularly lobed *(P.aphanidermatum)* produced terminally or intercalary on somatic hyphae.Zoospores are produced in a vesicle which emerge out of sporangium.ie.,zoospore differentiation takes place in vesicle.Sexual reproduction is by gametangial contact.**Paragynous** antheridium(Antheridium is by the side of oogonium).Oospores are smooth,thick walled,round,light brown and aplerotic (oospore wall do not fuse with oogonial wall) or plerotic (oospore wall fuses with oogonial wall).

Diseases: Damping off of vegetable seedlings of solanaceous crops caused by

Pythium debaryanum or *P.aphaniderma*



Genus **PHYTOPHTHORA :** (Phyto=plant,Phthora=destructor)

Fungus lives in soil on dead organic matter or parasitically on potato tubers. Mycelium is well developed,branched,coenocytic,hyaline,intercellular mycelium with haustoria.Thallus is heterothallic.

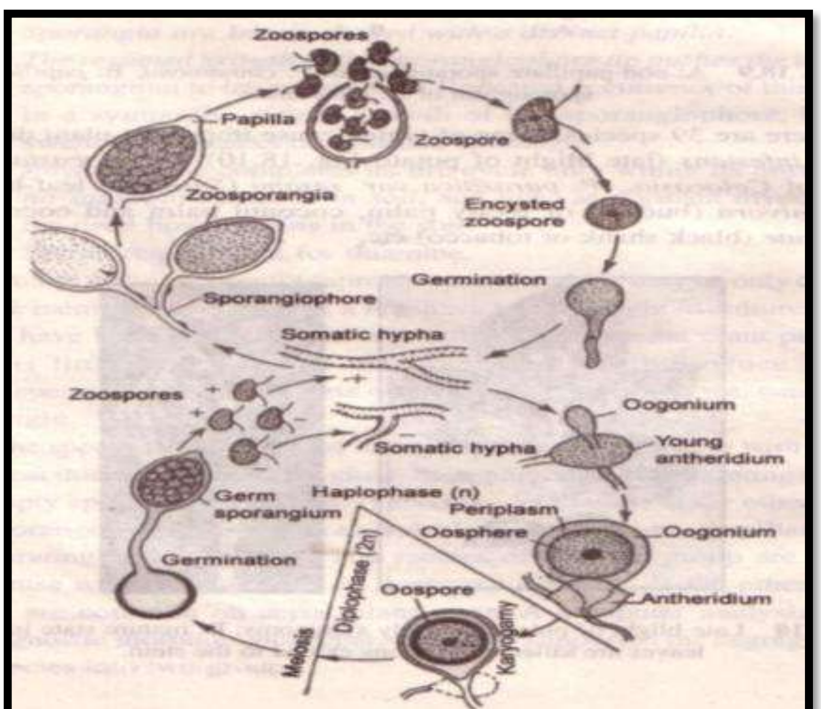
Asexual reproduction is by zoospores produced in sporangia.Sporangia are lemon or pear shaped,thin walled,papillate,formed terminally on sympodially branched sporangiophore (sympodium is with a more or less zig zag growth and characteristic swellings at nodes).Sporangiophores are distinct ie.,easily distinguished from somatic hyphae.Vesicle is not formed, zoospores are differentiated in zoosporangium it self.

Sexual reproduction is by gametangial contact.Antheridium is **amphigynous** (Oogonium penetrates the antheridium) or paragynous.Oospores are smooth,thick walled,round ,dark brown and plerotic.

Also produces resting spores called chlamydospores.

Diseases: *Phytophthora infestans* - Late blight of Potato

P. parasitica var. nicotianae - black shank and leaf blight of tobacco



Differences between *Pythium* and *Phytophthora*

Pythium	***Phytophthora***
1.Myceliumisbothinterand intracellular.Whenintracellular, no haustoria are produced.	Only intercellular. Haustoria are produced.
2. Production of sporangia on somatic hyphae. Sporangiophores are indistinct from hyphae.	Sporangiophores can be distinguished by sympodial branching and nodal swellings.
3.Sporangia are globose or elongated or lobed. They are produced intercalary or Terminally. No papillum.	Sporangia are lemon or pear or oval shaped. Produced terminally. Papillum is present.
4.Sporangia germinate by forming vesicle. Differentiation of zoospores takes Place in the vesicle.	No vesicle is seen. Zoospores differentiate in the sporangium .
5. Antheridium is of paragynous type.	Amphigynous type.
6. Homothallic	Heterothallic.
7.Asexual reproduction is by Zoospores in sporangia. 8.Oospores are plerotic / aplerotic.	Zoospores in sporangia and chlamydospores. Oospores are aplerotic
9.Appresorium not formed	Formed
10.Oospore hyaline,smooth	Brown,warty

FAMILY ALBUGINACEAE - IMPORTANT CHARACTERISTICS

1.Members are obligate parasites.
2.Mycelium is intercellular producing knob shaped haustoria.
3.Sporangiophores are specialized which are short, unbranched and club shaped.They are of indeterminate type.Sporangiophores are borne in close proximity to one another in compact layers or beds under the epidermis of the host.
4.Each sporangiophore gives rise to several aporangia which are produced in succession,one below the other,so that a chain of sporangia is formed with the oldest at the tip and youngest at the base (basipetal manner).
5.Sporangia are globose.Successive sporangia are connected by isthmus or disjunctor cell or separation disc.
6.Periplasm is conspicuous.
7.Single genus under the family i.e., *Albugo.*

The diseases caused by this genus are called white rusts. The term rust is restricted normally for the fungi belonging to the order Uredinales of class Teliomycetes of sub division Basidiomycotina and the diseases they cause. Since these white pustules resemble the pustules caused by true rusts in order Uredinales, the term white rust was coined to the group of diseases caused by *Albugo* sp. The white rusts also cause floral malformation and tumors on stems, leaves, petioles etc. due to hypertrophy of infected tissue.

Genus **ALBUGO:**

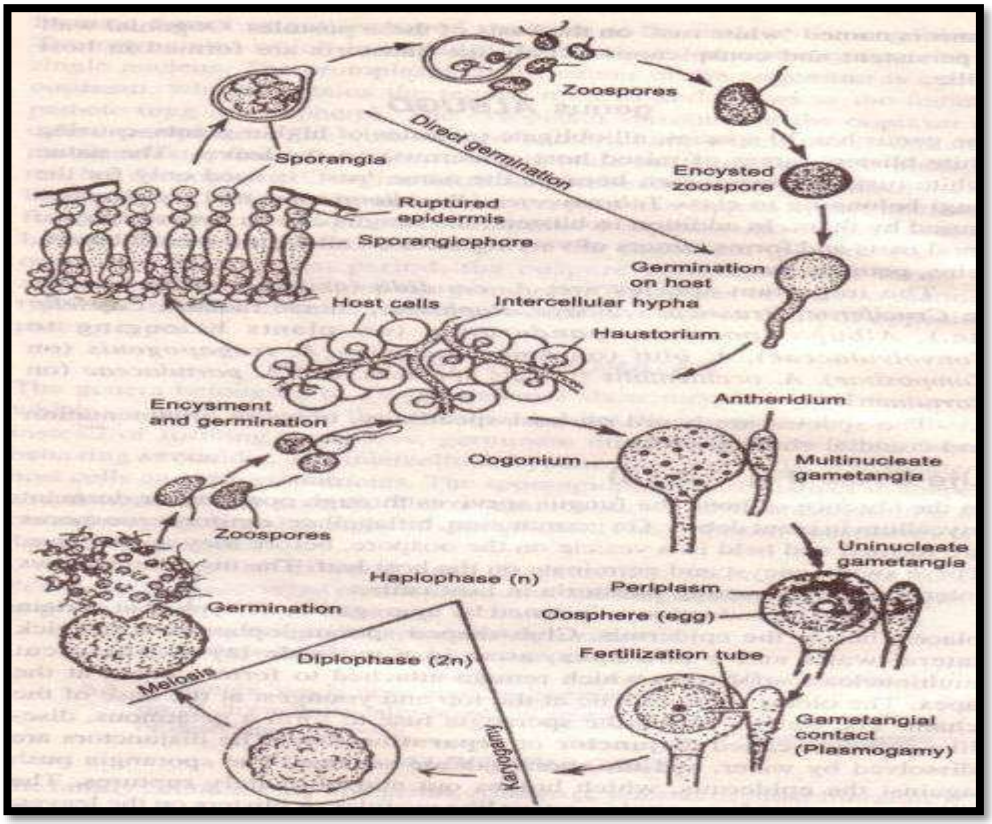
Fungus is an obligate parasite on crucifers and lives in soil in the form of oospores or parasitically on plants.

Mycelium iscoenocytic,hyaline,endophytic,intercellular with knob shaped haustotia.

Asexual reproduction is by zoospores produced in sporangia.Sporangiophores are unbranched,hyaline clavate,bears sporangia in chains in basipetal succession.Sporangia are spherical,thin walled,sessile, hyaline and germinate by zoospores.

Sexual reproduction is by gametangial contact.Oospores are round ,thick walled,dark brown and outer wall warty.

Diseases:White rust on mustard caused by *Albugo candida*



IMPORTANT CHARACTERISTICS OF FAMILY:3.PERONOSPORACEAE

1. All the members are obligate parasites of plants causing diseases called downy mildews.
2. Mycelium is coenocytic and intercellular with haustoria
3. Sporangiophores are well developed, specialized , characteristically branched and determinate type.Sporangiophores attain maturity and later produce sporangia at one time. ie.,single crop of sporangia are produced.

4.Sporangia deciduous, may be papillate (also called operculum) or may not be papillate. In most genera, sporangia germinate by zoospore. However, in some species they germinate by germ tube and function as conidia depending on environmental conditions.

5.Oospores may be plerotic or aplerotic.

6.Periplasm conspicuous.

The name downy mildews(downy= feathery or soft + mildew= superficial growth) is given because of soft feathery growth observed on the lower side of affected foliage consisting of sporangiophores of these fungi.

The members are further divided into different genera and distinguished based on two characteristics viz., 1. morphology of sporangiophore (branching pattern) 2. method of germination of sporangia.

Eg. *Peronospora, Pseudoperonospora, Peronosclerospora, Sclerospora, Plasmopara, Bremia, Sclerophthora.*

DISTINGUISHING CHARACTERISTICS OF DOWNY MILDEW GENERA:

1.***SCLESPORA****:*Sporangiophores are stout ,having upright branches, bearing sporangia on sterigmata.Sporangia are h yaline ,ovoid,smooth walled,papillate and germinate by zoospores.Oospore is plerotic.
Eg.*Sclerospora graminicola –downy mildew of bajra.*

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

3.*PERONOSCLEROSPORA :*Fungus possess characteristics of both *Peronospora* and *Sclerospora.*Sporangiophores are erect,short,stout,widening towards upper portion,dichotomously branched 2 -5 times at apex bearing sporangia on sterigmata.Sporangia are hyaline,elliptical or ovoid,thin walled, non-papillate and germinate by germ tube like *Peronospora.* Oospore is plerotic type like *Sclerospora.*
Eg.*Peronosclerospora sorghi*-downy mildew of jowar
P.philippinensis-downy mildew of maize

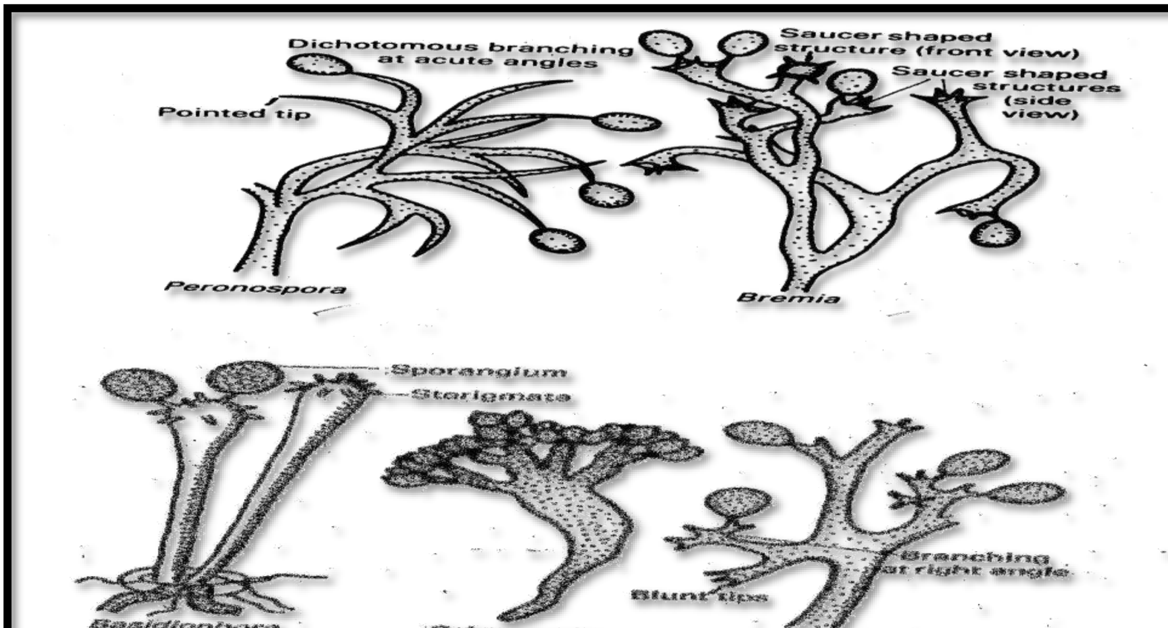


Fig. 4.59: Sporangiophores characteristic of five genera of the Peronosporaceae (Redrawn from Alexopoulos and Mims, 1979).

PSEUDOPERONOSPORA:Sporangiophores are branched at acute angles with curved,blunt tips,bearing sporangia on sterigmata.Sterigmata are unequal (1 big and 1 small).Sporangia are greyish,ovoid,papillate and germinate by zoospores. Eg.*Pseudoperonospora cubensis -downy mildew of cucurbits.*

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

6***.BREMIA*** :Sporangiophores are dichotomously branched ,tips of branches are expanded to cup shaped apophysis with four sterigmata bearing sporangia.Sporangia are ovoid,papillate and germinate by zoospores. Eg:*Bremia lactucae*-downy mildew of lettuce.

SUB-DIVISION: ZYGOMYCOTINA

CLASS: ZYGOMYCETES

IMPORTANT CHARACTERISTICS OF CLASS: ZYGOMYCETES, ORDER:MUCORALES:

1.Absence of motile zoospores (planospores) and production of non- motile sporangiospores (aplanospores).

2.Production of thick walled resting spore-zygospore

3.Well developed , coenocytic mycelium and cell wall with chitin

4.Asexual reproduction is by sporangiospores though some species produce Chlamydospores.

5.Sexual reproduction is by gametangial copulation of isogametangia or heterogametangia.

FAMILY:MUCORACEAE:

Eg.Rhizopus stolonifer

Genus:*Rhizopus:*

Rhizopus stolonifer, commonly called as bread mold is a general contaminant of several food materials. The fungus is mostly saprophytic but is a weak parasite.

1.Well developed coenocytic mycelium.Mycelium is differentiated into rhizoids, stolons and sporangiophores

2.Rhizoids / holdfast are a cluster of brown, slender, branched root like structures which arise from the lower side of stolons and penetrate into the substrarum. These are useful for anchoring the thallus into the substratum and for absorption of nutrients.

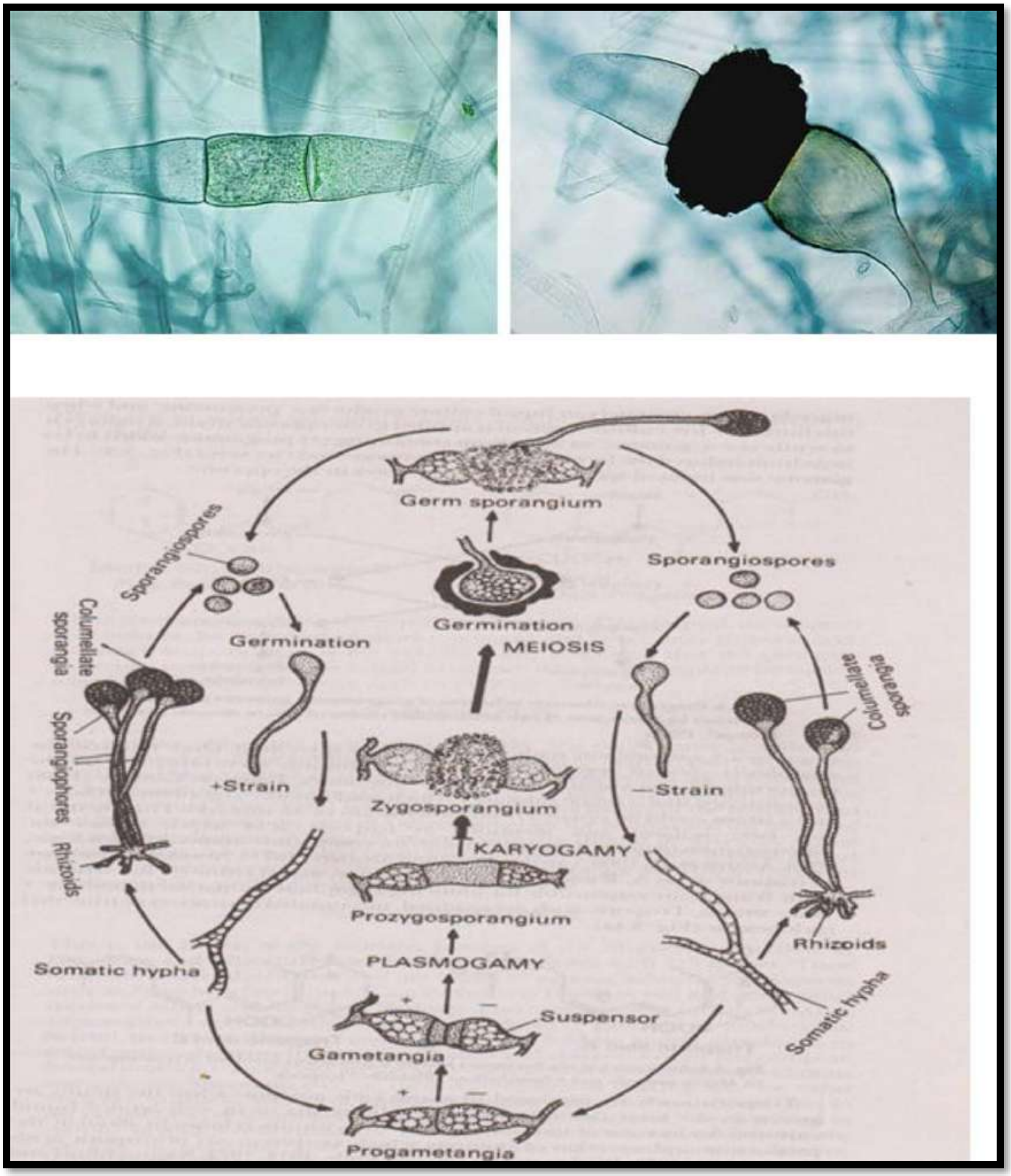
3.Stolons or runners are aerial hyphae which grow on the surface of substratum horizontally and connect the two nodal points (the junction of stolon and rhizoid or the point from which rhizoids are produced is called node).

4.Sporangiophores are erect, unbranched hyphae usually produced in fascicles (groups) only from the nodes during asexual reproduction. Each sporangiophore bears a single sporangium at its tip. Sporangia are large, globose , many spored with a sterile structure called columella.

5.Asexual reproduction is by non-motile sporangiospores which are uninucleate,globose,brown,smooth walled and are produced inside columellate sporangium.The sporangiospores are liberated by rupture of sporangial wall.The spores germinate under favourable conditions and gives rise to mycelium,

6.Fungus is heterothallic.Phenomenon of Heterothallism was discovered by in 1904 by A.F.Blakeslee.Heterothallism is favoured by sexual harmones called gammones or trisporic acid.

7.Sexual reproduction is by isogametangial copulation.Zygospores are thick walled,dark,warty sexual resting spores which develops in a zygosporangium. Diseases: Soft rot of sweet potato, fruits and vegetables.


Germ sporangium
Sporangiospores
Germination
Sporangiospores
Germination
MEIOSIS
Columellate sporangia
Sporangiophores
Rhizoids
+Strain
Zygosporangium
KARYOGAMY
−Strain
Columellate sporangia
Prozygosporangium
PLASMOGAMY
Somatic hypha
Rhizoids
Suspensor
Gametangia
Somatic hypha
Progametangia

SUB DIVISION: ASCOMYCOTINA

The members of sub division Ascomycotina are commonly called as sac fungi, because of production of sexual spores, ascospores in a sac like structure called ascus. The members of sub divisions Ascomycotina, Basidiomycotina and Deuteromycotina are also considered as higher fungi. The members are found in a variety of habitats . Some are parasitic on plants, some saprophytes living in soil or on decaying vegetable matter or grow on dung.

IMPORTANT CHARACTERISTICS OF SUB -DIVISION ASCOMYCOTINA :

1. Produce definite number (usually eight) of sexual spores (ascospores) in a sac like structure called ascus.
2. Mycelium is septate,branched and organized into tissues known as plectenchyma.
3. Production of sexual fruiting body called ascocarp in which asci are produced.
4. Absence of motile spores and presence of asexual spores called conidia.
5. Presence of a short dikaryotic phase in ascogenous hypha or

asc ogenous cell.

1. **Somatic characteristics**: Mycelium is septate and organized into fungal tissues. Some consists of septate hyphae except in a few cases like yeasts which are single celled. Mycelium is profusely branched. (except in yeasts) and th e hyphal walls containing chitin.In few species cellulose is also reported. The septum is simple, incomplete, perforated and have a central pore/ septal pore through which cytoplasm and nuclei move from one cell to another cell thus, cytoplasmic continuity is maintained.

2. **Fungal tissues**: Mycelium is mostly organized into fungal tissues known as plectenchyma. These tissues are chiefly associated with fruiting bodies called ascocarps viz.,cleistothecium,perithecium,apothecium and ascostroma.

3. **Asexual reproduction:Asexual stage is also called as anamorph or imperfect stage.** Asexual reproduction occurs by fission (Yeasts), budding (blastospores) (Yeasts),fragmentation(majority of fungi) chlamydospore and conidia. Conidia are short lived, indefinite(enormous) in number,may be produced directly from somatic hyphae, or from conidiogenous cells or from specialized hyphae called conidiophores. Conidiophores may be short or long,branched or unbranched or may form complex asexual fruiting bodies viz., pycnidium, acervulus, sporodochium and synnemata and the method vary with species and environmental conditions.

4. **Sexual reproduction**: Sexual stage is also called as teleomorph or perfect stage or ascigerous stage / state. Sexual spores are called ascospores which are produced in a sac like structure called ascus. The methods of sexual reproduction are gametangial copulation, gemetangial contact, spermatiz ation and somatogamy. The gametangia are antheridium (male sex organ) and ascogonium(female sex organ). Ascogonium is provided with a hair like structure called trichogyne (receptive neck of ascogonium), which is often long and functions as a fertilization tube.

5. **The asci may be formed by any of the following methods**.

A. **Direct** development of zygote into ascus - eg. In yeasts, the compatible nuclei brought together during plasmogamy, fuse (karyogamy) and the cells containing single diploid nucleus (zygote) directly develops into ascus.

B .**Indirect Development** of asci from ascogenous hyphae- eg. sexual reproduction and ascus development as exemplified by general life cycle pattern in *Pyronema omphalodes*.

6.Short dikaryotic phase is seen.Plasmogamy and karyogamy are separated both by space and time.

DEVELOPMENT OF ASCUS INDIRECTLY FROM ASCOGENOUS HYPHAE OR LIFE CYCLE OF *PYRONEMA OMPHALODES* :

1.The male sex organ is known as antheridium and the female sex organ is known as ascogonium.

2.During sexual reproduction,the male nuclei from the antheridium pass through the trichogyne into the ascogonium and pairs up with female nuclei to form dikaryon. (they do not fuse thus delaying karyogamy) .

3. The sexual act stimulate the ascogonium to produce a number of swellings/ papillae just opposite to groups of nuclei located in the periphery of the ascogonium.

4. The dikaryons in ascogonium multiply by conjugate division and as these swellings enlarge, the daughter nuclear pair from ascogonium begin to pass into swellings one by one.

5. Eventually, the swellings elongate into ascogenous hyphae. The nuclear pair or dikaryon in ascogenous hyphae undergoes conjugate divisions.Later, septa are formed in ascogenous hyphae in such a way that each cell of ascogenous hyphae is dikaryotic,except the terminal cell which is uninucleate.Thus,the dikaryotic phase in Ascomycotina is represented by ascogenous hyphae where in one nucleus is ascogonial origin and the other antheridial.

6.The penultimate binucleate cell of ascogenous hypha elongate s and bends over to form a hook like cell called as ‘ hook cell ‘ or ‘crozier ‘. The two nuclei in crozier cell undergoes conjugate division to form 4 nuclei.

7. Now septa are formed in hook cell in such a way that basal and apical cells consist of single nucleus each,and the middle cell consists of two nuclei.This binucleate middle cell is known as ‘Crook cell ’.

8.Crook cell enlarges and converted into ‘Ascus mother cell ’. Karyogamy takes place in ascus mother cell fusing two nuclei and forms diploid nucleus (2 n).

Thus, plasmogamy (in ascogonium) and karyogamy (in ascus mother cell) occur at different places.Meanwhile ascus mother cell elongates and develops into ascus.

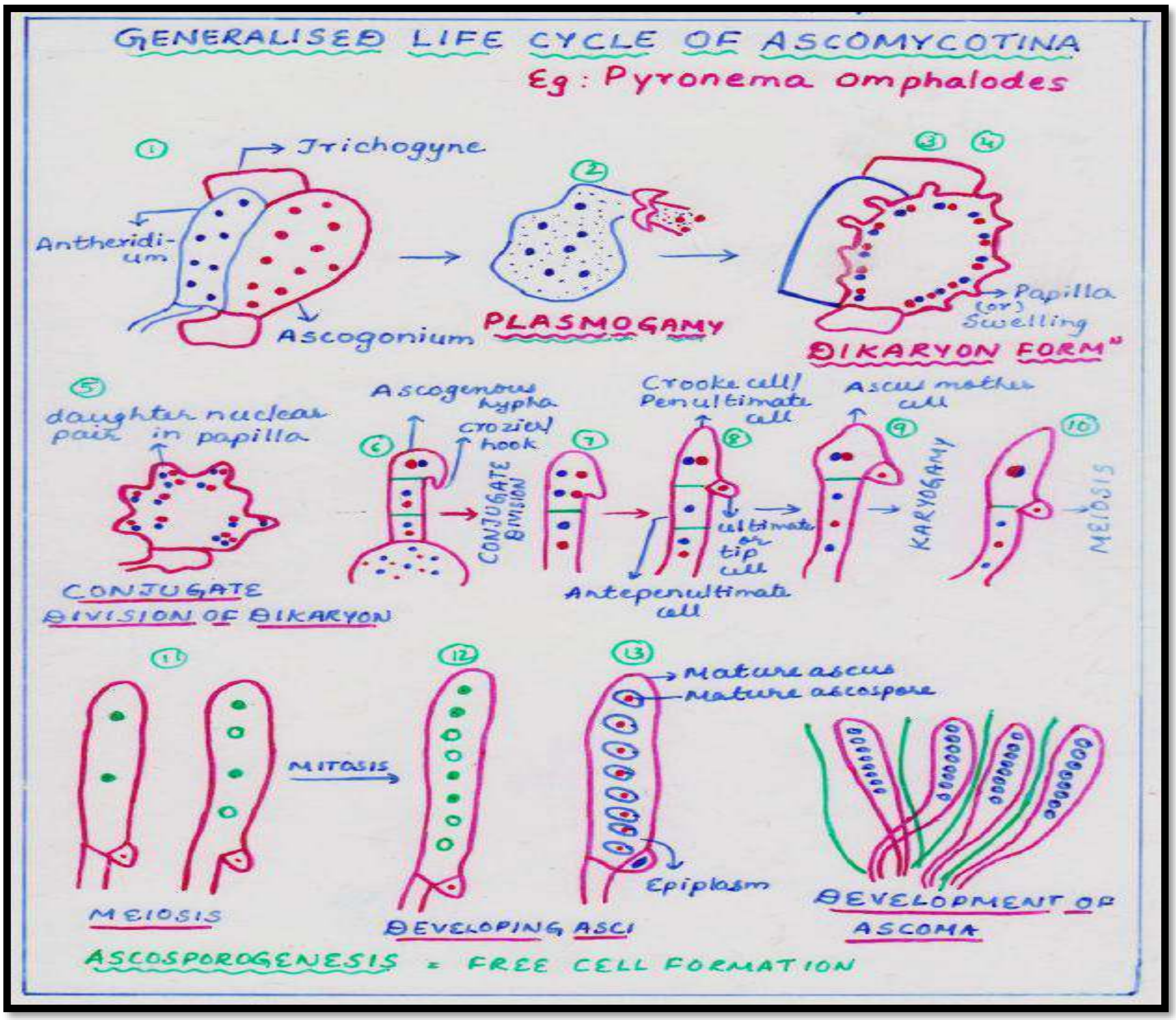
9.The diplod nucleus undergoes meiosis resulting in the formation of 4 haploid nuclei.

10.These 4 haploid nuclei further undergo mitosis forming 8 haploid nuclei.

11.The nuclei develop in to ascospores by reef cell formation.The process of formation of ascospores is called ‘Free cell formation’ or ‘Ascosporogenesis’. The ascospores are formed by aggregation of cytoplasm of the ascus around the nucleus forming definite walls. Epiplasm is the portion of cytoplasm left over, out side the ascospore walls , which supplies nutrients to the developing ascospores.

12. The number of ascospores may be 8, 16, 32, 64, or even more depending on the number of mitotic divisions following meiosis. The ascospores vary in shape, size and some times in color also.

13. Based on compatibility, the members may be homothallic(eg. *Aspergillus,* powdery mildew fungi) or heterothallic(E g.*Saccharomyces cerevisiae*).



MORPHOLOGY OF ASCI:

Ascus is a sac like structure usually containing a definite number of ascospores (typically eight) formed by a process called free cell formation after karyogamy and meiosis. In majority members of ascomycotina shape of ascus may be elongated, cylindrical , clavate or club shaped,except in some groups where they are globose or ovoid. Asci may be stalked or sessile. Generally ascus represents a single cell but in some ascus may be septate.

Origin of asci:

Asci may arise from a common place called fascicle and spread out like afan or they may arise singly and distributed irregularly at various levels in the fruiting body. They may also form at the base of the fruiting body in a definite layer called as hymenium. In some cases they are not produced in any fruiting body.

Types of asci based on structure of ascus wall:

The wall structure plays an important role in classifying the species.There are three types of asci based on structure of ascus wall.

1. **Prototunicate ascus**: This is the primitive type.The wall is very thin, dissolves at maturity and spores are released. The ascospores are released in a mucilaginous substance. Eg. *Eurotium*

2. **Unitunicate ascus:** The ascus wall consists of 2 layers which are rigid and unite together through out length and existence of the ascus. . The outer wall is called exotunica or exoascus and the inner wall is called endotunica or endoascus and not separated during spore release. The spores are released through a terminal pore, slit or operculum.E g. *Claviceps.*

ASCOCARPS:

Ascocarps are the fruiting bodies of members of Sub-division Ascomycotina which produce the asci containing the ascospores. In some members such as yeasts, *Taphrina* fruiting bodies are not produced and the asci are naked.

Types of ascocarps : 4 types.

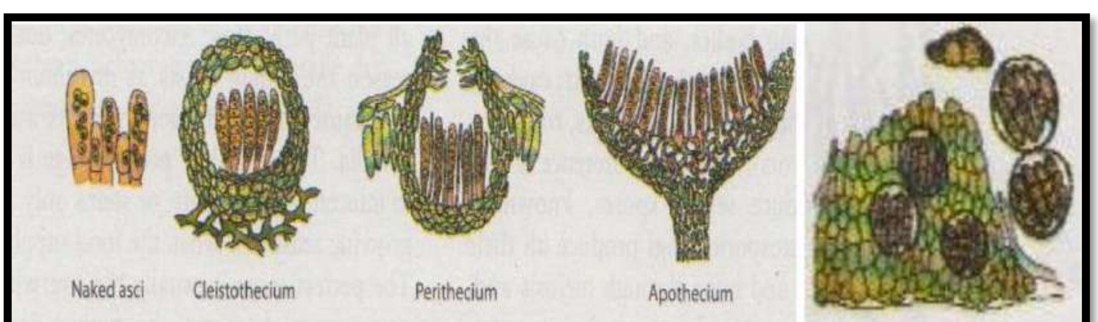
1. **Cleistothecium**: It is a completely closed ball like(globose) ascocarp and it is made up of a wall with pseudoparenchymatous tissue called as peridium. In some species these are provided with outer appendages. Asci are scattered or distributed at different levelsin ascocarp.When the asci are matured, ascospores are released by disintegration of peridium. Eg. *Eurotium, Erysiphe.*

2. **Perithecium**; It is a flask shaped more or less closed ascocarp but provided with a pore or opening at the tIp called true ostiole through which ascospores are released at maturity.Ostiole is lined inside with sterile structures called as periphysis. The wall is called peridium . The asci are arranged in definite layer called hymenium. In between the asci,there are sterile thread like structures called paraphyses which help in liberation of ascospores.Eg. *Claviceps, Xylaria.*

3. **Apothecium.:** It is an open cup shaped ascocarp with a wall peridium. The asci are arranged in a layer called hymenium , either exposed from the beginning or later exposed. The sterile structures called paraphyses (tips free / not fused) are also present intermingled with asci which help in liberation and dispersal of ascospores.**Epithecium** is a layer on the surface of hymenium of an apothecium formed by fusion of tips of paraphyses over the asci.E g. *Peziza, Tuber.*

4. **Ascostromata**: The asci are formed directly in cavities called locules with in stroma. The stroma itself serves as wall of ascostroma. Sterile structures called pseudoparaphyses are present in ascostromata.Eg.Elsinoe.

If the ascostromata is with a single locule ie., An unilocular ascostroma which resembles perithecium with pseudoparaphyses is called as pseudothecium.Eg.*Venturia.*



STERILE THREAD LIKE STRUCTURES IN ASCOCARP:

Ascocarps contain sterile thread like structures of various types.

1.Paraphyses: These are elongated, cylindrical , club shaped or sometimes branched threads arising from bottom of ascocarp. They may be septate or aseptate. They grow among asci in hymenium and remain free at their tips. However, in Discomycetes, the tips fuse together forming a layer known as epithecium. Paraphyses help in liberation and dispersal of ascospores. Eg. Perithecium (*Claviceps)* , Apothecium(*Peziza).*

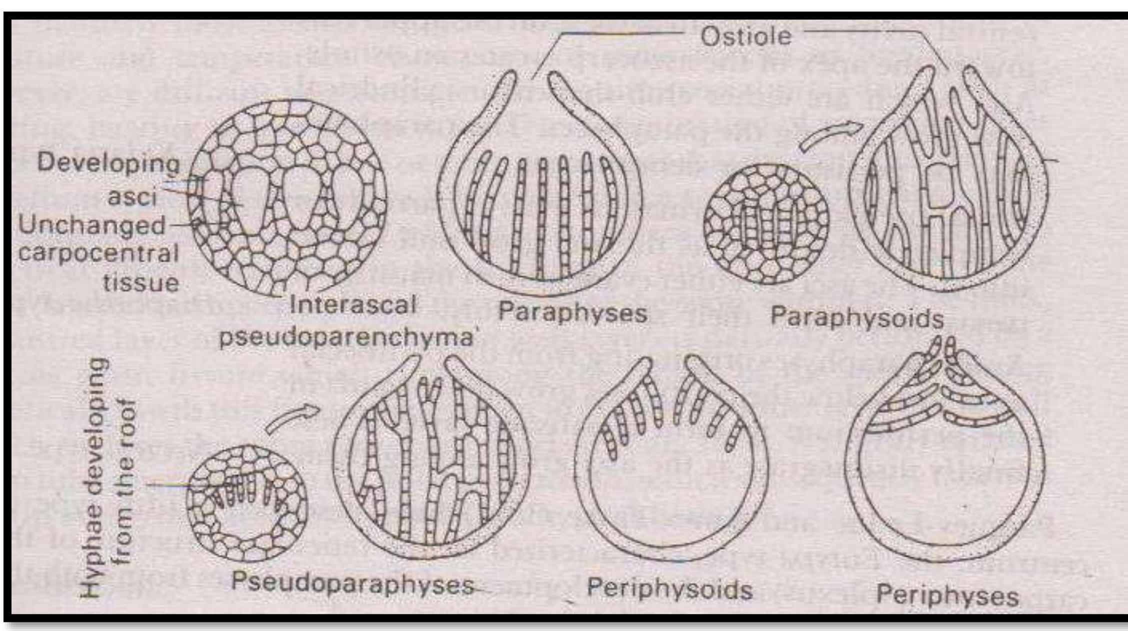
2.Paraphysoids:These are inter ascal tissue that stretch and resemble pseudoparaphyses,but remotely septate,very narrow,anastomose and tips remain free.

3.Periphyses: These are short, hair like threads lining in side of an ostiole of perithecium or pseudothecium. Their function is to direct the asci towards ostiole at the time of ascospore release.

Eg. Perithecium(*Claviceps)* , Pseudothecium(*Venturia).*

4.Periphysoids: These are the lateral periphyses which are short and originate above the level of developing asci but do not reach base of cavity and curve upwards towards apex.

5.Pseudoparaphyses: These are distinct,vertical, paraphyses -like hyphae,that originate above the level of asci and grow downwards between the developing asci,finally becoming attached to the base of the cavity,thus forming curtains between asci.These are often broader,regularly septate,branched and anastomosing.Eg. *Elsinoe.*



Ascomycotina is sub divided into six classes based on presence or absence of ascocarp and shape of the ascocarp.

Class 1. Hemiascomycetes 2. Plectomycetes 3. Pyrenomycetes 4. Discomycetes 5. Loculoascomycetes. 6. Laboulbeniomycetes.

Important plant pathogens are in the classes : Hemiascomycetes,Plectomycetes,Pyrenomycetes and Loculoascomycetes

IMPORT ANT CHARACTERISTICS OF CLASS HEMIASCOMYCETES

1.Mycelium is pseudomycelium or dikaryotic mycelium.

2.Ascocarp is absent i.e.,asci are naked.

3.Asci are not formed from ascogenous hyphae but formed directly from zygote or ascogenous cells.

4.Asci release ascospores by bursting or deliquescing of ascus.

5.Orders:

a.Protomycetales, Family:Protomycetaceae.Eg.Protomyces,Protomycopsis

b.Taphrinales, Family:Taphrinaceae Eg.Taphrina

IMPORTANT CHARACTERISTICS OF ORDER TAPHRINALES, FAMILY TAPHRINACEAE :

1. The order Taphrinales includes a single family Taphrinaceae and a single genus *Taphrina.*
2. Mycelium is septate containing typical thick walled binucleate cells called ascogenous cells.Hyphae may be intercellular, sub cuticular, or may grow with in walls of epidermis.

3. Asexual reproduction is through small oval or spherical uninucleate haploid blastospores that bud from ascospores either with in the ascus or after their release.
4. Ascocarps are not produced. Asci are naked. Sex organs are not formed. Asci are formed from special binucleate ascogenous cells. Asci are unitunicate and tip of the ascus bursts at the time of libetration of ascospores.

Eg. *Taphrina deformans* - peach leaf curl

T. maculans – leaf blotch of turmeric.

IMPORTANT CHARACTERISTICS OF CLASS PLECTOMYCETES

1. Ascocarp is a non-ostiolate cleistothecium.
2. Asci are thin walled, globose to pyriform,unitunicate.
3. Asci are produced from ascogenous hyphae,evanescent, scattered at various levels in the cleistothecium and not forming a definite hymenium.
4. Ascospores are unicellular, released by disintegration of ascus wall.

IMPORTANT CHARACTERISTICS OF ORDER : ERYSIPHALES, FAMILY : ERYSIPHACEAE :

1. Erysiphales is the exceptional order as it produces cleistothecium instead of perithecium. The reason is that the asci are grouped in fascicles or form a basal layer (hymenium) at maturity and ascospores are released violently with force.Cleistothecia are formed on superficial mycelium with out formation of stroma.
2. Members cause a disease called powdery mildew because they produce enormous number of conidia on the surface of infected host plants which appear to the naked eye as a white powdery coating.
3. Mycelium is hyaline and mostly ectophytic
4. Members are obligate parasites of plants and nourishment through haustoria.
5. Asci are persistant, globose to pyriform and explodes at the time of release of ascospores.
6. Important plant pathogenic genera are 1. *Erysiphe 2. Leveillula 3. Phyllactinia 4. Uncinula 5. Sphaerotheca 6. Podosphaera 7. Microsphaera*

Somatic characteristics:

Mycelium is well developed, septate, uninucleate, profusely branched entirely superficial (ectophytic) except *Leveillula* (endophytic) and *Phyllactinia* (semi-endophytic),produce haustoria into epidermal cells to absorb nourishment.

Asexual reproduction :

Asexual reproduction is through conidia produced on conidiophores. Conidiophores are long, erect and hyaline.

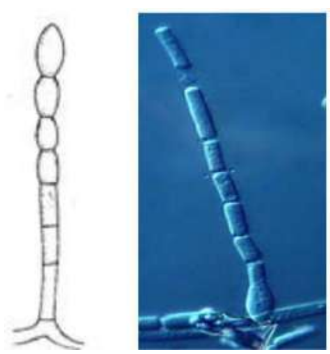
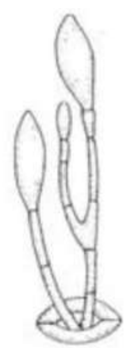
Three types of conidial stages are recognised in powdery mildews.

1. Oidium 2. Oidiopsis 3. Ovulariopsis

1. ***Oidium (Acrosporium)*** : Mycelium is ectophytic, hyaline. Conidia are developed from a flask shaped mother cell (spore mother cell) formed on a short conidiophore . Conidia are barrel shaped with flat ends and are produced in chains..The conidia are also referred to as meris tem arthrospores as these are formed by fragmentation of hyphae. Eg. The perfect stages viz., *Erysiphe,Podosphaera, Uncinula, Sphaerotheca and Microsphaera* produce *Oidium* as conidial stage.

2. ***Oidiopsis***: Mycelium is endophytic.Conidiophores may be branched or unbranched, erect, septate, hyaline and emerge through stomata. Conidia are produced singly and cylindrical in shape. Conidia are of two types. a. blunt tip b. pointed tip. Eg. *Leveillula* sp. produce *Oidiopsis* as conidial stage.

3. ***Ovulariopsis**:* Mycelium is partly ectophytic and partly endophytic.The conidiophores are hyaline, septate, unbranched, and bear a single conidium. Conidia are rhomboid in shape.In some species,the conidiiphores are spiral in shape. Eg. *Phyllactinia subspiralis. Phyllactinia sp* .produce ovulariopsis as conidial stage.


Oidium **Oidiopsis** **Ovulariopsis**

Powdery mildew conidia do not require free water for germination and are able to germinate at very low humidity levels.

Sexual reproduction:

Some species are homothallic and some are heterothallic. Antheridia and ascogonia are sex organs.Both gametangia are uninucleate .Fruiting body is cleistothecium which is produced on superficial mycelium as a result of gametangial contact. The cleistothecia are first white and finally black in color when mature. The wall is made up of pseudoparenchymatous tissue of several layers called peridium. Over wintering of powdery mildews takes place in clestothecial stage which are resistant to winter conditions. In perennials , the mycelium may over winter in the dormant buds of host. In warm weather , many species never form cleistothecia and perpetuate by means of conidia. The cleistothecia are provided with characteristic appendages which vary considerably in length and character.

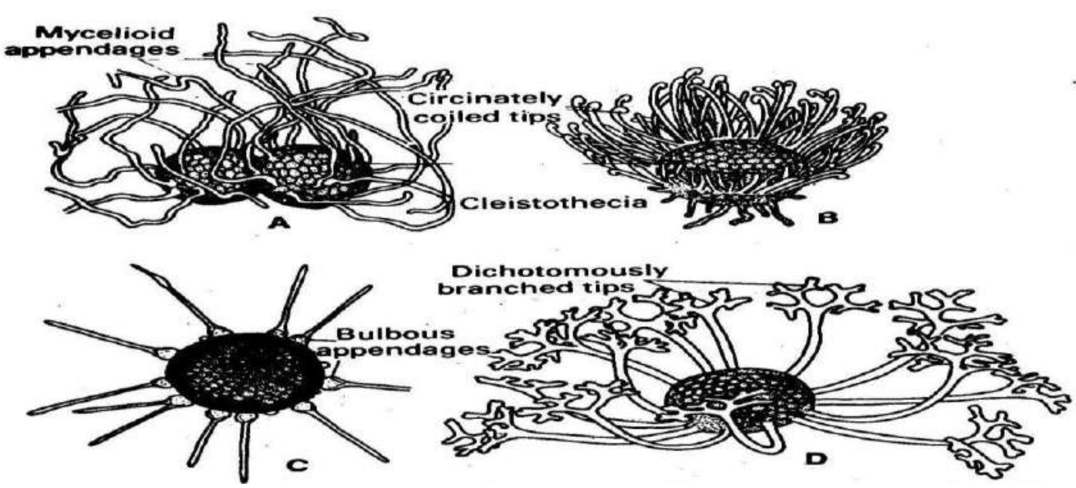
T ypes of cleistothecial appendages:

1. **Mycelioid appendage s:** These are flexible, flaccid and res emble somatic hyphae. Eg. *Erysiphe, Sphaerotheca, Leveillula.*

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

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

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



KEY FOR THE IDENTIFICATION OF POWDERY MILDEW GENERA:

1. Type of cleistothecial appendage

a. mycelioid

b. dichotomously branched c

. circinoid

d. bulbous base with pointed tip

2. Number of asci in cleistothecium

a.one

b.many

3. Type of conidial stage

a. Oidium

b. Oidiopsis

c. *Ovulariopsis*

4. Nature ofmycelium
a. ectophytic
b. endophytic
c . semi- endophytic

MYCELIUM

1. Ectophytic

a. One ascus per cleistothecium
Oidium type conidial stage

Mycelioid appendages- Eg. *Sphaerotheca*

Dichotomously branched appendages - Eg. *Podosphaera*
b. Several asci per cleistothecium

Oidium type conidial stage

Mycelioid appendages -Eg. *Erysiphe*

Circinoid appendages -Eg. *Uncinula*

Dichotomously branched appendages -Eg. *Microsphaera*

2. Endophytic

Many asci per cleistothecium

Oidiopsis type conidial stage

Mycelioid appendages-Eg. *Leveillula*

3. Semi- endophytic

Many asci per cleistothecium

Ovulariopsis type conidial stage

Bulbous base with pointed tip -Eg. *Phyllactinia*

Important powdery mildew diseases:

CROP	PATHOGEN
1. Pea	*Erysiphe polygoni*
2. Cucurbits	*E. cichoracearum*
3. Grasses	*E. graminis*
4. Mulberry	*Phyllactinia corylea*
5. Chillies	*Leveillula taurica*
6. Apples	*Podosphaera leucotricha*
7. Roses	*Sphaerotheca pannosa*
8. Lilac	*Microsphaera alni*
9. Grapes	*Uncinula necator*

IMPORTANT CHARACTERISTICS OF CLASS: PYRENOMYCETES

1. Ascocarp is mostly a true perithecium in which asci are arranged in a definite layer called hymenium. Perithecium may be globose or flask shaped. Some members produce cleistothecium.
2. Asci are unitunicate, persistant, club shaped or cylindrical.

This class includes 2 important Orders viz., Hypocreales and Sphaeriales.

IMPORTANT CHARACTERISTICS OF ORDER HYPOCREALES :

1.In the centrum ,apical paraphyses called peri-physoids arise from perithecial apex below the periphyses and finally disintegrate as the asci grow among them.

2.Ascocarps are usually bright coloured , fleshy, rarely non-ostiolate.

3.Asci are clavate to cylindrical.

4.Ascospores are colourless, non-septate or multiseptate .

IMPORTANT CHARACTERISTICS OF FAMILY CLAVICIPITACEAE ;

1.Members produce perithecia within a well developed stroma composed of entirely fungal tissue.

2.Asci are long, narrow and cylindrical with a thick cap perforated by a long cylindrical pore through which ascospores escape.

3. Lateral walls of ascocarps are lined with periphysoids (lateral paraphyses that originate all along lateral walls of perithecium but do not occur among asci at the base of perithecium.).

4.The ascospores are thread like and break into fragments after they are released and each fragment function as individual spore capable of giving rise to mycelium.

5.Many members are parasitic on grasses infecting gynoecium which later converts it into sclerotial bodies (ergots) and thus causing a group of diseases known as ergots.

6.Asexual stage:The fungus parasitises the ovaries of plants and form sporodochia (asexual stage) bearing short conidiophores with minute, oval conidia at their tips. These conidia are mixed with a sticky sweet nectar like

secretion.This sugary slime is called honey dew and hence the asexual stage is commonly called as **honey dew stage/sphacelia stage**.

7.Sclerotial stage:L ater mycelium hardens converts into purple black hard sclerotia.The sclerotium of *Claviceps* is known as ergot commercially. During the harvesting operation, many sclerotia are knocked off the spikelets and fall to the ground where they pass the winter.The ergots are highly poisonous as they contain powerful alkaloids such as ergonovin , ergometrine and ergotamine.When the animals or human beings consume ergot contaminated grains or flour, a serious disease termed **ergotism** occurs.

Another important disease in humans due to consumption of ergot contaminated grain flour of rye is **St. Anthony's fire.** Alkaloids have also got medicinal values. They are used to prevent haemorrhage (bleeding) during child birth and as artificial abortifacient. The drug prepared from ergot bodies is called **ergotin**.

Diseases:

Ergot of rye- *Claviceps purpurea* (I.S- *Sphacelia segetum*)

Ergot of bajra- *C. microcephala,C.fujiformis*

Sugary disease of sorghum- *Claviceps sp.* (I.S: *Sphacelia sorghi)*

Parasitic on insects - *Cordyceps sp.*

IMPORTANT CHARACTERISTICS OF CLASS LOCULOASCOMYCETES

1. Ascocarp is ascostromata or pseudothecium .
2. Presence or absence of sterile structures pseudoparaphyses in ascocarp.
3. Asci are bitunicate and are borne in locules in stromatic tissue.

Order: 1. Pleosporales

Family: Venturiaceae

Eg. *Venturia inaequalis(I.S: Spilocaea pomi)*

Family: Pleosporaceae

Eg. *Cochliobolus miyabeanus(I.S:Bipolaris oryzae)*

Order 2. Myriangiales

Family: Myriangiaceae

Eg. *Elsinoe ampelina (I.S:Sphaceloma ampelinum)*

Order 3. Dothidiales

Family: Dothidiaceae

Eg.*Mycosphaerella arachidis*

(I.S:Cercospora arachidicola)

Mycosphaerella berkeleyi

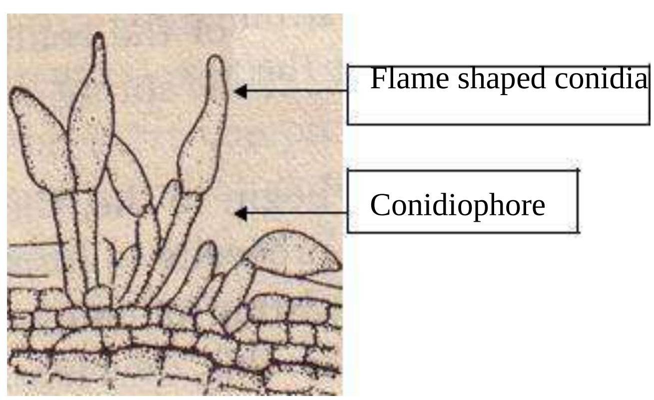
(I.S:Cercosporidium personatum)

IMPORTANT CHARACTERISTICS OF ORDER: 1. PLEOSPORALES, FAMILY: VENTURIACEAE

1. Fruiting body is called pseudothecium produced sub epidermally or sub cuticularly.
2. Presence of pseudoparaphyses in fruiting body.
3. Conidiophores are short producing flame shaped conidium.
4. Conidiophore and conidia resemble a short burning candle.
5. Ascospores are 2 celled, ellipsoid, unequal in size, hence the name of the species "inequalis".

Eg. Apple scab- *Venturia inaequalis (I.S:Spilocaea pomi)*

Pear scab- *V. pyrina*



IMPORTANT CHARACTERISTICS OF FAMILY : PLEOSPORACEAE

1.Ascocarp is pseudothecium.

2.Ascospores a re filiform and many celled.

3.Conidia are dark, cylindrical with many transeverse septa (pseudosepta)

Eg. Brown spot of rice- *Cochliobolus miyabeanus* (*I.S: Bipolaris oryzae)*

Leaf spot of maize- *C. heterostrophus*

IMPORTANT CHARACTERISTICS OF ORDER:2. MYRIANGIALES

FAMILY: MYRIANGIACEAE

1. Ascocarp is ascostromata with uniascal locule.

2.Locules are distributed at various levels of ascostromata.

3.Asci are globose, thick walled with 8 ascospores.
4.Ascospores are 4 celled.
Eg. Citrus scab- *Elsinoe fawcetti*, Grape anthracnose- *E. ampelina*
Mango scab- *E. mangiferae*

IMPORTANT CHARACTERISTICS OF ORDER :3, DOTHIDIALES,

FAMILY : DOTHIDIACEAE

1. Ascocarp is pseudothecium, spherical in shape, immersed in host tissue, ostiolate with periphyses, polyascal locules, ps eudoparaphyses absent.
2. Asci are clavate with 8 ascospores.
3. Ascospores are 2 celled, hyaline.
4. Sexual reproduction is by spermatization in some of the species producing spermatia in spermagonium.

Eg. Tikka disease

a)Early leaf spot of groundnut- *Mycosphaerella arachidis*

(syn: *M. arachidicola)* (I.S: *Cercospora arachidicola)*

b)Late leaf spot of groundnut- *Mycosphaerella berkeleyi*

(I.S:Phaeoisariopsis *personata)* (syn: *Cercospora personata)*

Sigatoka leaf spot of Banana:Mycospherella musicola (I.S:cercospora musicola)

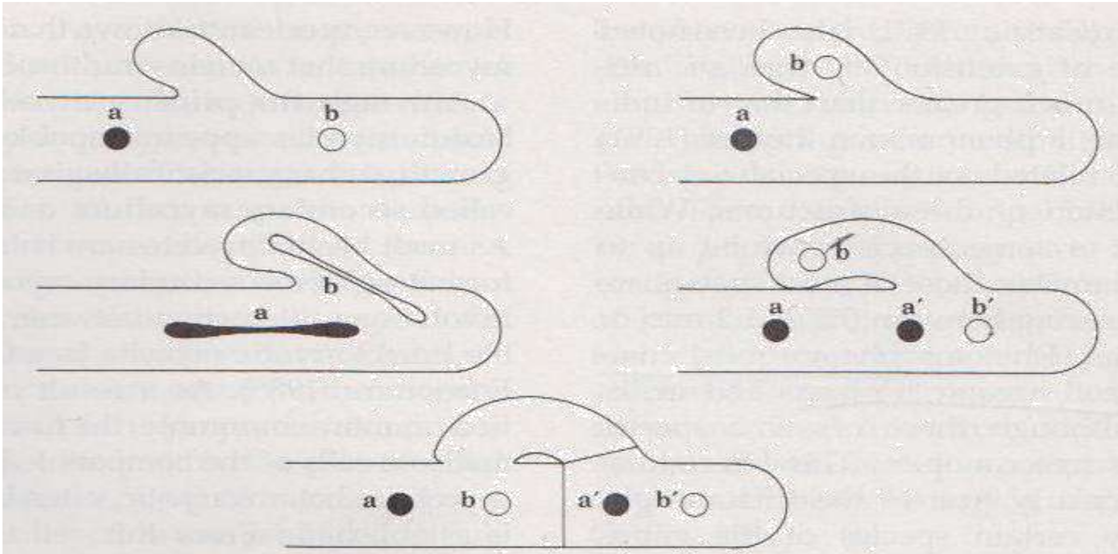
IMPERFECT STAGES FOR THE GENERA OF CLASS LOCULOASCOMYCETES:

PERFECT STAGE	***IMPERFECT STAGE***
1**.** *Venturia inaequalis*	*Spilocaea pomi*
2.Cochliobolus miyabeanus	*Bipolaris oryzae*
3.Elsinoe ampelina	*Sphaceloma ampelinum*
4.Mycosphaerella arachidicola	*Cercospora arachidicola*
5.Mycosphaerella berkeleyi	*Phaeoisariopsis personatum*
6.Mycospherella musicola	*Cercospora musicola*

somatogamy between compatible cells of monokaryotic mycelium or fusion of 2 basidiospores or spermatization.It exists during major part of the life cycle.Thus, this stage is an independent and extensive phase unlike the short dikaryotic phase of Ascomycotina.This is associated with special structures called clamp connections through which dikaryotization takes place.(dikaryotiz ation is a process by which monokaryotic primary mycelium is converted to dikaryotic secondary mycelium).

3.Tertiary mycelium: This is the binucleate mycelium which is organized into specialised tissues which form into fruiting bodies called sporophores (basidiocarps) in the members of higher Basidiomycotina .

Clamp connections: It is a hook like structure formed laterally in between the dividing nuclei in a dikaryotic hypha. It acts as a by-pass for the nuclei , as they can not pass through septal pore ie., dolipore septum. It is meant for multiplication of dika ryotic cells.



Mode of development of clamp connection: When a binucleate cell is ready to divide, a small lateral branch called clamp connection arises from the cell between the 2 nuclei (a and b) and begins to form a curved hook.Then the 2 nuclei divide simultaneously. One division orients obliquely so that one daughter nucleus “b” forms in the clamp connection and the other daughter nucleus “b^1 ” forms in the dividing cell. The second division orients itself along the length of the dividing cell so that one daughter nucleus “a” forms near one end of the cell and the other “ a^1 ”**approaches** the nucleus “ b^1 “of the first division near the other end of the cell. In the mean time, the clamp bents over and its free end fuses with the cell so that clamp forms a bridge through which one of the daughter nucleus “ b” passes to the other end of the cell and approaches daughter nucleus “ a “. A septum is formed to close the clamp at the point of origin and another septum vertically under the bridge to divide the parent cell into two daughter cells with “ a” and “ b ” in one

daughter cell and nuclei “ a^1 ” and “ b^1 ” in the other cell.The clamp remains permanently attached to hyphae. Its presence indicate s that the hypha is dikaryotic.

SUB- DIVISION: BASIDIOMYCOTINA

1.Members of this sub-division are highly advanced fungi.

2.The name Basidiomycotina is given because the fungi produce sexual spores on a special club shaped fruiting body called basidium.

3.A definite number of sexual spores called basidiospores (usually four in number) are produced on each basidium .

4.Fungi belonging to this sub division are referred as club fungi.

5.The group includes mushrooms,toadstools,shelf fungi,jelly fungi, puff balls, coral fungi,bracket fungi, birds nest fungi,stink horns, rusts and smuts.

General characteristics:

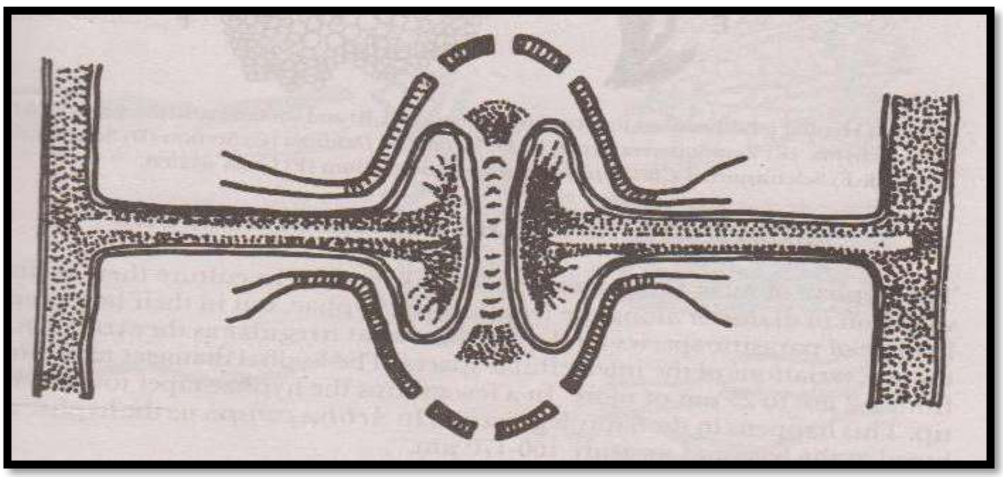
1. Produce sexual spores (basidiospores) on the out side of a specializ ed spore producing structure called basidium.
2. A typical basidium is a club shaped structure ,bearing specially 4 basidiospores on pointed projections called sterigmata.
3. Basidiospores are haploid, uninucleate and are the result of plasmogamy, karyogamy and meiosis.
4. Dikaryotic phase dominates the life cycle.
5. Presence of clamp connections on the mycelium .
6. Presence of dolipore septum, except in rusts and smuts.
7. Absence of motile spores .

Somatic structures:

The mycelium consists of well developed septate mycelium.The mycelium passes through three distinct stages before the completion of life cycle. They are primary, secondary and tertiary mycelium.

1.Primary mycelium: (homokaryon or monokaryotic mycelium) .It consists of hyphae with uninucleate cells. It usually develops from the germination of a basidiospore.It may be multinucleate at first when the nucleus of basidiospore divides many times as the germ tube emerges and grow. This multinucleate stage is short lived because septa are formed dividing the mycelium into uninucleate cells.

2.Secondary mycelium: (dikaryon or dikaryotic mycelium).This originates from primary mycelium and its cells are dikaryotic (binucleate, n+ n nucleus) formed **Dolipore septum:** Both primary and secondary mycelium consists of dolipore septum. The septum around the central pore swells at the center forming a barrel shaped structure with open ends,thus forming a septal pore.The septal pore is surrounded by a cup like or dome shaped membrane called parenthosome or septal pore cap or nuclear pore cap. It is made up of a double membrane and its function is to shut the pore. The dolipore septum will not allow the movement of nuclei in hyphae but maintai ns continuity of cytoplasm.



Asexual reproduction: Asexual reproduction takes place by means of budding (conidia), fragmentation of hyphae (arthrospores) , uredospores. Conidial production is common in smuts while rusts produce uredospores (summer spores) that are conidial in origin and function.

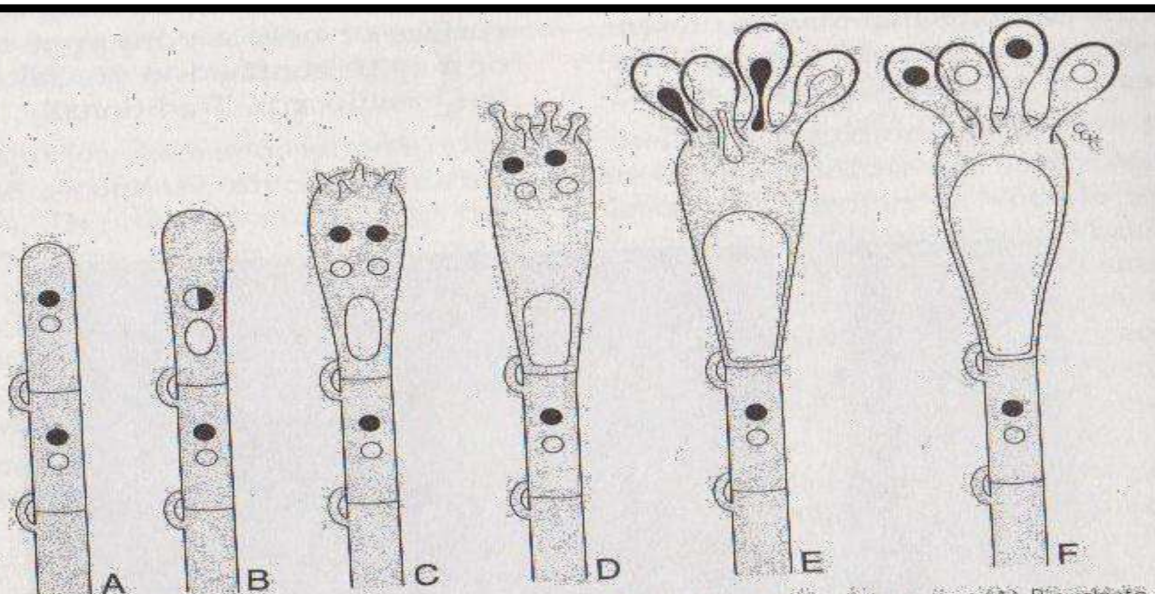
Sexual reproduction: Sexual reproduction results in the production of basidium bearing haploid basidiospores. Basidiospores are formed as a result of karyogamy and meiosis taking place in basidium. In most of the members, sex organs (gametangia) are not produced and the somatic hyphae or detached somatic cells (arthrospores) undergo sexual process by somatogamy.In *Puccinia* sexual process is accomplished by spermatization through specialized organs called spermatia acting as male gametes and receptive hyphae as female organs.Thus,sexual cycle involves in typical cases, a monokaryotic phase and establishment of dikaryotic phase by somatogamy or spermatization of primary mycelium and then karyogamy and meiosis in the basidium and return to monokaryotic phase by means of basidiospores.Thus,in the life cycle there is an alternation of monokaryotic and dikaryotic phases.

Basidium: Basidium is a club shaped, sexual, fruiting body bearing on its surface a definite number of (usually 4) basidiospores which are formed as a result of karyogamy and meiosis.

Development of basidium: A simple, club shaped basidium originates as a terminal cell of a binucleate hyphae and is separated from the rest of the hyphae by a septum over which a clamp connection is generally seen. At first, basidium is narrow and elongated and later it enlarges and becomes broader.Mean while, the

2 nuclei with in the young basidium, fuse (karyogamy) and the zygote nucleus soon undergoes meiosis giving rise to 4 haploid nuclei. In the meantime, four small outgrowths termed as sterigmata push out at the top of the basidium and their tips enlarge eventually forming the basidiospore initials. During this time, a vacuole forms at the base of the basidium and as it increases in size, it pushes the

contents of basidium out into basidiospore initials which finally become basidiospores.



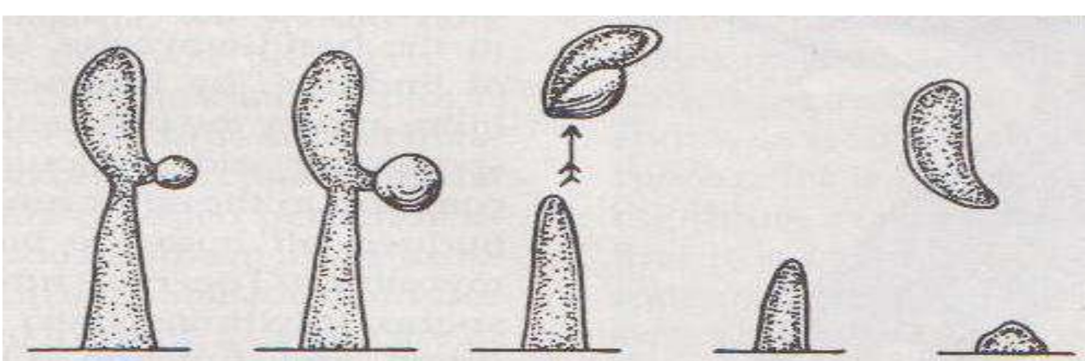
Successive stages in development of a basidium and basidiospores. (A) Binucleate hyphal tip. (B) Uninucleate, diploid basidium following karyogamy. (C) Postmeiotic basidium with four haploid nuclei. Sterigmata have begun to develop. (D) Basidiospore initials on sterigmata and nuclei preparing to migrate into the spore initials. (E) Migration of nuclei into basidiospore initials. (F) Highly vacuolate, maturing basidium bearing four young uninucleate basidiospores.

Parts of basidium: Basidium is divided into 3 patrs. Probasidium (portion where nuclear fusion takes place),metabasidium / promycelium (portion where meiosis occurs) and sterigmata (any portion between metabasidium and basidiospore).

In smuts and rusts, fusion of 2 nuclei takes place in a specially formed thick walled spores called chlamydospores and teleospores respectively. During the germination of chlamydospore / teleospore, fusion of 2 nuclei takes place in the spore, followed by meiosis. A germ tube called promycelium is formed which becomes transversely septate into 4 cells, each cell containing a haploid nucleus. The basidiospores are formed on the sterigmata on promycelium.

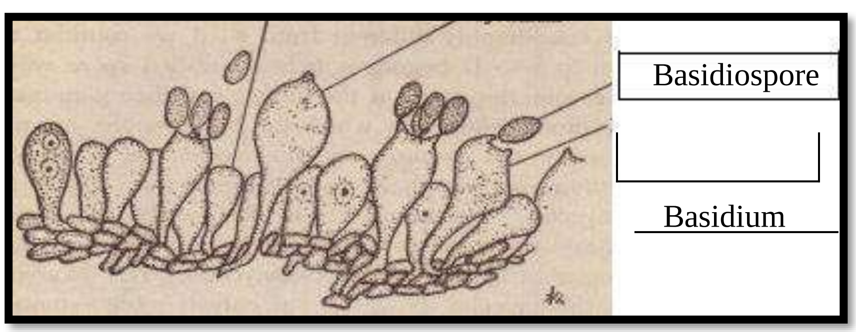
Basidiopspores: A basidiospore is typically a unicellular, uninucleate (exceptional 2 nuclei) haploid structure .The basidiospores are formed exogenously on the basidium in contrary to the endogenous formation of ascospores. The basidiospores may be globose, oval, elongate or sausage shaped and may be hyaline or coloured.

Dispersal of basidiospores: In majority cases, the spores are released violently and such spores are called ballistospores.Many possible mechanisms of spore discharge have been suggested. Buller was one of the first to examine critically the spore discharge.According to him, Basidiospores rest on the tip of sterigmata in an oblique fashion and a bubble or drop (called Bullers drop consist of liquid which forms at the hilar appendix ie.,a minute projection of the spore near the point of attachment to the sterigmata) is responsible for basidiospore discharge . This drop keeps on increasing in size and its expansion results in explosive discharge of spore to a distance of about 0.1mm. The spores are discharged in succession at intervals of several seconds to minutes.



Basidiocarp (Fungus flowers): Basidiocarp is a fruiting body that bears basidia which may be crust like, gelatinous, papery, spongy, corky, woody in texture. They vary in size from microscopic to a meter or more in diameter. Most Basidiomycotina bear their basidia in basidiocarps except in rusts and smuts. Basodiocarp producing fungi are mushrooms, shelf fungi/ bracket fungi, coral fungi, puff balls,bracket fungi,birds nest fungi,earth stars etc. Basidia are formed typically in definite layers called hymenium. The hymenium is a layer composed of basidia and any other sterile structures like cystidium (larger and protrude beyond the other structures and of taxonomic importance) and basidiole (resemble basidium but with out basidiospores and provide support to fertile basidium).

Basidiole Cystidium



Hymenium

Compatibility: The members are either homo or heterothallic (majority).

IMPORTANT CHARACTERISTICS OF CLASS TELIOMYCETES:

1. Include rusts and smuts.
2. Basidiocarp is lacking and replaced by thick walled teleospores or chlamydospores in sori with in the host tissue.
3. Basidia arise from thick walled resting spores i.e., teleospores or chlamydospores.
4. Members are obligate parasites or facultative saprophytes.

In class Teliomycetes there are two orders.1.Uredinales 2.Ustilaginales

IMPORTANT CHARACTERISTICS OF ORDER UREDINALES:

1. The popular name for the Uredinales is the rust fungi, which relates to the reddish brown colour of some of the spores. All are obligate parasites of crop plants.
2. The mycelium is primary in the early stage and in the later stages secondary. The mycelium is inter cellular and produce haustoria that penetrate the host cells and obtain nourishment. There is no tertiary mycelium and hence there is no basidiocarp.
3. Clamp connections are rare or absent. Dikaryotisation takes place either through somatogamy or spermatisation.
4. Teleospores originate from the apical cells of dikaryotic hyphae. They may be uni or multi cellular. The structure of teleospores forms the basis for identification of the rust genera. The teleospore acts as an encysted basidium in which karyogamy occurs. It germinates by producing a promycelium (metabasidium) in which meiosis takes place.
5. The rusts have **polymorphic life cycle**. Production of many spore forms in the life cycle is called polymorphism. Generally 5 types of spores are seen during the life cycle viz., spermatia (uninucleate) in spermagonium, aeciospores(binucleate)

in aecium,uredospores(binucleate) in uredium , teleospores(binucleate)in telium and basidiospores (uninucleate) on promycelium or metabasidium.The spermagonium represents gametic stage (male gamete- spermatium, female sex organ- receptive hypha), aecia represent the stage in which dikaryotisation occurs,uredia represent conidial or repeating asexual stage, telia represent sexual stage and act as encysted basidium in which karyogamy occurs and subsequently giving rise to basidiospores from promycelium or metabasidium.

6. **Autoecious rust:** If all the spore stages are produced on the same host then the fungus is called autoecious and the phenomenon is called **autoecism.**Eg.*Melampsora lini*- linseed rust, *Uromyces appendiculatus* - bean rust. 7. **Heteroecious rust:** If spore stages are formed on two unrelated hosts ie., pycnia and aecia on one host and the uredia and telia on the other host, such rusts are called heteroecious rusts and phenomenon is called **heteroecism.** Eg. *Puccinia graminis f. sp. tritici*- black stem rust of wheat. **Primary host:** The host in which heterocious rust produce the telial stage is called primary host (Eg. wheat). **Secondary or alternate host** The host in which telial stage is not produced is called alternate or secondary host (Eg. barberry) .

8. Based on life cycle pattern, rusts are divided into macrocyclic, demicyclic and microcyclic rusts.

Macrocyclic rust: (**long cycled rust):** Rusts in which all 5 spore forms are produced or produce at least one type of binucleate spore in addition to teleospores are called macrocyclic rusts. It may be autoecious macrocyclic rust (Eg.*Puccinia helianthi*- sun flower rust) or heteroecious , macrocyclic rust *(Eg.Puccinia graminis f.sp. tritici* - black stem rust of wheat).

Demicyclic rust: The rust in which uredial stage is absent. eg. *Gymnosporangium juniperi – virginianae*- cedar apple rust.

Microcyclic rust (short cycled rust): Rusts which produce no binucleate spore other than teleosporei.e., teleospore is the binucleate spore produced and both aecia and uredia are lacking. E g.*Puccinia malvacearum*- hollyhock rust.

IMPORTANT CHARACTERISTICS OF FAMILY PUCCINIACEAE:

1.Teleutospores are free or variously united, but never in the form of layers or crusts.

2.Teleutospores are stalked. E g. *Puccinia, Uromyces, Hemileia*

Genus Puccinia:

Obligate parasites.Teleutospores are two celled and stalked.They lie free in the sorus.

Disease: ***Puccinia graminis f.sp. tritici***- black stem rust of wheat

Genus Uromyces:

Teleutospores are single celled with a thick apex (papillum) and stalked. The stalks are fragile and short.

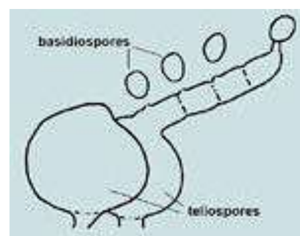
Eg. *U. appendiculatus* - bean rust

Genus Hemileia:

Uredospores are reniform, bifacially ovate resembling orange segments, concave side smooth, convex side echinulate.

Teleutospores are turnip shaped. 1 celled, stalked, smooth walled and produced on erumpent,club shaped stalks which arise through stomata.

Eg. H. vastatrix - coffee rust



Puccinia ***Uromyces*** ***Hemileia***

LIFE CYCLE OF *PUCCINIA GRAMINIS F. SP. TRITICI*

The pathogen is an obligate parasite and causes black stem rust of wheat. It is a heterocious rust that requires 2 hosts for completion of its life cycle. The primary host (wheat) and the secondary host (barberry). .On barberry it produces pycnia and aecia while uredial telial stages are produced on wheat.

It is a macrocyclic rust producing all the five types of spores. The different kind of spores and their spore stages are designated as follows.

Stage	Spore	Nucleus status
O	spermagonia with spermatia (pycnia with pycniospores)	uninucleate

I	aecia with aeciospores	binucleate
II	uredia with uredospores	binucleate
III	telia with teleospores	binucleate
IV	basidia with basidiospores	uninucleate

It produces the first 2 stages in barbery and other 3 stages on wheat or other graminaceous hosts.

Significance of each stage :

***Stage " O** ": The spermatia produced in spermagonia were till recently thought to be functionless asexual spores. Mycologists have not found them to germinate to produce mycelium as in case of otHer asexual spores. Hence, they thought that they are vestigial bodies. At the time when mycologists do not know the function of pycnia and pycniospores the stage was designated as " O " stage. But in 1927, Cragie found that spermatia are male gametes and are essential for spermatisation of receptive hyphae (female organ) and consequent formation of aeciospores. This stage " O" represents the sexual stage of rust fungi but the nomenclature stage " O " retained even today to to avoid confusion.*

***Stage I**: Aeciospores are the first binucleate spores formed in the life cycle.*

***Stage II:** Uredospores are also called as repeating asexual spores as they functionas conidia for the propagation of the rust fungus.*

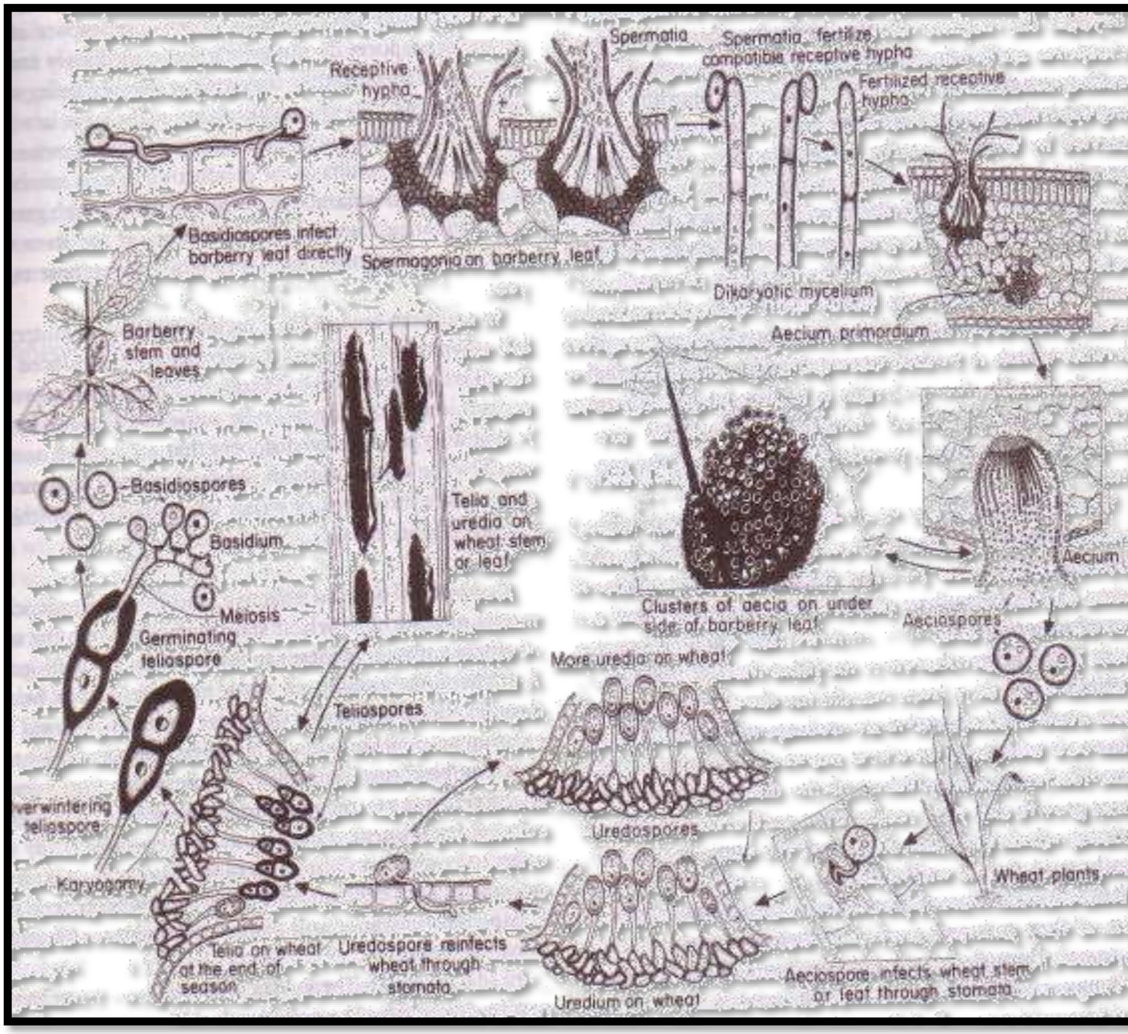
***Stage III**: Teleutospores represents the perfect stage because karyogamy and meiosis ocuur in them.*

***Stage IV:** Basidiospores represent the sexual spores.*

Stages " O" and " I" occur on barbery while stages " II" and " III " occur on wheat. Basidiospores can infect only barbery plant where as aeciospores can infect only wheat plant.

***Stage " O"*: Spermagonia with spermatia:**

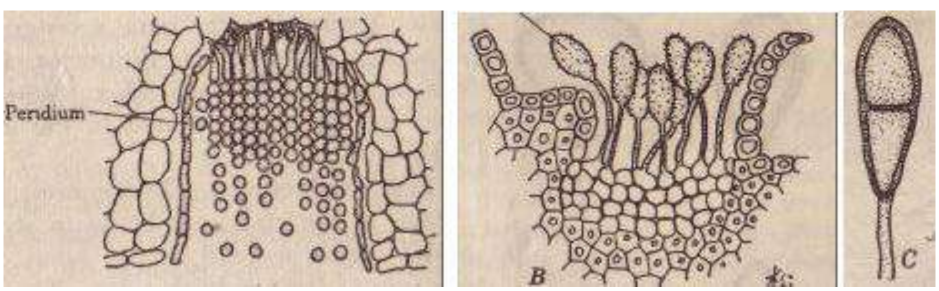
The spermagonia or pycnia are the structures which bear the sex organs of the pathogen. It contains spermatia which are the male sex organs and the receptive hyphae which are the female sex organs. These spermagonia are formed near the upper epidermis in about 4 days after infection of the host by a basidiospore. In nature it generally happens that several basidiospores at random will reach and infect the same barbery leaf so that both + and – mycelium develop side by side and intermingle in the barbery tissue. Each spermagonium contains numerous spermatia. These are exuded (ooze out) in small droplets of nectar present in the spermagonium. Each spermatium carries + or – nucleus depending on the strain of mycelium which produced the spermagonium. All spermatia from a single spermagonium carry the same factor or genetic make up as that of receptive hyphae. These arise from upper part of spermagonia and protrude through the ostioles. Spermatisation i.e., fusion between receptive hyphae and spermatia of opposite sex takesplace through agency of insects which are attracted by the honey fluid. The spermatial contents pass into the receptive hyphae . Meanwhile the mycelium penetrates the entire leaf and the hyphae near the lower epidermis develop number of aecial primordial. It is presumed that spermatial nuclei which pass from the spermatia into the receptive hyphae reach the cells of the aecial promordia rendering them binucleate. It has been demonstrated that aecial primordial fail to develop into aecia until and unless spermatisation takes place.



Life cycle of ***Puccinia graminis f. sp. tritici***

Stage"I" : Aecia and aeciospores are formed in the lower epidermis soon after dikaryotisation. These are the first binucleate spores produced in the life history of the fungus. An aecium is a group of binucleate hyphal cells (aeciospore mother cell) which give rise to aeciospores in chains. The aeciospores finally disseminated by the wind and under favourable conditions germinate on graminaceous host . These can not infect barbery.

Stage " II": Soon after infection by aeciospores on graminaceous host , binucleate mycelium begins to form masses of cells. These are called uredia from which binucleate uredospores are borne on long stalks. The uredospores are one celled, oval, yellowish and spiny. They germinate readily in water and produce one or more germ tubes. The uredospores are those spores which perpetuate the fungus throughout the growing season and they are capable of reinfecting the graminaceous host on which they produce. Hence, they are also known as repeating asexual spores. They spread from plant to plant and from field to field and the disease soon becomes an epiphytotic. The uredospores upon germination produce binucleate mycelium which grows between the cells of the host and in a few days produce new uredia and uredospores.



Aecium **Uredium** **Teliospore**

Stage " III" : Late in summer, at the time of ripening of grain another kind of spores known as teleospores or teleutospores are developed in the same mycelium when the uredia begin to cease. The pustules which produce teleospore s are known as telia and constitute the black stage of rust. The teleospores are ellipsoidal, oblong or obclavate, typically two celled, and thick walled with slight constriction at the septum. The young teleospore is binucleate . Karyogamy eventually take s place and render the teleosspores diploid and uninucleate . The teleospores are not capable of germinating immediately and should have resting period of several months and thus remain dormant until the following spring

Stage " IV" : Early in the spring each cell of teleospore germinate and produce a basidium (promycelium). The diploid nucleus in teleospore migrates in to the promycelium and undergoes meiosis and four haploid nuclei are formed. Then septa are formed, separating the nuclei from one another into four cells. Each cell of promycelium produces a sterigmata on which basidiospore is formed. The nuclei now migrate into the basidispore. Two of the basidiospores are of one strain (+) and two are of other strain (--) . Soon after their formation ,the basidiospores are ejected and are carried away by wind. They can not infect graminaceius host, but can infect barbery and produce a well developed monokaryotic mycelium. Thus, the life cycle gets repeated on these two hosts viz., wheat and barbery.

DISTINGUISHING CHARACTERISTICS OF GENERA (OR) KEY FOR IDENTIFICATION OF GENERA:

Ustilago: 1.Teleospores singles

2.Sori dusty at maturity

3.Sori covered peridium (membrane) of host origin

Spacelotheca: 1.Teleospores singles

2.Sori dusty a t maturity

3.Sori covered by membrane (peridium) made up of fungal cells

4.Central columella present

Tolyposporium:1.Spores in balls

2.Spore balls permanent, spores adhering by thickenings of exospore .

DISEASES CAUSED BY THE GENERA*:*

U. nuda tritici- loose smut of wheat

Sphacelotheca sorghi- short or grain or kernal smut of jowar *S. cruenta*- loose smut of jowar

S. reliana- head smut of jowar

Tolyposporium ehrenbergii- long smut of jowar

T. penicillariae- smut of bajra

DIFFERENCE BETWEEN RUSTS AND SMUTS

Character	Rusts	smuts
1. Systematic position	Order: Uredinales	Ustilaginales
2. Plant parts affected	foliar parts (leaves, stem, petiole)	floral parts(flowers)
3. Symptoms	reddish brown coloured pustules	ovaries turn into black
4. Parasitism	obligate parasites	facultative saprophytes
5. Polymorphism	polymorphic	not polymorphic

Germinating teliospores of bunt fungi

DISTINGUISHED CHARACTERISTICS (OR)KEY FOR IDENTIFICATION OF GENERA:

T illetia:

1.Teleospores singles

2.Spores dusty and escaping at maturity

3.Sporidia are fused to form H shaped structures

Neovossia:

1.Teleospores singles

2.Spores dusty and escaping at maturity

3.Sporidia do not fuse, no H shaped structures

Urocystis :

1.Teleospores in balls

2.Sori dusty, spore balls surrounded by an adhering layer of hyaline sterile cells.

3. spore balls escape from sorus

DISEASES CAUSED BY THE GENERA:

Tilletia caries and T. foetida- bunt of wheat

Neovossia horrida- bunt of paddy

N. indica- Karnal bunt of wheat

Urocystis cepulae- onion smut

U. tritici- flag smut of wheat

DIFFERENCES BETWEEN SMUTS AND BUNTS :

S.No.	**Smuts**	**Bunts**
1	Belongs to family Ustilaginaceae	Belongs to family Tilliteaceae
2	Promycelium is Septate	Promycelium is non-Septate and hollow tube like
3	Basidiospores are formed laterally from each cell of the promycelium	Basidiospores are formed at the tip of the promycelium
4	Basidiospores are usually four	Basidiospores are more than four usually eight
5	H shaped structures are not formed	H shaped structures are present in which plasmogamy occurs.
6	Meiosis occurs in promycelium or teliospores	Meiosis always occurs in teliospores before germination
7	No fishy odour is observed	Characteristic stinking fishy odour is observed
8	Genera included are *Ustilago, Sphaecelotheca, Tolyposporium*	Genera included are *Tilletia, Neovossia, Urocystis*

IMPORTANT CHARACTERISTICS OF HYMENOMYCETES:

1.These fungi are popularly called as mushrooms.

2.It includes bracket or pore fungi, toadstools, jelly fungi, honey mushrooms, etc.

3.Basidia are formed on a hymenium of a well developed fruiting body, basidiocarp.

4.Basidiocarps are gymnocarpous or hemiangiocarpous.

5. Basidia are not formed from teleospores.

6.The hymenium is exposed in the fruiting body from the beginning and thus basidiospores are exposed before they mature.

7.Basidiospores are called ballistospores (the spores which are perched obliquely and discharge forcibly and violently are called ballistospores).

8.Members are saprophytes or facultative parasites.

IMPORTANT CHARACTERISTICS OF ORDER APHYLLOPHORALES:

1. All the members produc e single celled , club shaped basidia in well defined hymenium.Basidiocarp is tough and non fleshy, may be cottony, leathery, corky or woody in texture.
2. The development of basidiocarp is gymnocapous i.,e., the hymenium is exposed while the spores are still mature.Thus, hymenium is exposed through out development.
3. Hymenophore(the layer that supports hymenium) may be smooth, flatte ned or resupinate, teeth like, with pores etc.
4. This order consists of both terrestrial and wood inhabiting forms. Some are serious pathogens of forest trees causing root rot and heart rot. Dead trees and lumber are commonly attacked by certain members.

IMPORTANT CHARACTERISTICS OF FAMILY GANODERMATACEAE;

1.Members are commonly called as bracket fungi or shelf fungi and members are lignicolous forms.

2.The fruiting body of the fungus is called bracket which is formed laterally at the base of affected plant as a leathery stalked fan shaped or bracket shaped or with out stalk,made up of trimitic hyphal system,hymenophore poroid. The bracket is tough,leathery or woody in texture and size vary from 1-20 inches in diameter.The stalk is cylindrical and brown to black in colo ur.

3.The upper surface of bracket is reddish brown in colour and coated with a hard shiny substance resembling sealing wax, while the lower side is white or yellowish in colo ur. When examined with a lens, minute holes or pits are seen all over the under surface. These are the openings of numerous hymenial tubes or pores which are vertically oriented ins ide the fruiting body.Each basidium gives rise to 4 sterigmata, each of which bears a basidispore at tis tip.

4.Basidiospores are coloured,two layered and cystidia are absent in hymenium.Bracket shaped basidiocarp ,broadly and horizontally attached to the tree trunks by means of a short stalk or stipe.*Ganoderma* differs from other bracket fungi in having much longer span of spore release,extending upto 5 months. **Diseases caused by *Ganoderma*** :

Ganoderma lucidum- root rot and wilt of coconut & other palm trees and citrus.

Ganoderma

22.SUB- DIVISION: DEUTEROMYCOTINA

These are a group of fungi which reproduce only by means of asexual spores or fragmentation of hyphae or modified mycelium. The asexually produced spores are generally called as conidia. A conidium is a non-motile asexual spore formed at the tip or side of sporogenous cell. For several genera of this group sexual reproduction/ sexual stages/ perfect stages/ teleomorphic stages are not known or have not been discovered or not found or rarely formed or have been dropped from the life cycles in the evolution of these organisms.

Thes e fungi are commanly called as **imperfect fungi** and technically called as **fungi imperfecti** as they have only imperfect stages or conidial stages.Whenever the perfect stage of an imperfect fungus is detected in nature or laboratory cultures, it is shifted to proper place on the basis of fruiting body.In most cases the perfect stages have been found to belong to sub-division Basidiomycotina.

Mycelium is well developed, septate with branched hyphae and multinucleate cells.

Since , present classification is based on characters of sexual stage, these fungi are not fit for natural classification.

For most of these genera perfect states are not known or rare in nature, they are temporarily grouped as members of form class, form order, form family , form genus and form species.

CLASSIFICATION OF DEUTEROMYCOTINA :

The classification is completely artificial. It is based on their conidial peculiarities and neither bears connection to their sexual stage nor to their origin or evolution. It can not therefore be called as a natural classification.

The main characteristics (criteria) on which classification of fungi imperfect fungi is based are

1. presence or absence of asexual spores(conidia)
2. type of asexual fruiting body
3. manner of production of asexual spores
4. morphology (shape, size, color and septation) of asexual spores.

SACCARDOAN (1906) SPORE GROUP SYSTEM :

Traditionally, the form sub classes, Coelomycetidae and Hyphomycetidae have been divided in to sections. The section is not an official category in the classification system. The various families under each section were divided further by Saccardo into seven sections based on conidial characters viz., shape, color, septation. Saccardo (1906) later, modified the section names with the prefixes hyalo or phaeo depending upon whether the conidia were hyaline or pigmented. This approach is referred to as the Saccardoan Spore Group System since it was Saccardo (1899) who initially proposed the system.

Saccardo described the spores in Deuteromycotina based on shape, septation and colour.

I. Amerosporae: conidia non septate (single celled) , spherical, ovoid to elongated, or short cylidric.

a)Hyalosporae(Hyalo =colourless): conidia hyaline Eg: *Phoma*

b)Phaeosporae(phaeo=coloured): conidia coloured Eg: *Sphaeropsis*

II. Didymosporae : conidia ovoid to oblong, one septate (two celled)

a)Hyalodidymae: conidia hyaline Eg: *Fusarium* micro conidia

b)Phaeodidymae: conidia coloured Eg*: Botryodiplodia*

III. Phragmosporae : conidia oblong, two to many septate (3 or more celled) , only transverse septa present. a)Hyalophragmae:

conidia hyaline Eg: *Pyricularia* b)Phaeophragmae:

conidia coloured Eg: *Drechslera*

IV. Dictyosporae : conidia ovoid to oblong, both longitudinal and transverse septa present (muriform) .

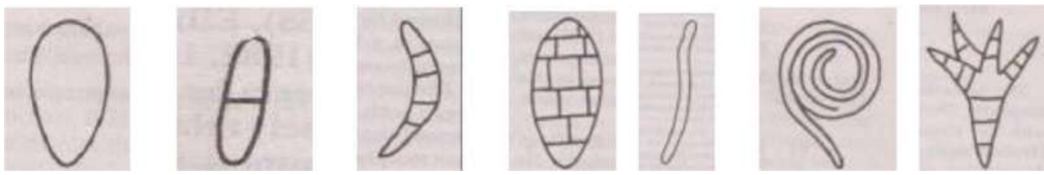
a) Hyalodictyae: conidia hyaline Eg: *Epicoccum*

b)Phaeodictyae: conidia coloured Eg: *Alternaria*

V. Scolecosporae: conidia thread like to worm like, filiform, septate or aseptate (one to several celled) Eg: *Cercospora*

VI. Helicosporae(Allantosporae) : conidia spirally cylindrical, curved (allantoid), septate or aseptate. Eg:*Helicomyces*

VII. Staurosporae : conidia stellate (star shaped) , radially lobed, septate or aseptate (one to several celled). Eg: *Actinospora*



Amerosporae Didymosporae Phragmosporae Dictyosporae Scolecosporae Helicosporae Staurosporae

Color of conidia

1. **Hyalosporae** : cell wall of conidia hyaline
2. **Phaeosporae** : cell wall of conidia coloured/ pigmented.

AINSWORTH (1973) CLASSIFICATION:

According to Ainsworth (1973), 2 form classes are there in Deuteromycotina.

1. Coelomycetes
2. Hyphomycetes

IMPORTANT CHARACTERISTICS OF CLASS COELOMYCETES:

The conidia are borne on conidiogenous cells with or with out distinct conidiophores, enclosed in fungal fructifications (asexual fruiting bodies) such as pycnidium or acervulus.

Coelo mycetes is divided into 2 form- orders 1.Sphaeropsidales 2. Melanc oniales

IMPORTANT CHARACTERISTICS OF ORDER SPHAEROPSIDALES:

The fruiting bodies are called **pycnidia**. A pycnidium is a globose or flask shaped asexual fruiting body that is lined inside with conidiophores. It may be completely closed or may have an opening called ostiole. It may be papillate or beaked or long necked at apex , leading to an opening. They vary greatly in their shape, size, color and consistency of pseudoparenchymatous wall.

Sphaeropsidales are further divided in to 4 form families 1 Sphaeropsidaceae 2. Excipulaceae 3. Nectrioidaceae (Zythiaceae) 4. Leptostromataceae

Family : 1. Sphaeropsidaceae

Pycnidia are flask shaped or globose, thin or thick walled, dark coloured, ostiolate, hard texture. Eg. *Phoma*, *Phomopsis*, *Macrophomina*, *Phyllosticta*, *Septoria*, *Diplodia* , *Botryodiplodia*.

DISTINGUISHED CHARACTERS OF THE GENERA:

Phoma:

Pycnidia - small, dark coloured, immersed or semi immersed in the host tissue. Globose or flask shaped, thin walled, and ostiolate. Wall consisting of dark pseudoparenchymatous cells. Conidiophores / conidiogenous cells are short, hyaline lining the inner pycnidial wall producing conidia in succession.

Conidia **-**hyaline, aseptate, guttulate(oil globules) , pyriform to globose and ooze out in long thread like cirrhus through the ostiole.

Eg. *Phoma lingam* – black leg of crucifers

P. vexans – blight and fruit rot of brinjal

Phomopsis:

Pycnidia- brown to black, globose, papillate ostiole, with one or more locules.

Conidiophores / conidiogenous cells- simple or branched.

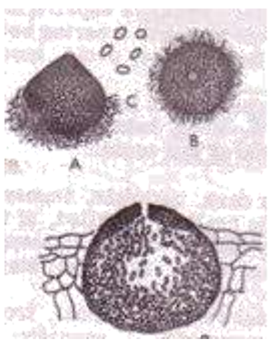
Conidia of 2 types. (a)alpha conidia- hyaline , ovoid, 1 celled, (b) beta conidia – hyaline, filiform, straight or curved, , 1 celled.

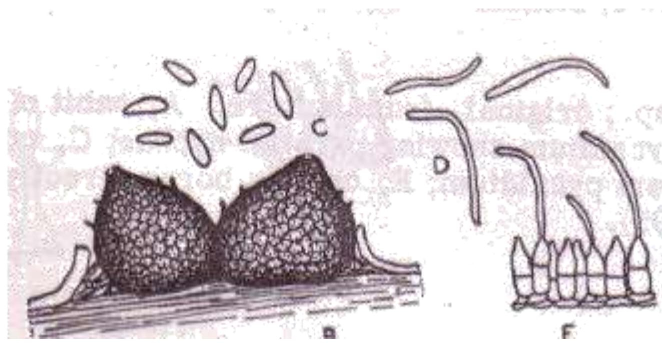
Eg. *Phomopsis vexans*- fruit rot and blight of brinjal

Phyllosticta :

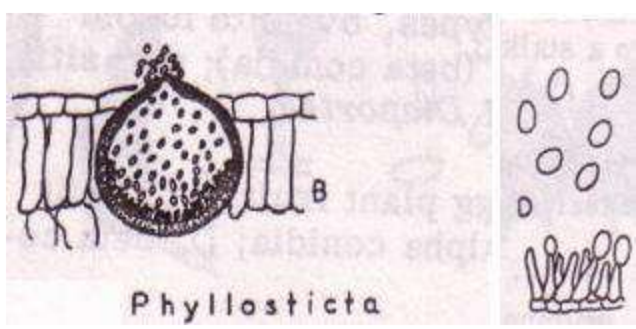
Pycnidia dark, ostiolate , globose, immersed in host tissue, erumpent or with a short beak. Conidiophores are short and obsolete.Conidia are small, one celled, hyaline,ovoid to elongate.

Phyllosticta and Phoma are differentiated on the basis of plant organs attacked. Phyllosticta principally occurs on leaves causing leaf spots and shot holes While, Phoma occurs mainly on stem, twigs and fleshy roots. Eg: *P. gingeberis* – leaf spot of ginger





Phoma ***Phomopsis***



Conidia – hyaline , aseptate, cylindrical to fusiform

Sclerotia- more common in cultures, black, smooth, hard.

Eg. *Macrophomina phaseolina* – charcoal rot, canker, damping off, of jowar, maize, ground nut.

Septoria:

Pycnidia – immersed in host tissue, globose, brown, thick walled, papillate and ostiolate. Wall consists of pale brown cells.

Conidiophore / conidiogenous cells – hyaline, broad and round at base and narrow above or barrel shaped.

Conidia – hyaline, many septate, filiform.

Eg. *Septoria nodorum*- glume blotch of wheat

S. lycopersici- leaf spot of tomato

Diplodia :

Pycnidium - black, globose, papillate, ostiolate,

Conidiophore/ conidiogenous cells - slender, hyaline

Conidia – brown, 2 celled, ovoid , apex obtuse (round) and base truncate (shorten) .

Eg. *Diplodia natalensis* - *Diplodia gummosis of citrus*

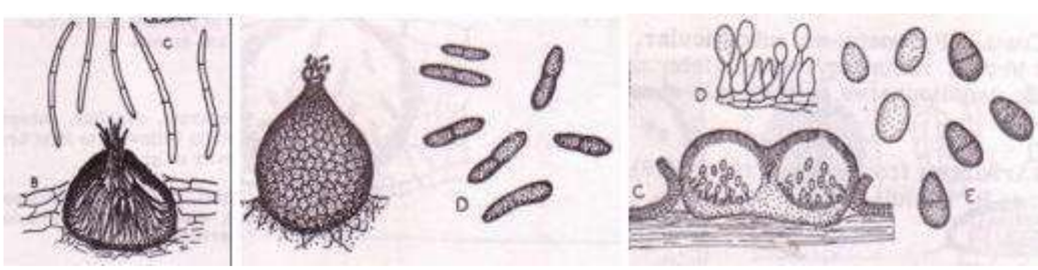
Botryodiplodia:

Pycnidium – carbonaceous, dark brown or black, no ostiole,

Conidiophores- simple and short.

Conidia – dark brown, 2 celled, ovoid.

Eg. *Botryodiplodia theobromae* – Flat limb of sapota



Septoria ***Diplodia*** ***Botryodiplodia***

23.IMPORTANT CHARACTERISTICS OF FAMILY EXCIPULACEAE

Pycnidia are cup shaped.

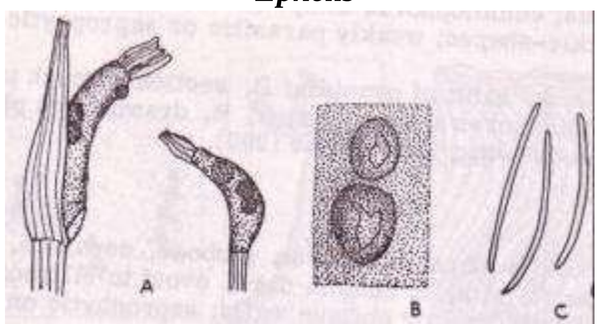
Ephelis:

Pycnidium – cup shaped,

Conidia – hyaline, 1 celled, acicular (needle shaped).

Eg. *Ephelis oryzae*- udbatta disease of rice .

Ephelis



(A= Stroma and pycnidia, B= Pycnidia (cup shaped), C= Conidia)

FAMILY 3. NECTRIOIDACEAE (ZYTHIACEAE):

Pycnidia resemble perithecia of Nectria and hence the Family name Nectrioidaceae .

Zythia:

Pycnidia - flask shaped, coloured, soft textured (fleshy) , ostiolate.

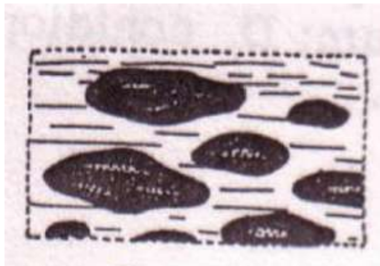
Conidia – hyaline, aseptate, oblong, rounded at each end.

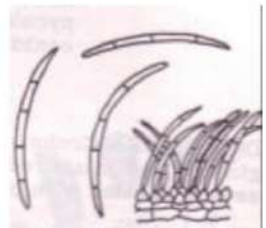
Eg. *Zythia fragariae*- leaf blotch and stem end rot of straw berry

Family 4. Leptostromataceae :

Pycnidia are shield shaped or elongated or flattened.

Leptostroma





Shield shaped pycnidia Conidiophores and conidia

Leptothyrium:

Pycnidium – shield shaped, dark, dimidiate (one half smaller than other).

Conidiophores- simple.

Conidia – hyaline, 1 celled, falcate (curved like sickle) .

Eg. *Leptothyrium pomi*- fly speck of apple

IMPORTANT CHARACTERISTIS OF ORDER MELANCONIALES, FAMILY MELANCONIACEAE:

All the members of this order are grouped into a single family Melanconiaceae. The fungi producing asexual fruiting bodies are called Acevulus. Acervulus is a mycelial mat not having wall of its own and produces a cavity with in which closely packed short conidiophores forming a bed like mass are produced.

DISTINGUISHED CHARACTERISTICS OF THE GENERA:

Colletotrichum:

Cushion shaped acervulus is seen below epidermis or cuticle with dark setae.

Macrophomina:

Pycnidia- globose, dark brown, papillate ostiole.

Conidiogenous cells- barrel shaped, hyaline.

Setae – septate, stout at base and pointed at tip, dark brown, long, present in the periphery or in between the conidiophores.

Conidiophores – simple, elongate, septate, hyaline to brown,

Conidia- sickle shaped, , guttulate (oil globule), hyaline, single celled.

Eg. *Colletotrichum capsici*- fruit rot and die back of chillies

C. lindemuthianum- anthracnose of bean

C .falcatum- red rot of sugarcane

Gloeosporium:

This genus is differentiated from Colletotrichum based on absence of setae in acervulus.

Eg. *Gloeosporium ampelophagum* - anthracnose or bird's eye disease of grapes. *G. musarum* – anthracnose of banana

Pestalotiopsis:

Acervuli are formed below the epidermis.

Conidiophores- hyaline, branched, septate, cylindrical.

Conidia - fusiform , 5 celled , basal cell hyaline with a single appendage, apical cell hyaline with 2 or more apical , simple or branched appendages , middle cells dark brown and thick walled.

Eg. *Pestalotiopsis palmarum* – grey blight of coconut and palmyra

P. mangiferae- leaf spot of mango

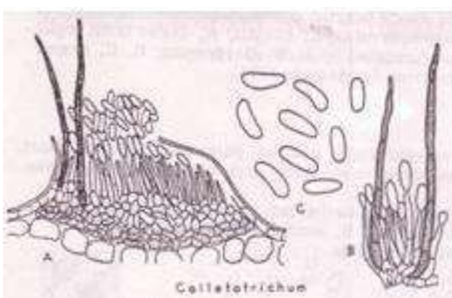
Pestalotia:

Acervulus**-** sub epidermal.

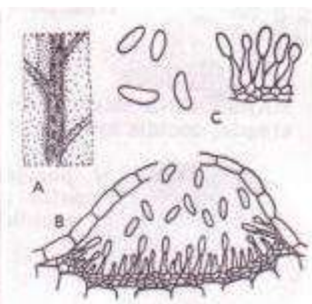
Conidiophores- short, simple or branched,

Conidia- similar to conidia of Petalotiopsis except 6 celled conidia.

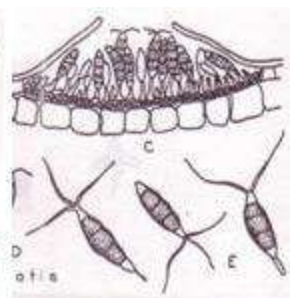
Eg. *Pestalotia psidi*- grey blight, scab and fruit spot of guava.



Colletotrichum



Gloeosporium



Pestalotia

24.IMPORTANT CHARACTERISTICS OF CLASS HYPHOMYCETES

Conid ia and conidiophores are borne directly on hyphae. Conidiophores bearing conidia may be separate or in aggregates arising from the mycelium. There are certain fungi which lack conidial formation and forming mycelial structures such as scretotial bodies. The members are identified based on morphology of conidia.

Hyphomycetes is divided into 4 form orders.

1. Hyphomycetales/ Moniliales/ Hyphales
2. Tuberculariales
3. Stilbellales
4. Agonomycetales.

IMPORTANT CHARACTERISTICS OF ORDER MONILIALES:

Conidia are produced on unorganized, .hyaline conidiophores or directly from hyaline hyphae. This order is divided into 2 families 1. Moniliaceae 2. Dematiaceae.

FAMILY MONILIACEAE ;

Produce free conidiophores or conidiogenous cells from somatic hyphae. Mycelium, conidiophores and conidia are hyaline or light coloured but not brown or black.

DISTINGUISHING CHARACTERISTICS OF THE GENERA:

***Aspergillus* :**

Well known saprophyte, grown on all types of substrate and also a weak parasite. commonly called as " weed of the laboratory" Mycelium- septate, branched, with multinucleate cells .

Conidiophore-The hyphal cell that gives rise to conidiophore is called foot cell. Conidiophores arise singly on somatic hyphae, long, erect, non septate and bears at its tip a spherical structure called vesicle, which bears two layers of bottle shaped structures called sterigmata or phialides on which conidia are produced in chains.The sterigmata of first layer (lower most) are called primary sterigmata and the second layer (upper most) are called secondary sterigmata.

Conidia: globose, one celled, multinucleate, thick , rough walled and black.
Eg**.** *Aspergillus niger*- collar rot of groundnut

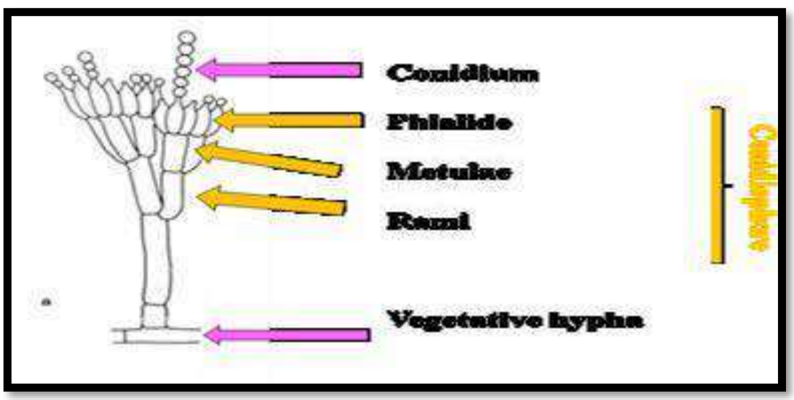
Aspergillus

Penicillium **:**

The conidial apparatus technically is called **"** penicillus" because it resembles a small brush or broom, hence the name penicillium Mycelium***:*** highly branched, septate.

Conidiophore: arise from any cell of hyphae (not from foot cell), branch once or twice about 2/3 of the way to the tip in a characteristic symmetric or asymmetric broom like fashion. The first generation branches are called primary branches or rammi, on which whorls of second generation branches called metulae are produced. Each metula ultimately bears bottled shaped phialides which bears conidia in chains in basipetal succession. Conidia: globose, hyaline.

Eg. *Penicillium notattum*- citrus blue mold.



Conidia- hyaline, pyriform, broader at base and tapering towards apex , usually 3 celled.

Eg. *Pyricularia oryzae*- paddy blast.

Trichoderma:

The members are saprophytes, found in soil and several species are found to be antagonistic by producing non-volatile antibiotics against a range of plant pathogens. These are easily recognized by rapidly growing white, yellow or green colonies.

Conidiophores: hyaline, erect,solitary or aggregated into tufts, much branched with phialides in singles or in groups(non-verticillate).

Conidia- hyaline,grey, one celled,ovoid borne in small terminal clusters as balls on phialides. Eg: *Trichoderma viridi, T.harzianum* – biocontrol fungi.

Botrytis:

Conidiophores- branched, septate, long, slender, hyaline . Apical cell of conidiophore with swollen tips bearing clusters of conidia on short sterigmata. Conidia – hyaline, 1 celled, ovoid.

Entire structure resemble like grape bunch.

Eg. *Botrytis cinerea*- grey mold of gram, bean, apple and grape.

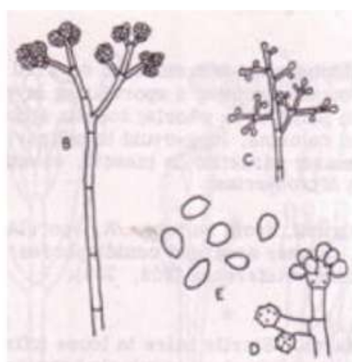
***Verticillium* :**

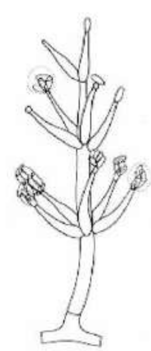
Conidiophores- slender, septate ,branched, some of the branches bearing verticillate (in whorls) phialides that give rise to conidia.

Conidia- ovoid to ellipsoid, 1 celled, borne singly or in moist clusters(mucus) apically.

Eg. *Verticillium albo- atrum* - wilt of cotton and tomato.

V. dahliae- wilt of tobacco and brinjal.





Pyricularia ***Botrytis*** ***Verticillium***

IMPORTANT CHARACTERISTICS OF FAMILY DEMATIACEAE

The hyphae, conidiophores and usually the conidia are brown or black, but some times the hyphae alone or the conidia only are dark.

DISTINGUISHING CHARACTERISTICS OF THE GENERA:

***Alternaria* :**

Mycelium – branched, septate, dark brown.

Conidiophores – simple, straight or curved , 1-3 septate , dark coloured.

Conidia – dictyospore , brown, obclavate with a beak, 3-8 tranversely septate and 1-2 longitudinally or obliquely septate, conidia are produced acropetally in chains (catenulate) through the pores formed at the apex of the beak of conidia.

Eg. *Alternaria solani*- early blight on tomato and potato

A.brassicae- leaf spot of crucifers

***Drechslera*:**

Mycelium**-** branched, septate, brown.

Conidiophores**-** emerge through stomata, erect, septate, simple or branched, dark brown, geniculate (knee joints), indefinite in growth (continue growth sympodially even after production of conidia)

Conidia- dark brown, cylindrical, straight , several celled, many pseudoseptate, germinate from any or all cells .

Eg. *D. turcica*- leaf blight of sorghum

D. nodulosum- seedling blight and foot rot of ragi

Helminthosporium :

Mycelium – dark.

Conidiophore**-** single or clustered, tall, brown, simple.

Conidia- develop laterally through pores beneath septa, often appear in whorls, obclavate, brown, many pseudoseptate with prominent basal scar.

Eg. *Helminthosporium maydis*- southern corn leaf blight

H. victoriae- victoria blight of oat.

***Bipolaris* :**

Differentiated from Drechslera based on method of germination of conidia and shape Conidia- germinate characteristically from two polar (end) cells only, fusoid and slightly curved.

Eg. *Bipolaris oryzae* – brown spot of rice ;P.S:Cochliobolus miyabeanus (
old: *Drechslera oryzae)*

***Cercospora* ;**

Mycelium **:** immersed in host tissue, branched, septate , pale brown

Conidiophore: emerge in clusters through stomata, brown, septate, simple or rarely branched with knee joints (sympodially extending) marking the scars of fallen spores

Conidia: terminal, arise singly from conidiophore, hyaline, filiform, severa celled (4 -12 septate), a scar at the base.

Eg. . *Cercospora arachidicola*- tikka disease (early leaf spot)on groundnut
P.S:Mycosphaerella arachidicola

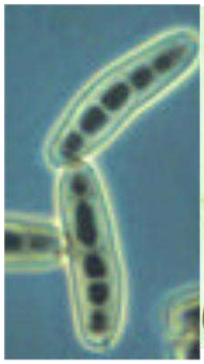
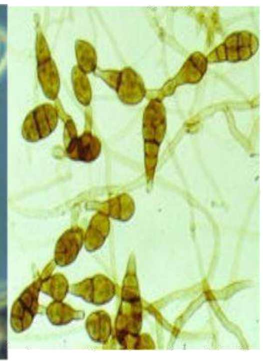
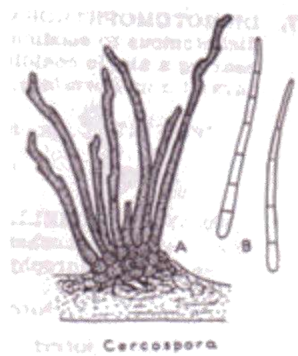
***Phaeosariopsis (Cercosporidium*) :**

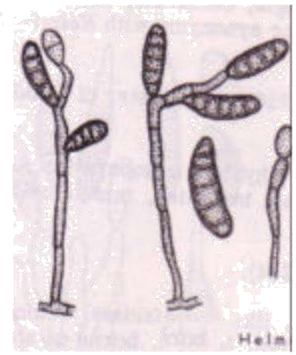
Mycelium **:** septate, intercellular with branched haustoria, pale brown, immersed entirely in leaf tissue.

Conidiophores : emerging through ruptured epidermis in clusters, pale to olivaceous brown, smooth, geniculate, septate , simple with prominenet conidial scars.

Conidia: light coloured, cylindrical, usually straight or slightly curved, rounded at ends, base shortly tapered with a conspicuous hilum, mostly 3-4 septate.

Eg**.** *Phaeoisariopsis personata (Cercosporidium personatum* ***)*** tikka disease
(late leaf spot) on groundnut
P.S:Mycosphaerella berkeleyii



Helminthosporium ***Alternaria*** ***Cercospora*** ***Drechslera***

IMPORTANT CHARACTERISTICS OF ORDER TUBERCULARIALES

FAMILY TUBERCULARIACEAE:

Include the fungi which produce sporodochium. Sporodochium is a cushion shaped structure consisting of cluster of conidiophores with conidia woven together on a mass of hyphae .

DISTINGUISHING CHARACTERISTICS OF THE GENERA:

Fusarium:

Mycelium **-**superficial, cottony in culture, septate, hyaline, grouped into sporodochia Conidiophore- slender,short,hyaline,simple, stout or branched irregularly bearing a whorl of spore producing structures called phialides bearing conidia.

Two types of conidia - macroconidia (several celled, slightly curved or bent, pointed at the both the ends, sickle shaped with a foot cell, hyaline), microconidia(1 or 2 celled, ovoid, single or in chains, hyaline) and also chlamydospores.

Chlamydospores : hyaline, thick walled, terminal or inter calary, produced singly or in chains by the mycelial hyphae or macroconidia. formed by modification of previous cell.

Eg**.** *Fusarium oxysporum f. sp. ciceri*- wilt of gram

*Fusarium oxysporum f.*sp. *vasinfectum* – wilt of cotton

Fusarium oxysporum . sp . *udum*- wilt on redgram

Myrothecium:

Sporodochia - cusion like, marginal hyaline setae.

Conidiophores- sub hyaline to coloured, repeatedly branched, bearing conidia on phialides

Conidia- 1 celled, sub hyaline to dark, ovoid, gathering in slimy mass.

Eg. *Myrothecium roridum*- shot hole on leaves of tomato, bhendi

IMPORTANT CHARACTERISTICS ORDER STILBELLALES, FAMILY STILBELLACEAE:

Include fungi which produce synnemata. Synnemata (sing. synnama) is a structure in which conidiophores are united together through out their length and free at their tip producing slimy head of conidia at their tip or all around the aggregated conidiophores. The whole structure resemble a long feather duster or brush.

Graphium:

Synnemata- tall, dark, bearing a rounded , terminal mass of conidia embedded in mucus

Conidiophores- simple, hyaline , produced in abundance , bearing oblong conidia

Eg. *Graphium ulmi*- dutch elm disease

IMPORTANT CHARACTERISTICS ORDER AGONOMYCETALES, FAMILY AGONOMYCETACEAE

Includes the fungi which do not produce conidia, form sclerotial bodies i.e., modification of mycelium , reproduction is by random fragmentation of hyphae.

DISTINGUISHING CHARACTERISTICS OF THE GENERA:

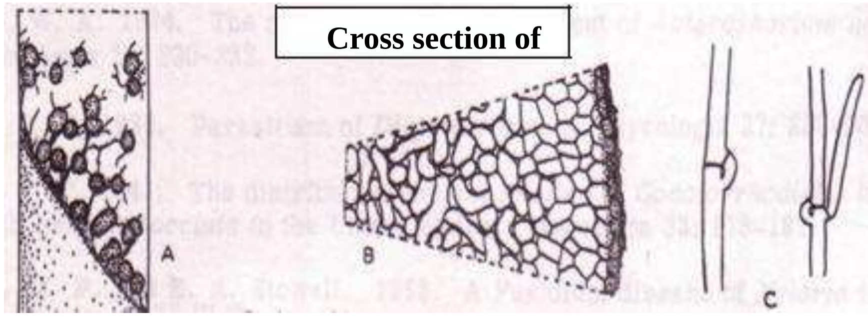
Sclerotium

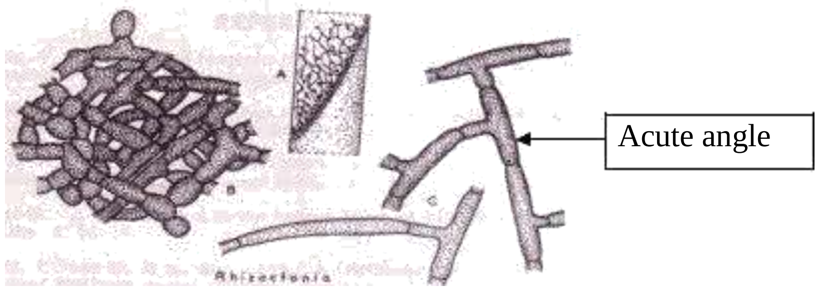
Spores lackin

Mycelium-white or light coloured, Sclerotia hard, dark brown, globose , compact, bigger than sclerotial bodies of Rhizoctonia, (more than 1 mm diameter in size), consisting of colourless to light coloured , thin walled rectangular cells inside and brown to black , thick walled cells at the periphery.

Eg. *Sclerotium rolfsii*- root rot of groundnut

Sclerotium oryzae- stem rot of paddy





Mycelium: brown, stout, septate branches arise at acute angles, hyphal cells barrel shaped and long.

Sclerotia: black, variable in form (globose, oval or irregular), loosely formed and connected by mycelial threads,hard, frequently small (less than 1 mm diameter), no differentiation of sclerotial tissue.

Eg***.****Rhizoctonia bataticola*- charcoal rot of soybean and sheath blight of paddy

R. solani- black scurf of potato

Bacteria and mollicutes: general morphological characters. Basic methods of classification and reproduction in bacteria

Bacteria

Bacteria (sing. bacterium) are simplest prokaryotic unicellular microorganisms having the common chemical composition of DNA, RNA and protein. They are highly adaptable and can survive extremes of temperatures, pH, oxygen tension, osmotic and atmospheric pressures, and hence found in almost all natural conditions.

Morphological characters: Being unicellular organism, bacteria may form groups of cells as filaments. They are either motile or non-motile and lack the definitely organized nucleus. Bacterial cell possess five shapes- (i) spherical (*Micrococcus*), (ii) rod-like /bacilliform (*E. coli*) and (iii) spiral-shaped (*Spirillum*) and (iv) curved-rod (*Vibrio*) and (v) club-shaped (*Clavibacter*). Motile cells are having long, whip-like flagella which may arise from one or both ends of the cell (polar) or from all over the cell (peritrichous). Based on flagellar arrangement bacteria is classified into 6 groups:

(i) Monotrichous - single polar flagellum at one end (*Xanthomonas*)
(ii) Amphitrichous - single polar flagellum at both ends (*Pseudomonas*)
(iii) Cephalotrichous - several flagella at one end (*P. fluorescens*)
(iv) Lophotrichous - several polar flagella at both ends (*Spirillum*)
(v) Sub-polar - single sub-polar flagellum (*Agrobacterium*)
(vi) Peritrichous - all over the cells (*Erwinia*)

Many bacteria have filamentous appendages called fimbriae or pilli. The size of bacteria ranges from 1-5 µm and normal range of volume of a structural unit lies within 5-50 µm. Structurally, a bacterial cell can be divided into following 5 regions as follows:
i.**Surface appendages**: Flagella and pilli.
ii. **Surface adherents**: Capsules and slime layers. The capsule in the outer most layer and composed of polysaccharide or disaccharide and in some cases polypeptides. When polysaccharide is more fluid in consistency, it forms a gelatinous slime layer around the cell wall.

iii. **Cell wall**: It provides shape to the cell and protects underlying protoplasm having cytoplasm, chromatin, vacuoles, globules etc. The bacterial cell wall is made up of mucopeptide (murein). On the basis of two types of chemical composition of cell wall, bacteria are grouped into two as Gram +ve (85% or more mucopeptide and rest is simple polysaccharide) and Gram -ve (only 3-12% mucopeptide and rest are lipo-protein and lipo-polysaccharides)

iv. **Cytoplasm and organelles**: They contain soluble cytoplasmic constituents, nucleoid, mesosomes, ribosomes, lamellae (thylakoid) or vesicles (=chromatophores, found in photosynthetic bacteria) and some reserve materials like granules. Gas vacuoles or gas vesicles, chlorosomes, carboxysomes and magnetosomes are also special type of organelles found in some bacteria.

v. **Special structures**: Some bacteria form sporulation structures. Most characteristic spore structures are endospores, exospores, conidia, spores(akinetes), myxospores, cysts, bdellocyst are also formed by some genera of bacteria.

Morphological properties:

Genera	**Shape**	**Size (μm)**	**Motility**
Xanthomonas	Rod	0.4-1.0 x 1.2-3	Single polar flagellum
Pseudomonas	Rod	0.5-1.0 x 1.5-4	One or many polar flagella
Erwinia	Rod	0.5-1.0 x 1.0-3	Peritrichous
Agrobacterium	Rod	0.8 x 1.5-3	Sub-polar or peritrichous(1-4)
Clavibacter	Club-shaped/Rod	0.5-0.9 x 1.5-4	Non-motile/ motile with 1-2 polar flagella
Ralstonia	Rod	Single polar flagella	
Streptomyces	Filamentous	0.5-2 (dia)	Non-motile
Xylella	Rod	0.3 x 1-4	Non-motile

Cultural characteristics:
Genera Characters

Agrobacterium	Colonies are non-pigmented, smooth, gram -ve, oxidative metabolism
Clavibacter	Usually non pigmented, gram +ve, oxidative metabolism
Erwinia	Usually non-pigmented, gram -ve, fermentative metabolism

Pseudomonas Green diffusible fluorescent, brown diffusible pigment or no pigment, gram -ve, oxidative metabolism.

Xanthomonas	Yellow, non-diffusible, gram -ve, oxidative metabolism
Ralstonia	Non-pigmented, creamy white colonies, oxidative metabolism, gram-ve

Streptomyces Colonies are at first white coloured, small (1-10 mm dia), smooth, later become powdery velvetty due to weft of aerial mycelium, gram -ve, produce variety of pigments depending on the substrates, oxidative metabolism

Xyllela Produce long filamentous strand when cultured, gram-ve, colonies are small, smooth or undulated margins, non-pigmented, arerobic/oxidative metabolism

Taxonomy, classification and nomenclature of bacteria: Taxonomy is the art of biological classification which includes identification as well as description of the basic taxonomic units (species) as completely as possible; it also determines the correct way of arrangement (cataloguing) of these units.

Major divisions of bacteria on the basis of cell wall structure

Kingdom : Prokaryotae

Division I : Gracilicutes (thin skin/cell wall, gram negative bacteria)

Class : Scotobacteria

Anoxyphotobacteria

Oxyphotobacteria

Division II : Firmicutes (strong/durable cell wall, gram positive bacteria)

Class : Firmibacteria

Thallobacteria

Division III : Tenericutes(soft/tender cell wall, mycoplasma)

Class : Mollicutes

Division IV : Mendosicutes (faulty cell wall)

Class : Archaebacteria

Division and groups based on Bergey's Manual of Systematical Bacteriology (1984)

Kingdom : Prokaryotae

Division I : Cyanobacteria(blue green algae , myxophyceae)

Division II: Bacteria

Part 1 : Phototrophic bacteria : 1Order, 3 Family, 18 Genera

Part 2 : Gliding bacteria : 2 Orders, 8 Family,21 Genera

Part 3 : Sheathed bacteria : 17 Genera

Part 4 : Budding and Appendaged bacteria : 17 Genera

Part 5 : Spirochetes : 1 Order, 1 Family, 5 Genera

Part 6 : Spiral and curved bacteria : 1 Family, 2 Genera

Part 7 : Gram-negative Aerobic rods and cocci : 5 Family, 14 Genera

Part 8 : Gram-negative Facultative Anaerobic rods : 2 Family, 17 Genera

Part 9 : Gram-negative Anaerobic bacteria : 1 Family, 3 Genera

Part 10 : Gram-negative Cocci and Coccobacilli : 1 Family, 2 Genera

Part 11 : Gram-negative Anaerobic Cocci : 1 Family, 3 Genera

Part 12 : Gram-negative Chemolithotrophic bacteria : 2 Family, 17 Genera

Part 13 : Methane producing bacteria : 1 Family, 3 Genera

Part 14 : Gram-positive Cocci : 3 Family, 12 Genera

Part 15 : Endospore forming Rods and Cocci : 1 Family, 5 Genera

Part 16 : Gram- positive Asporogenous rod-shaped bacteria : 1 Family, 1 Genus

Part 17 : Actinomycetes and related organisms : 4 Genera not assigned to any family; 1 Family with 2 Genera; 1 Order with 8 Family and 31 Genera

Part 18 : Rickettsias : 2 Order, 4 Family, 18 Genera

Part 19 : Mycoplasmas : 1 Class, 1 Order, 2 Family, 2 Genera

Nutrition and effect of physiochemical factors on growth:

A. Nutrition: Many organic substrates are the sources, two nutrients viz. carbon (C) and energy which are important for bacterial growth. Certain bacteria e.g. *Pseudomonas* can use more than

90% organic compounds as a sole source of C and energy. Some bacteria can use two substrates (methane and methanol by methane producing bacteria) or only one substrate (cellulose decomposing bacteria). Bacteria need CO2 (5-10%) for satisfactory growth on organic media. Thiamin (Vitamin B1) is also required for the growth of bacteria. However, the bacterial species which can synthesise thaiamin, do not require any special compound.

While bacteria are grown on/in artificial medium, the medium should have balanced mixture of necessary nutrients. Synthetic (ingredients are chemically known) and complex (ingredients are chemically unknown) media are used for artifical culture of bacteria. Commonly used elements in synthetic medium are K, Mg, Fe, Ca, Mn, Mo, Co, Zn, NH4 and glucose (for C). For nitrogen fixing bacteria, N is not needed in media. Complex medium viz. nutrient medium contains peptone and beef extract and is used to grow wide range of micro-organisms including those microbes whose precise requirements (growth factors) are not known. Based on nutritional requirement also bacterial classification is made using some specific terms like autotrophic, heterotrophic, phototrophic, chemotrophic, lithotrophic and organotrophic.

B. Growth and Reproduction: In all cellular organisms, growth is achieved through cell multiplication. Hence, multiplication of a multicellular organisms result in an increase in size, while the multiplication of unicellular organisms results in increase in number. Growth in bacteria takes place through multiplication where one bacterium doubles at regular intervals (doubling time or generation time is 20-30 minutes) by binary fission (asexual reproduction). Thus number of bacterial cells increases exponentially. Formation of endospores, cysts, fragmentation, sporangiospores and conidia are some other means of asexual reproduction in bacteria. The sexual reproduction in bacteria is represented by transformation, conjugation, transduction and lysogenic conversions. The growth curve of bacteria can be plotted with four phases viz. lag phase (slow growth), log phase (exponential growth), stationary phase (no growth) and death phase (decline of living cells).

C. Effect of physical factors / forces on growth and reproduction:

(i) **Temperature**: Bacteria can survive temperatures of 0° to 85°C or even more depending upon the species. On the basis of temperature requirement, bacteria are divided into 3 catagories viz. psychrophilic (0-30°C, optimum 15°C), mesophilic (min. 5-25°C , opt. 18-45°C, max.30-50°C) and thermophilic (min. 25-45°C, opt. 55°C,max.60-93°C).

(ii) **Moisture**: Bacteria are more aquatic than terrestrial and can survive in presence of high percentage of water.

(iii) **Light:** Ordinary visible light does not affect bacterial activity. But different spectrum of light viz UV light, infra-red light have different effect on the activity of bacterial species.

(iv) **Pressure**: Ordianary mechanical pressure can not affect bacterial cells. Principle of osmosis is the best used pressure for destruction of bacteria.
(v) **Hidrogen-ion concentration**: Suitable pH range for bacterial growth and reproduction is 5.0 to 9.0

Bacterial Genetics and Variability: Knowledge on the genetic system of bacteria was dull till 1940. Prior to this period, no definite nucleus had been demonstrated in bacteria although variability in bacterial cells was recognized well before. Only the development of science in Molecular Biology helped to recognize transfer of genetic material i.e. DNA to the daughter cells at the time of binary fission.

Variability among bacteria is resulted from the following processes:
(i) **Conjugation**: Two compatible bacterial cells come into contact. Then the recipient female cell (F-) receives the DNA from the donor male cell (Hfr). Thus genetic make up of both the cells is changed.

(ii) **Transformation**: The bacterial cell absorbs DNA exuded by compatible cells or freed by dissolution of the cell-wall into the external medium.

(iii) **Transduction**: This process is a “phage-mediated genetic transfer”. The bacterial viruses (bacteriophages or phage) can acquire DNA from one cell and transfer it to the other cells attacked by them. If attacked cell is not destroyed due to infection by the phase, it reproduces to form new races with different genetic character.

(iv) **Lysogeny**: It involves association of genetic material of a virus with that of bacterium. Although it is different from above three processes, it also provides a permanent genetic modification of the bacterial genome.

Mollicutes

Mollicutes is a class of bacteria distinguished by the absence of a cell wall. The word "Mollicutes" is derived from the Latin *mollis* (meaning "soft" or "pliable"), and *cutis* (meaning "skin"). Individuals are very small, typically only 0.2–0.3 μm (200-300 nm) in size and have a very small genome size. They vary in form, although 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*.

Mollicutes are parasites of various animals and plants, living on or in the host's cells. Many cause diseases in humans, attaching to cells in the respiratory or urogenital tracts, particularly species of *Mycoplasma* and *Ureaplasma*. Phytoplasma and *Spiroplasma* are plant pathogens associated with insect vectors.

Whereas formerly the trivial name "mycoplasma" has commonly denoted any member of the class Mollicutes, it now refers exclusively to a member of the genus *Mycoplasma*.

History of the classification

The classification of the Mollicutes has always been difficult. The individuals are tiny, and being parasites, they have to be cultivated on special media. Until now, many species could not be isolated at all. In the beginning, whether they were fungi, viruses, or bacteria was not clear. Also, the resemblance to L-forms was confusing. At first, all members of the class Mollicutes were generally named "mycoplasma" or pleuropneumonia-like organism (PPLO). Mollicutes other than some members of genus *Mycoplasma* were still unidentified. The first species of *Mycoplasma*/Mollicutes, that could be isolated was *Mycoplasma mycoides*. This bacterium was cultivated by Nocard and Roux in 1898.

In 1956, D.G. Edward and E.A. Freundt made a first proposal for classifying and naming PPLOs. They left undecided, however, whether they belong to the bacteria (prokaryotes, in 1956 called "Schizomycetes") or to the eukaryotes. As type species (name-giving species) of the PPLOs/mycoplasmas, Edward and Freundt proposed *Mycoplasma mycoides*, being the causative organism of bovine pleuropneumonia and referring to the pleuropneumonia-like organisms. Until then, *Mycoplasma mycoides* was known as *Asterococcus mycoides*, but later that name was not recognized as valid. In their publication of 1956, they described 15 species of *Mycoplasma*.[9] In 1967 the class Mollicutes, containing the order Mycoplasmatales, was proposed by the Subcommittee on Taxonomy of the Mycoplasmata.[5] Now, the name *Mycoplasma* should exclusively be used for members of the genus *Mycoplasma*, rather than the use as a trivial name for any mollicute. As the trivial name has been used in literature for a long time, this is yet not always the case.

Viruses: nature, architecture, multiplication and transmission

Viruses

Matthew (1981) defined a virus as “a set of one or more nucleic acid template molecules, normally encased in a protective coat, or coats of protein or lipoprotein, which is able to organize its own replication within suitable host cells. Within such cells, virus production is (a) dependent on the host’s protein synthesizing machinery, (b) organized from pools of the required materials rather than by binary fission, and (c) located at sites which are non separated from the host cell contents by a lipoprotein, bilayer membrane”.

Many plant diseases which are now known to be caused by viruses had been encountered long ago. The causes of those diseases were not known. The first breakthrough was made by Adolf Mayer in 1886, in the Netherlands, while studying the highly contagious, mysterious disease of tobacco which he called “Mosaikkrankheit” i.e. mosaic like disease. He found that healthy plants could be infected by injecting the sap of diseased plants. He also observed that the unknown agent could be inactivated by boiling the sap. He concluded that the disease was the manifestation of a bacterium. In 1892, Ivanovsky confirmed Meyer’s report and further showed the sap to remain infections even after passage through bacteria-proof filter. However, he claimed the incitant to be a microbe. But Martinus Beijerinck realized the causal agent to be something novel. His results further confirmed the findings of Meyer and Ivanovsky and also showed that the incitant could diffuse into an agar gel. Based on all these findings, Beijerinck, in 1898, concluded that the mysterious pathogen was not a bacterium, but a *contagium vivum*.

fluidum i.e. contagious infective material or infectious living fluid. He thought the contagium to be able to reproduce itself in living plants and referred it as a virus.

Architecture of viruses and viriods

Morphologically, virus particles are (i) isometric (spherical, polyhedral) and (ii) anisometric (rigid or flexuous rods, bacilliform or bullet-shaped). Many isometric viruses have symmetric polyhedra which are either of three cubic symmetry i.e. tetrahedral, octahedral or icosahedral. Isometric particles measure the diameter 17nm (satellite virus of tobacco necrosis virus) to 70nm (reoviruses). The bacilliform viruses measure up to 300 nm length x 95 nm width (rhabdovirus group). The rod-shaped viruses having short rigid rod measure 114-215 nm length x 23 nm width

(the tobraviruses) and those with long flexuous particles measure up to 2,000 nm length x 10 nm in width (the closteroviruses). The rod shaped particles of tobacco mosaic virus (TMV) consist of protein sub-units (capsomeres) built up in a regular, helical array, with the RNA chain compactly coiled in a corresponding helix on the inside of the protein sub-units. The protein coat (capsid) and RNA genome surround an axial hole or canal. In membrane-bound viruses, the inner nucleoprotein core is called as nucleocapsid.
Viroids are smallest (1.1-1.3 x 105 mol. wt.), simplest and non-encapsidated RNA. They consist of a single molecular species of circular or linear form.

Chemical composition: Plant virus particles consist of infectious nucleic acid (the genome), which is encapsidated within a protective protein coat or shell. The genome, essential for virus replication, is composed of ribonucleic acid (RNA in most groups of viruses) and deoxyribonucleic acid (DNA in the caulimovirus and geminivirus groups). The RNA and DNA may be single stranded (ss) or double stranded (ds) Besides these two basic components, an envelop of lipid or lipoprotein membrane is present in some plant viruses. Other components are metallic ions and polyamines present in varying amounts. Some enzymes are found in reoviruses and rhabdoviruses. Water constitutes 10-50 percent of the mass of virus particle.

The nucleic acid may be present as a single continuous strand (single molecular species) in a particle. It is called mono-partite genome. Some nucleic acid genomes have two or more pieces (molecular species) in different particles; usually they are not always encapsidated within separate protein shells. Such genomes are termed as bi-, tri-, or multi-partite or the viruses with divided genome.

In some RNA viruses, the genetic information is divided into two or more parts. They are called multi-component viruses and the individual components are not infectious alone. Hence two or more genomic elements are needed to cause infection and replication.

The genomic organization of viruses depicts structure and function of genes or cistrons. Some triplet bases called codons are responsible for expression of genes. There are two types of codons, (i) initiation codons (AUG, GUG) and (ii) termination codons (UAG, UAA, UGA) and they control functions of genes and translation products.

Nomenclature of viruses and classification: A number of addition and deletion was made in naming viral pathogens. Linnaean style of binomial nomenclature is not followed. Instead, plant pathogenic viruses are named based on the common or vernacular name of the affected host plant such as tobacco mosaic virus, rice dwarf virus, caulimoviruses, potato virus X and Y etc. Later, these vernacular names were further simplified by abbreviating them such as TMV for tobacco mosaic virus, CMV for cucumber mosaic virus, potex virus for potato virus X, CaMV for cauliflower mosaic virus etc. In addition to such names, a system of cryptogams was introduced to give concise information on the properties (immediate summary) of one virus for example:

TMV = R/1 : 2/5 : E/E : S/O

1st term : Type of nucleic acid (RNA, DNA)/number of strands of nuleic acid (1=ss, 2=ds)

2nd term : Molecular weight of nuleic acid in millions/ % of nuleic acid in infective particle

3rd term : Outline of particle shape (E=elongate, S=spherical, B=bacilliform)/outline of nuclear capsid (E, S, B)

4th term : Type of host infected (B=bacteria, F=fungus, I=invertebrate, S=seed plant)/ type of vector (Ap=aphid, Au=leafhopper, Cl=beetle, Fu=fungus, Ne=nematode, Th=thrips, W=whitefly, O=spread without vector, Se=seed transmitted)

A system of plant virus classification was introduced by International Committee on Taxonomy of Viruses (ICTV) based on the characteristics such as morphology of virus particle, type and quantity of nucleic acid, genomic structure and type of vector. For example Classification based on particle morphology and type of nucleic acid:

I. Elongated, Helical, ss RNA

A. Rigid

(a) Monopartite

(b) Multipartite

B. Flexuous, all monopartite

II. Isometric

A. Single stranded RNA

(a) Monopartite

(b) Multipartite

(b1) With envelope

B. Double stranded RNA

C. Single stranded DNA

D. Double stranded DNA

III Bacilliform

A. Without envelop

B. With envelop

Grouping of plant viruses

Like families and genera cited in the classification of fungi and bacteria, plant virologists have been using "groups" for viruses. A total of 26 groups have been accepted by ICTV and some of those are,

1. Alfalfa mosaic virus group
2. Bromoviruses
3. Carlaviruses
4. Caulimoviruses
5. Comoviruses
6. Dianthoviruses
7. Geminiviruses etc.

There are about 11 unclassified virus groups are known, e.g.

1. Barley yellow mosaic virus group
2. Carnation mottle virus group
3. Rice stripe virus group
4. Satellite virus group etc.

Criteria for identification of viruses

Viruses causing plant diseases can be identified correctly by number of ways:

1. *Behaviour in host*: Host range, symptoms and their types, tissue restriction, type and location of intracellular inclusion bodies, seed transmissibility.
2. *Vector relation*: Taxa, acquisition and inoculation thresholds, persistence in vector, multiplication in vector, modes of transmission (e.g. transovarial transmission).
3. *Particle properties*: Shape and symmetry, size, presence or absence of envelope, capsomeric structure, sedimentation properties (number of components and

sedimentation co-efficient); coat protein properties (no. of polypeptides and their molecular weight); properties of nucleic acid (RNA, DNA, strandedness, no. molecules and molecular weight, presence or absence of 5'-terminal M7 Gppp, 5'-terminal VPg, 3'-terminal Poly (A)); electrophoretic mobility; isoelectric point, serological relationship.
4. *In vitro properties in crude sap*: This is determined by the tests viz. thermal inactivation point (TIP), dilution end point (DEP), longevity of virus *in vitro* (LIV).
5. *Cross-Protection tests*: Virus identity and strain relationship can be done. However, this sort of test is less applied now-a-days.

Important techniques for virus detection and identification:

1. *Electron microscopy*: used to know shape, symmetry, size, presence or absence of envelope and capsomeric structure.
2. *Immunosorbent electron microscopy* (ISEM).
3. *Serology*: The technique includes

(i) Precipitin tests (precipitin-tube test, precipitin-ring test, microprecipitin test).
(ii) Immunodiffusion tests (single, radial diffusion test, gel double-diffusion or Ouchterlony test)
(iii) Agglutination test (slide-agglutination or chloroplast-agglutination test).
(iv) Enzyme-linked immunosorbent assay (ELISA): It includes indirect ELISA and direct double antibody sandwich (DAS) ELISA.
(v) Dot immunobinding assay (DIBA)
(vi) Molecular hybridization analysis (spot hybridization or dot-blot technique)
(vii) Monoclonal antibodies (MAb)

Multiplication and infection nature of plant viruses: The events in virus infection involve three steps: adsorption, penetration or entry and uncoating or disassembly. The initial contact between virus particle and host cell is referred to as adsorption or entry. The process during which the virion or its nucleic acid passes into the cytoplasm of the cell is known as penetration or entry. Uncoating is the removal of various components of the mature virion and subsequent release of viral genome and other constituents that plays a major role in establishing infection.

(i)Multiplication of virus in plants*:* The replication of RNA and DNA plant viruses differ from diffent groups of viruses or for individial viruses. The mechanism known for different groups of plant viruses are – ssRNA virus- monopartite genomes, ssRNA virus-bipartite genome, ssRNA virus- tripartite genome, dsRNA virus- monopartite genome, satellite viruses, helper viruses and satellite RNAs, dsDNA viruses. The progeny RNA moves out to cytoplasm where the assembly sythensized proteins and encapsidation of virion take place. The process continues till the host is alive and a large number of new virus particles are formed.

(ii)Accumulation and movement of viruses in plant: The nascent virus appears in the cell about 10 hours after infection. The concentration of virus varies based on the type of virus, temperature, nutrition and duration of light. The virions are found aggregated in amorphous or crystalline forms or they are dispersed in cytoplasm and nucleus.

In plant system, two stages of virus movement have been recorded. These are:

a. Cell to cell or short distance movement: This type of virus movement takes place through protoplasmic bridges, the plasmodesmata. The plasmodesmata selectively allows passage to the macromolecules and thus virus can move through it with the help of virus-coded 'movement protein' mechanism.

b. Movement from one part to another part of plant: This is a long distance movement of the viruses taking place through vascular system. The movement is faster in elongated young cells than in round and older cells. Moreover, virus moves fast at high temperature because the protoplasmic streaming and cellular activities are higher at high temperature. The nature of cells (parenchyma, xylem, phloem, sieve tubes) also determined rate movement of viruses in plant.

As a result of the multiplication and distribution of the viruses in the plant system, the host plant(s) are infected and exhibited varying degrees of disease symptoms.

Transmission of plant viruses: Viruses are distributed or transmitted from the infected plants to the healthy ones in various ways in nature. As the plant viruses can not penetrate cuticle of their hosts and hence they can enter into the host tissue through wounds only. The means of transmission are:

1. *Mechanical transmission*: The sap of the infected plant is manually transferred to the healthy plants. It is the easiest method of experimental inoculation.

2. *Graft transmission*: In this practice, if either the scion (shoot portion) or stock (root stock)

is infected, the virus usually moves to the healthy partner which may later express visible symptoms of disease.

***3.*Transmission through vectors**

(i) Insects: Some insect species are the vector of plant viruses which can carry/ transmit viruses from infected plants to the healthy plants e.g. aphid (potato virus Y, PLVR), white flies (tobacco leaf curl), beetles (cowpea mosaic virus), mealy bugs (cacao mottle leaf), thrips (tomato spotted wilt), lace bugs (sugar beet viruses), mites (sterility mosaic of arhar), leaf hoppers (beet curly top, rice tungro etc.), planthoppers (maize mosaic, maize rough dwarf), tree hopper (tomato pseudo curly top).

(ii) Nematodes: Five genera of nematodues viz., *Xiphinema*, *Longidorus*, *Paralongidorus, Trichodorus* and *Paratrichodorus* can transmit plant viruses.

(iii) Fungi: Some species of fungi can also transmit viruses e.g. *Olpiduim brassicae* (tobacco necrosis), *O. cucurbitacearum* (cucumber necrosis), *Polymyxa graminis* (oat mosaic, wheat mosaic), *P. betae* (beet necrotic yellow vein) and S*pongospora subterranea* (potato mop top) etc.

4. *Dodder transmission*: Many viruses can be transmitted through dodder (*Cuscuta* spp.). Dodder transmission is used in the laboratory to transfer viruses from the hosts.

5. *Transmission through seeds and pollens:* Seed coat (testa), embryo, and also pollens of some plants can transmit viruses. e.g. alfalfa mosaic, barley stripe mosaic, bean common mosaic, lettuce mosaic are transmitted by both seeds and pollens of *Medicago sativa*, *Hordeum vulgare, Phaseolus vulgaris* and *Lactuca sativa*, respectively.

Basic characteristics of insect transmission: Virus transmission, specially in case of the aphid transmission, takes place by three ways viz. non-persistent (stylet borne), semi-persistant and persistent (circulative). These modes of transmission have been distinguished on the basis of acquisition feeding time, inoculation feeding period, latent period and multiplication or nomultiplication of the viruses within their vector etc. Apart from aphids, semi-persistent mode is recorded in mealy bug (*Planococcoides njalensis* - cacao swollen shoot virus) and leaf hopper (*Graminella nigrifrons* - maize chlorotic dwarf virus; *Nephotettix impicticeps* - rice tungro virus) and persistent mode is recorded in leaf hopper (*N. cincticeps* - rice dwarf virus; *Agallia constricta* - wound tumer virus), plant hopper (*Peregrinus maidis* - maize mosaic virus), tree hopper (M*icrutalis malleifera* - tomato pseudo curly top virus), beetles (*Ceratoma trifurcata* –

cowpea mosaic virus; *Phyllotreta* sp. – turnip yellow mosaic virus) and thrips (*Frankliniella fusc*a – tomato spotted wilt virus).

Some viruses pathogenic to plant can be transmitted only in presence of a second virus (helper virus) in the host and this type is called dependent transmission. For example, aphid (*Myzus persicae*) transmits potato aucuba mosaic virus only.

Nematodes: General morphology and reproduction, classification of nematode Symptoms and nature of damage caused by plant nematodes (Heterodera, Meloidogyne, *Anguina* etc.)

Introduction

Nematology is an important branch of biological science, which deals with a complex, diverse group of round worms known as Nematodes that occur worldwide in essentially all environments. Nematodes are also known as eelworms in Europe, nemas in the United States and round worms by zoologists. Many species are important parasites of plants and animals, whereas others are beneficial to agriculture and the environment. Nematodes that are parasites of man and animals are called helm inthes and the study is known as Helminthology. The plant parasitic forms are called nematodes and the study is known as Plant Nematology. The name nematode was derived from Greek words nema (thread) and oides (resembling). Annual crop losses due to these obligate parasites have been estimated to be about $ 78 billion wordwide and $ 8 billion for U.S. growers. The estimated annual crop loss in Tamil Nadu is around Rs. 200 crores.

The soils in a hectare of all agro ecosystem typically contain billions of plant parasitic as well as beneficial nematodes. The damage to plants caused by nematodes is often overlooked because the associated symptoms, including slow growth, stunting and yellowing, can also be attributed to nutritional and water related disorders.

Even though nematodes occupy nearly every habitat on earth, they are remarkably similar in morphology and life stages. Despite their structural complexity, certain basic principles are common to all nematodes. Nematodes are triploblastic, bilaterally symmetrical, unsegmented, Pseudocoelomate, vermiform and colourless 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 (Paratylenchus) to about 11.0mm (Paralongidorus maximus). Their 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). The swelling increases the reproductive potential of the organism. 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 spicules.

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 helminth parasitising whale fish is about 27 feet long. The study on these animal and human parasites are known as Helminthology.

Nematode exhibits considerable variation in their external and internal structure. Despite this structural complexity, certain basic principle is common to all nematodes

General shape & size

Nematodes : Triploblastic, bilaterally symmetrical, unsegmented, colourless, pseudo coelomate, vermiform and circular in cross section animals.

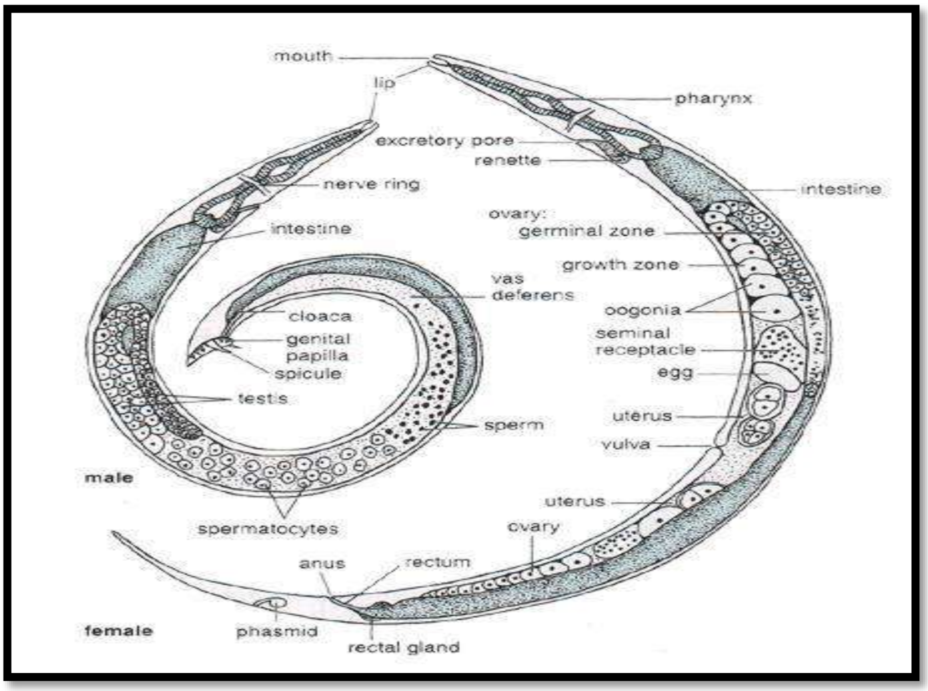


Fig: General Morphology of Nematode

Shape: Nematode show great variation in their morphological characters. The plant parasitic nematodes are slender, spindle shaped or fusiform organisms. The nematodes when relaxed with gental heat either lie straight (*Pratilenchus)* or slightly curved (*Hoplolaimus)* or curved in 'C' shaped (*Tylenchorynchus)* or form a spiral (*Helicotylenchus).* Sexual dimorphism in few species. Lemon, pear, kidney, saccate shape.

Size: Their size may vary from 0.2 mm to about 12 mm length with an average of 0.01 mm and 0.5 mm in breadth (1 to 15 % to length). Males are smaller than females.

Body regions: The nematode body is not divisible into definite regions as that of insects, however there are certain subdivisions like anterior part of the body having the mouth, lips and stoma is called head and it is continuous with main body. The portion between the head and the base of oesophagus is the neck. The part of the body beginning from the anus or cloca and extending up to posterior extremity is the 'tail'. Longitudinally, the body can divided into four zones: the ventral which bears the natural openings like excretory pour, anus or cloaca and vulva; the side apposite to the ventral is dorasal. The other two sides are right and left laterals.

Lip region: The lip region is also called as head exhibits great variation which may be used taxonomic purpose.

Tail region: It is the post-anal elongation of the body present in all stages of nematodes.

General structure of nematode:

The body of nematode is tubular which may be divided into three regions I) Outer body tube or body wall

Inner body tube –Digestive system

body cavity– Reproductive system, Nervous system, Excretory system

Outer body tube

Exoskeleton or cuticle,

Hypodermis and

Muscle layer.

Exoskeleton or cuticle:

It is outermost covering of body wall which is non-cellular, semipermeable and tough layer secreted by the epidermal cells. It invades all natural opening of body including the mouth, rectum, cloaca, vagina, excretory pore, amhids and phasmids.

The cuticle of many nematode species has markings on the surface. They are varied and complex and often used by taxonomist in identification of nematode species. The cuticular lining/markings are categorized in different types are as follows.

Cuticular lining or markings:

Punctations – They are commonly appearing as minute or round areas which are arranged in pattern. It acts as a structure for strengthening cuticle and transport of proteins.

Transverse markings or Annules or Striations – There are several transverse lines present on the surface of cuticle. These markings are exhibit on most of the plant parasitic nematodes and often used for identification. Annulations give segmented appearance *e.g.* scales in Criconemoides & perineal pattern of root-knot nematodes. Necessary for dorsoventral undulatory movement.

Longitudinal markings – These markings are the lines on the cuticle, which runs longitudinally throughout the nematode body.

i) Ridges – These are raised areas, which run length of the body and occur on sub-median as well as lateral surface.

ii) Alae – These are thickening or projections occur in lateral or sub-lateral region. They assist in locomotion. There are three types of alae

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

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

Longitudinal alae – These are limits to the lateral fields. They are transverse by striations or furrows varying in number from one to twelve which provide locomotion and may permit slight change in the width of nematode.

Cuticular layering or covering:

The nematode cuticle is basically three layer structure and composed of (a) Cortical layer, (b) Median layer and (c) Basal layer.

Cortical layer – It is often divided into external cortical layer and internal cortical layer. The surface of external cortical layer is exposed to the environment. This layer is very thin measuring about 25 to 40 mµ. The external layer has been considered to be kertatine (protein) chemically. In cyst nematode the cuticle of the female on maturity becomes tough and leathery to form cyst which protect eggs under dry conditions.

Median layer – The average thickness of the median layer is 0.1 µ in the larva of *Meloidogyne* and *Heterodera.* Chemically the median layer consist of protein, which resembles collagen (Non osmophilic collagen protein).

Basal layer – It consist of regularly arranged vertical rods or striations. It is composed of protein with very close linkage between the molecules, resulting in resistant layer which protect the nematode from outer environment. The thickness of basal layer varies from 125 to 500 mµ (Osmophilic protein close to keratine)

Functions of cuticle:

Protects the nematode from harsh environment.

Serves as exoskeleton

Provide mechanism of movement of the nematode through the soil and plant tissue.

Hypodermis –

The hypodermis is cellular or partially cellular layer. It secretes the cuticle. It lies between cuticle and somatic muscle layer. It is important metabolic active part of the nematode. Forms 4 cords (dorsal, ventral and two lateral). Contains hypodermal glands

Muscle layer -

It is arranged in a single layer. The muscle cells are spindal shaped and attached to the hypodermis throughout their length. It is well connected to the nervous system. The stimulation of the muscles by dorsal and ventral nerves cause contractions in the dorso-ventral plane and result in the characteristic scinusodial movement of nematode.

On the basis of arrangement of the basic cells, following three types are identified:

a. Holomyarian: Having two muscle cells in each zone.

b. Meromyarian: Two or five muscle cells in each interchordal zone.

c. Polymyarian: More than five muscle cells in each zone

1. **Reproductive system of nematode:-**
    - The males are generally slightly smaller than females.
    - The nematodes are dioecious or amphigonus having a separate male and female within a species.
    - Generally the males are lesser in number than females or even be completely absent. This indicates a tendency towards hermaphroditism and parthenogenesis.

A. Female Reproductive system:-

- **Monodelphic-** The nematodes may have a single ovary the female is called as monodelphic.

- **Didelphic-** The nematodes may have two ovaries then the female is called as didelphic.

- **Prodelphic-** When a single gonad is present, it may be either directed towards anterior to vulva then female is called as prodelphic.

- **Opisthodelphic-** The gonad either directed towards posterior to vulva then female is opisthodelphic.

- **Amphidelphic-** The two ovaries are opposite to one another, such as one is anteriorly directed and other posteriorly directed.

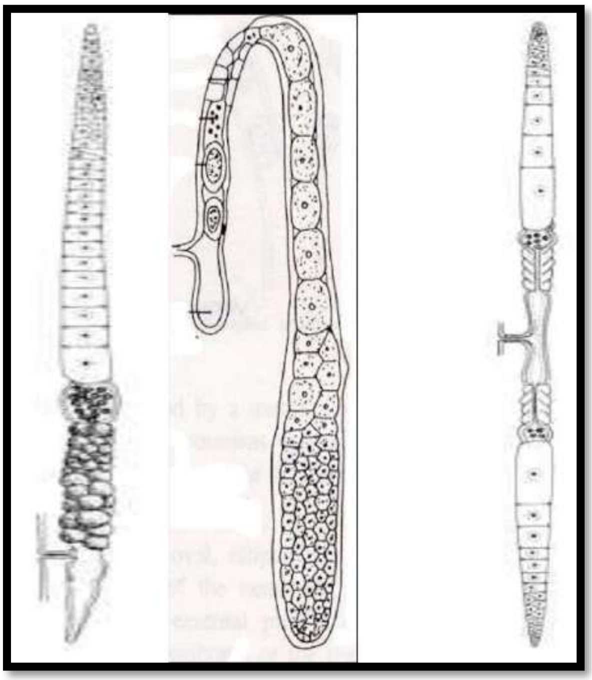


Fig. Prodelphic, Opisthodelphic and Amphidelphic

The female reproductive system typically consists of ovary, oviduct, uterus, vagina and vulva.

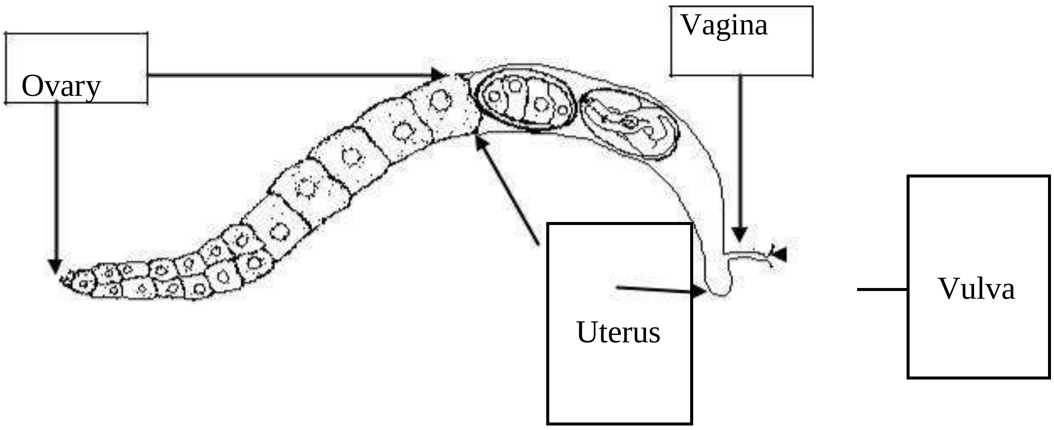


Fig. Female Reproductive System

(i) The ovary-

It is hollow elongate tube. The apical end of ovary has a cap cell at the tip which is called as germinal or zone of multiplication in which rapid cell division takes place to give rise germinal cells. This region is followed by growth zone which constitutes the greater part of ovary. The oocytes or germ cells in this zone become big and ripe which are generally arranged in single rows. After maturity they are called oogonia.

(ii) Oviduct-

Next to growth zone of ovary the gonad has oviduct. The oocytes when ripe they pass in to oviduct. Oviduct may serve as spermathica in some nematode. However in others, the spermathica is in the proximal part of uterus or in the post-vulvar sac at the distal end of gonad.

(iii) The uterus-

It is the largest and most complex part of the gonad, serves and function of fertilization, egg shell formation and laying of eggs. As started above, the upper part of uterus serves as spermathica in some nematodes.

(iv) Vagina-

The uterus entered in common vagina, which is a short, narrow and flattened tube lined with cuticle and provided with muscles.

(v) Vulva-

The vagina opens through female gonopore, the vulva. The eggs are expelled through a vulva which is normally situated middle of the body.

B. Male Reproductive system:-

- **Monarchic-** The nematode may have one testis are called monarchic.
- **Diarchic-** The nematode may have two testis are called diarchic.

The male reproductive system generally consists of three primordial parts: the testis, seminal vesicle, and vas deference.

(i) The Testis-

In the testis the germinal and growth zone can be easily distinguished. In germinal zone Spermatogonial division takes place, while in growth zone, spermatocytes increases in size. The spermatocytes are arranged in single or double rows.

(ii) Vas deference-

It consist of an anterior glandular region and posterior muscular region and containing the ejaculatory duct at the posterior end.

(iii) Ejaculatory duct-

The ejaculatory duct helps in the ejection of sperms during fertilization. It tapers gradually and opens ventrally into the cloca. The cloca is provided male copulatory structures such as spicules, gubernaculums etc.

Classification of Nematodes

Class- Adenophorea

Class- Secernentea

Sub-class: Enoplia

Sub-class: Chromatorea

Super Order: Marenoplica

Super Order: Terrenoplica

Order: Enoplida
Oncholaimida
Tripylida

Order: Dorylaimida
Isolaimida
Mononchida
Stichosomida

Order: Araeolaimida
Chromadorida
Desmoscolecida
Desmodorida
Monhysterida

Class- Secernentea

Sub-class: Rhabditia

Sub-class: Spiruria

Sub-class: Diplogasteria

Order: Rhabditida
Family
Heterorhabditidae
Steinernrmatidae

Order: Ascaridida
Family
Ascarididae
Dictophymatidae

Order: Spirurida
Family
Drocunculidae
Filariidae

Order: Tylenchida

Order: Diplogasterida
Family
Diplogasteridae

Sub-order: Tylenchina

Sub-order: Aphelenchina
Family- Aphelenchina

Sub-order: Sphaerulariina
Family- Fergusobiidae

Super family: Tylenchoidae
Family: Anguinidae, Belonolaimidae
Dolichodoridae, Heteroderidae
Tylenchidae, Hoplolaimidae

Super family: Criconematoidae
Family: Criconematidae
Tylenchulidae

Ecological classification of nematodes

There are two major classes

I. Above ground feeder
II. Below ground feeder

I. Above ground feeder

a. Feeding on flower buds, leaves and bulbs
   i) Seed gall nematode: *Anguina tritici*
   ii) Leaf and bud nematode: *Aphelenchoides*
   iii) Stem and bulb nematode: *Dictylenchus*

b. Feeding on tree trunk
   i) Red ring nematode: *Rhadinaphelenchus cocophilus*
   ii) Pine wilt nematode: *Bursaphelenchus xylophilus*

II. Bellow ground feeder

It is again classified in to three classes

I) Endoparasitic nematodes
II) Semiendoparasitic nematodes
III) Ectoparasitic nematodes

a) Endoparasitic nematodes

The entire nematode is found inside the root and the major portion of nematode body found inside the plant tissues. They are two types

1) Migratory endoparasite:- These nematodes move in cortical parenchyma of host root. While migrating they feed on cells, multiply and cause necrotic lesion. Example, *Pratylenchus* spp., *Radopholus* spp. and *Hirschmanniella* spp.
2) Sedentory endoparasite: - the second stage larvae penetrate the root lets and become sedentary throughout the life cycle, inside the root cortex. Examples, *Heterodera* spp. and *Meloidogyne* spp.

b) Semiendoparasitic nematodes

The anterior part of nematode, head and neck being permanently fixed in the cortex and the posterior part extends free into the soil. Examples, *Rotylenchulus reniformis* and *Tylenchulus semipenetrans*.

c) Ectoparasitic nematodes

These nematodes live freely in the soil and move closely or on the root surface, feed intermittently on the epidermis and root hair near the root tip. They are two types,

1) Migratory ectoparasites:- These nematodes spend their entire life cycle free in the soil, feeding externally on the host plants, deposit eggs in soil. When the

roots are disturbed they detach themselves. Examples, *Criconemoides* spp., *Paratylenchus* spp. and *s* spp., etc.

2) <u>Sedentory ectoparasites</u>:- In this type of parasitism the attachment of nematode to the root system is permanent but for this, it is similar to the previous one. Examples, *Hemicycliophora arenaria* and *Trichodorus* spp., etc.

1) Root-knot Nematode, *Meloidogyne* spp.

Systematic Position:-

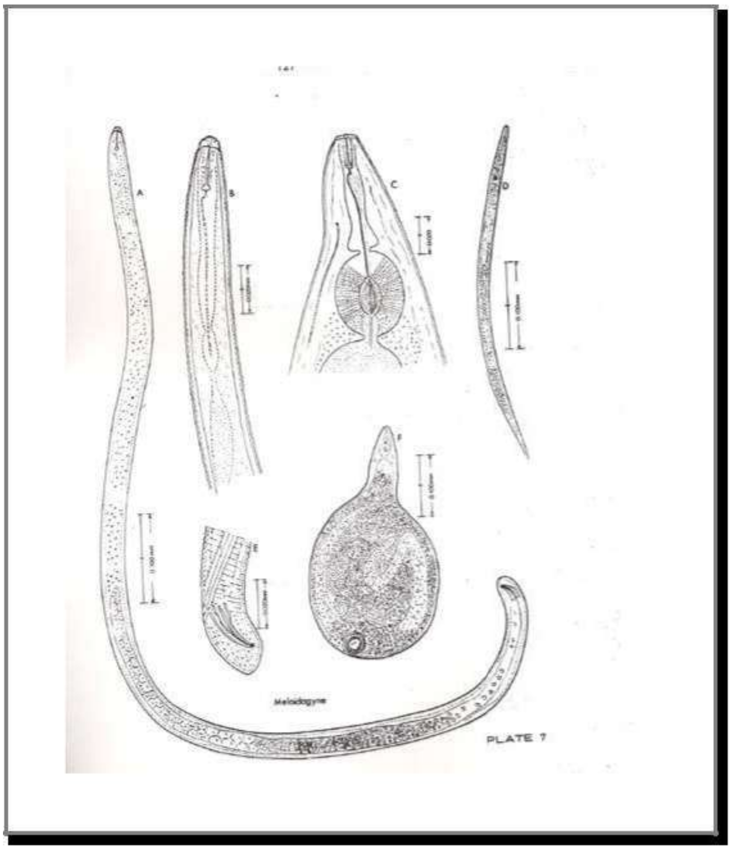
Order - Tylenchida
Sub order - Tylenchina
Super family - Tylenchoidea
Family - Heteroderidae
Sub family - Meloidogyninae
Genus - Meloidogyne
Species -
i) *incognita*
ii) *javanica*
iii) *arenaria*
iv) *hapla*

Parasitism & Habitat:-

i) Females and III & IV stage of larvae are Sedentory endoparasites.
ii) Males and II stage larvae are migratory.

Morphological characters:-

i) Body - Elongate larvae and male Typically saccate, spheroid with a distinct neck in females.
ii) Stylet - In males, Strong with rounded knob & In females, more slender than males.
iii) Oesophagous – With large median bulb followed by short isthumus.
iv) Excretory pore - Often seen with part of excretory tube in the area between posterior part of stylet knobs and opposite to median bulb.
v) Vulvas & anus - Females typically opposite to neck and surrounded by a pattern of fine lines like human fingerprint.(Perennial pattern)
vi) Spicule - Very near the terminus of males Bursa is absent.



- Yellowing of leaves
- Stunted growth
- Reduced vigor

- Reduced size & number of fruits
- Gall formation
    - **Multinucleate cell** – Giant cell (Nurse cell)
    - **Hypertrophy** – Enlargement of cell
    - **Hyperplasia –** Multiplication of cell

Control:-

- Two to three deep Ploughing
- Rotation with cereal crops
- Apply carbofuron (Furdan 3G) @ 7 g/m^2
- Resistant varieties of Tomato eg. Hisar Lalit, PNR 7

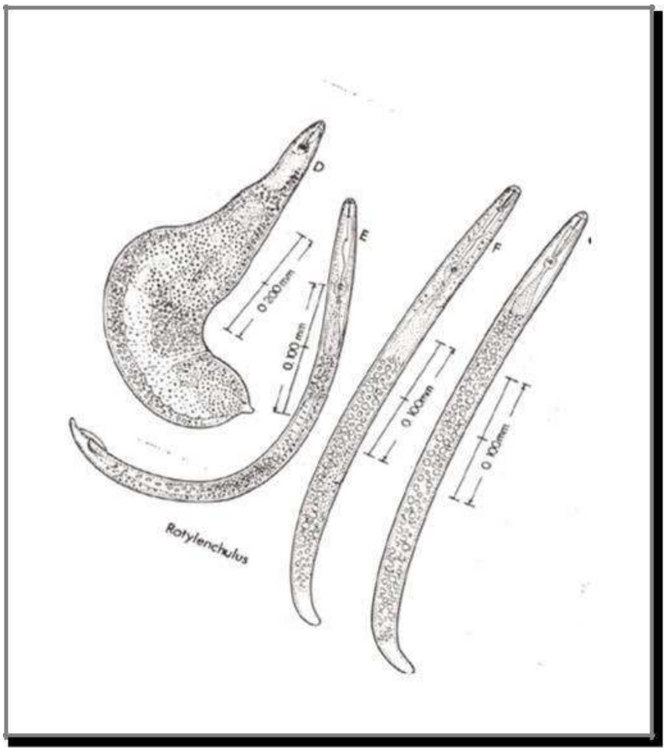
2) Reniform Nematode, *Rotylenchulus reniformis*

Systematic Position:-

Order	- Tylenchida
Sub order	- Tylenchina
Super family	- Hoplolaimoidea
Family	- Hoplolaimidae
Sub family	- Hoplolaiminae
Genus	- *Rotylenchulus*
Species	- *reniformis*

Parasitism & Habitat:- Females are Semiendoparasitic on many plants.

Morphological characters:-



i) Body - Males and immature females are slender and small, adult females are kidney shaped
ii) Oesophagous - Dorsal oesophageal glands opens about one stylet length posterior to stylet knobs.

Symptoms:-

Yellowing of leaves, delayed germination, reduced plant growth and vigor, stunted growth, browning of roots due to penetration of nematode are the general symptoms of this nematode. Young and tender plants are more vulunerable to nematode attack.

3) Root-lesion Nematode, *Pratylenchus* spp.

Systematic Position:-

Order	- Tylenchida

Sub order - Tylenchina
Super family - Tylenchoidea

Family - Pratylenchidae

Sub family - Pratylenchinae

Genus - *Pratylenchus*

Species - i) *coffeae* - Citrus, Banana & coffee

ii) *zeae* - Maize

iii) *thornei* - Pulses

Parasitism & Habitat:-

- Migratory endoparasites
- Feeding on root cortex of many crop/plant
- All stages found in root or soil.

Morphological characters:-

i) Body length - 0.4-0.8 mm.
ii) Lip region - Slightly set-off from body.
iii) Stylet - Typically short, strong with massive knob.
iv) Ovary - Monodelphic
v) Vulva - Posterior fourth of the body (75-80%).
vi) Tail - Nearly round to pointed and in males, the tail has bursa.
vii)

Symptoms:-

Late emergence of seedlings, less germination and stunted growth with necrotic lesions on the root surface which are initially small coalesce at the later stage and cause death of the rootlets. Root system is reduced.

Control:-

- Raise nursery in nematode free soil
- Pull and burn infected plants

-

4) Spiral Nematode, *Helicotylenchus* spp.

Systematic Position:-

Order - Tylenchida
Sub order - Tylenchina
Super family - Tylenchoidea
Family - Hoplolaimidae
Sub family - Rotylenchoidinae
Genus - *Helicotylenchus*

Parasitism & Habitat:- Endoparasitic and ectoparasitic on many plants

5) Spiral Nematode, *Helicotylenchus* spp.

Systematic Position:-

Order	- Tylenchida
Sub order	- Tylenchina
Super family	- Tylenchoidea
Family	- Hoplolaimidae
Sub family	- Rotylenchoidinae
Genus	- *Helicotylenchus*

Parasitism & Habitat:- Endoparasitic and ectoparasitic on many plants

Morphological characters:-

i) Body - Arcuate to 'C' shape when relaxed

ii) Stylet - Moderately long, typically located more than one half stylet length posterior to stylet knobs.

iii) Ovaries - Two (didelphic)

iv) Vulva - Posterior to middle of body (60-70%)

v) Tail - In females, rounded to nearly pointed often with short projection on ventral side and In males, tail is short with bursa.

Symptoms:- The nematodes attack root cortex and produce necrotic lesions.

5) Cyst Nematode, *Heterodera* spp & *Globodera* spp.

Cyst means any abnormal membranous sac or blister like pouch containing fluid.

Systematic Position:-

Order	- Tylenchida
Sub order	- Tylenchina
Super family	- Tylenchoidea
Family	- Heteroderidae
Sub family	- Heteroderinae
Genus	- i) *Heterodera*
	ii) *Globodera*

Species of *Heterodera* -

i) *avenae* - Cereal cyst nematode(wheat & barley) found in north India

ii) *zeae* - Maize cyst nematode

iii) *cajani*- Pigeon pea cyst nematode (tur, mung, Udid & cowpea)
iv) *oryzicola* - Rice cyst nematode (rice & banana) found in Kerala, M.P., Orissa & West Bengal.

Species of *Globodera* -

i) *rostochinensis*- Potato cyst nematode or Golden nematode

ii) *pallida*

Host plants - Potato, Tomato & Brinjal

Parasitism & Habitat:-

Parasitic on many plants mostly in temperate zone (Notably potatoes, sugar beets, oats & other grains, clover, soybean & various cruciferous)

Morphological characters:-

i) Body - Slender in males (1.0-2.0 mm) and larvae (0.3-0.6 mm) In females, typically swollen, lemon shaped (0.5-0.8 mm)

ii) Colour - White or yellow, cyst dark brown, lemon shaped (0.8 mm long & 0.5 mm wide) or nearly same shape as that *Meloidogyne* female.

iii) Stylet - Short in males with rounded basal knobs & in larvae, more than 0.02 mm long.

iv) Oesophagous - With well-developed median bulb & lobe extending back & overlapping the intestine.

v) Spicule - Near the posterior end of males

Globodera - Similar to *Heterodera* spp. slight difference in adult females are globular (rounded) in shape and hence the genus is named as *Globodera*.

Symptoms:-

Heterodera - The diseased plants show yellowing of leaves, stunted growth, reduced tillering. Earheads if formed are very small known as **'Molya'** disease' *Globodera* - Typical symptoms of heavy infestation are stunted plants with unhealthy foliage, premature yellowing, poor development of root system, reduction in size and number of tubers. Such plants exhibit temporary wilting during hotter part of the day.

Control:-

Heterodera

- Two- three summer ploughing at 10-15 days interval.
- Rotation with Mustard, chick pea
- Apply Carbofuron @ 1-2 kg a.i./ha.

Globodera

- Rotation with pea, cabbage, carrot, cauliflower during autumn season.
- Grow resistant varieties of potatoes - Kufri Swarna, Kufri Thenmalai

6) Daggar Nematode, *Xiphinema* spp.

Systematic Position:-

Order	- Dorylaimida
Sub order	- Dorylaimina
Super family	- Dorylaimoidea
Family	- Longidoridae
Sub family	- Xiphineminae
Genus	- *Xiphinema*

Parasitism & Habitat: - Migratory ectoparasites

Morphological characters:-

i) Body - Females elongate, cylindrical, forming open spiral with a greater curvature in posterior half.

ii) Stylet - Typically long..

iii) Ovaries - Monodelphic or didelphic.

iv) Vulva - Situated at middle of body.

v) Tail - Bluntly rounded or with projections on ventral side in both males and females.

vi) Males extremely rear, not essential for reproduction.

vii) Males similar to females but more slender caudal alae subterminal.

Disease Caused:- Alfa disease of Rice.

Symptoms:-

At vegetative phase, yellowing or white splash pattern of leaf sheath where margins become concorted. Later splash patterns develop brownish stains and internodes and stems turn black.

At the reproductive phase, the nematode collects around the floral primordia and feed upon the developing earheads. Earheads emerges as crinkled or twisted with empty spiklets **(ripe ufra)** or does not emerge at all **(swollen ufra).**

8) Citrus Nematode, *Tylenchulus semipenetrans* Systematic Position:-

Order	- Tylenchida
Sub order	- Tylenchina
Super family	- Criconematoidea
Family	- Tylenchulidae
Sub family	- Tylenchulinae
Genus	- *Tylenchulus*
Species	- *semipenetrans*

Parasitism :- Endoparasitic on roots of citrus and other plants. Mature females are semiendoparasitic.

Morphological characters:-

i) Body - Small all stages. Mature females swollen.

ii) Stylet - Small in larvaes and males, well developed in mature females.

iii) Oesophagous - With distinct posterior bulb in larvae young males and immature females.

iv) Vulva - Prominent in posterior end of young and adult females.

v) Excretory pore - Typically situated posteriorly in protuberance just anterior to vulva.

vi) Anus - Absent or difficult to see in immature stages.

vii) Bursa - Absent.

Symptoms:-

The diseased trees show reduction in growth and vigor with yellowing of leaves. Such trees show gradual dieback symptoms starting from the uppermost portion.

Roots of infected trees appear larger in diameter and darker than the healthy trees mainly due to adherence of soil particles to the gelationous matrix excreted by the adult females. Cortex of highy infested feeder roots decays and gets sloughed off easily.

9) Burrowing Nematode, *Radopholus similis*

Order	- Tylenchida
Sub order	- Tylenchina
Super family	- Tylenchoidea
Family	- Pratylenchidae
Sub family	- Pratylenchinae
Genus	- *Radopholus*
Species	- *similus*

Parasitism: - Endoparasitic on roots of Banana and citrus.

Morphological characters:-

i) Body - 0.4-0.9 mm in length.

ii) Lip - Rounded in females, set off and knob like in males.

iii) Stylet - Short and stout in females, slender and rudimentary in males.

iv) Oesophagous - Forming a lobe, dorsally overlaps to intestine.

v) Vulva - Located at middle of the body.

vi) Ovaries - Didelphic

vii) Tail - Blunt end in females and male long tail with bursa.

Symptoms:-

In banana, bearing plants show poor growth and small fruit size, prone to toppling over under high wind pressure. The nematode causes wounding of roots resulting in reddish brown cortical lesions which are clearly visible by splitting the affected roots longitudinally. Purplish streaks on the young roots. The lesions lead to the formation of tunnels and cavities in the roots. The infection spreads to young suckers also in which necrotic tissues develop.

Symptoms Caused by Nematodes

Most of the plant parasitic nematodes affect the root portion of plants except *Anguina* spp, *Aphelenchus* spp, *Aphelenchoides* spp, *Ditylenchus* spp, *Rhadinaphelenchus cocophilus* and *Bursaphelenchus xylophilus.* Nematode suck the sap of the plants with the help of stylet and causes leaf discolouration, stunted growth, reduced leaf size and fruits and lesions on roots, galls, reduced root system and finally wilting.

Symptoms of nematode disease can be classified as

A) Symptoms produced by above ground feeder nematodes
B) Symptoms produced by below ground feeder nematodes

A) Symptoms produced by above ground feeder nematodes

i) **Dead or devitalized buds** – Nematode infection kills growing buds *e.g. Aphelenchoides fragariae* on strawberry.

ii) **Crinkled stems and foliage -** *e.g.* Wheat gall nematode, *Anguina tritici* Ulfa disease of rice, *Ditylenchus angustus.*

iii) **Seed galls** – *e.g.* Wheat gall nematode, *Anguina tritici* larva enter into the flower primordium and develops in to a gall.

iv) **Necrosis & discolouration –** *e.g.* Red ring disease of coconut, *Rhadinaphelenchus cocophilus*. Due to the infestation, red coloured circular area appear in the trunk of infested palm.

v) **Leaf lesions -** Symptom on broad-leafed foliage plants. *e.g.* Chrysanthemum foliar nematode, *Aphelenchoides ritzemabosi*

vi) **Twisting of leaves and stem:** *e.g.* In onion basal leaves become twisted when infested with *Ditylenchus dipsaci.*

vii) **Leaf discolouration:** The leaf tip become white in rice due to rice white tip nematode *Aphelenchoides besseyi.*

B) Symptoms produced by below ground feeder nematodes

The nematode infest and feed on root portion and exhibit symptoms on below ground plant part as well as on the above ground plants parts and they are classified as

I) Above ground symptoms
II) Below ground symptoms

I) <u>Above ground symptoms:-</u>

i. Stunting: Reduced plant growth and the plant cannot able to withstand in adverse conditions. Patches of stunted plants appears in the field. *e.g. Heterodera avenae* – Molya disease in wheat & barley. *Globodera rostochiensis* – Golden nematode in potato

ii. Discolouration of foliage: Also due to nutritional deficiency *e.g.* Root lesion nematode, *Pratylenchus coffeae* White tip nematode, *Aphelenchoids besseyi* Citrus nematode, *Tylenchulus semipenetrans*

iii. Wilting: *e.g.* Root-knot nematodes, *Meloidogyne spp*

iv. Decline and die back: eg. In banana decline and die back are caused by *Radopholus similis.*

II) <u>Below ground symptoms:-</u>

i. Root galling: *e.g.* ***Meloidogyne spp***. – Characteristic galls on host roots ***Nacobbus spp*** **–** Larger galls on beet & tomato ***Ditylenchus radicicola*** **–** Small galls on cereals. ***Hemicycliophora arenaria*** **– G**alling on lemon roots ***Xiphinema diversicaudatum*** **- G**alling on roses

ii) Reduced root system: Due to nematode feeding the root tip growth is arrested and the root produced branches. This may be of various kinds such as coarse root, stubby root and curly root.

a) Stubby roots – Stubby branches or rootlets arranged in cluster eg. *Trichodorus christiei* on corn

b) Coarse root – Lateral roots stopped growth with no branches *e.g. Belonolaimus longicaudatus* on corn.

c) Curly root – The nematode retard the elongation of roots and cause curling of roots known as **'Fish hook'** symptom. Eg. Injury caused by *Xiphinema* spp.

iii) Root lesions – Necrotic lesions *e.g. Pratylenchus spp* (soybean), *Radopholus similis* (citrus & banana), *Helicotylenchus multicinctus* (banana)

iv) Rotting – Nematode + Micro-organisms. *e.g. Ditylenchus destructor – potato rot.*

v) Excessive root branching – *e.g. Meloidogyne hapla* in tomato

Principles and metods of plant disease management

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.

A. Principles of plant disease management: There is six basic concept or principles or objectives lying under plant disease management.

1. **Avoidance of the pathogen**: Occurrence of a disease can be avoided by planting/sowing a crop at times when, or in areas where, inoculum remain ineffective/inactive due to environmental conditions, or is rare or absent.

2. **Exclusion of the pathogen**: This can be achieved by preventing the inoculum from entering or establishing in a field or area when it does not exist. Legislative measures like quarantine regulations are needed to be strictly applied to prevent spread of a disease.

3. **Eradication of the pathogen**: It includes reducing, inactivating, eliminating or destroying inoculum at the source, either form a region or from an individual plant (rouging) in which it is already established.

4. **Protection of the host**: Host plants can be protected by creating a toxin barrier on the host surface by the application of chemicals.

5. **Disease resistance**: Preventing infection or reducing the effect of infection of the pathogen through the use of resistance host which is developed by genetic manipulation or by chemotherapy.

6. **Therapy**: Reducing severity of a disease in an infected individual.

The first five principles are prophylactic (preventive) procedure and the last one is curative.

B. Methods of plant disease management

1**. Avoidance of the pathogen:**

i. Choice of geographical area

ii. Selection of a field

iii. Adjustment of time of sowing.

iv. Use of disease escaping varieties

v. Use of pathogen-free seed and planting material

vi. Modification of cultural practices

2. **Exclusion of inoculum of the pathogen**

i. Treatment of seed and plating materials

ii. Inspection and certification

iii. Quarantine regulations

iv. Eradication of insect vector

3. **Eradication of the pathogen**

i. Biological control of plant pathogens

ii. Eradication of alternate and collateral hosts

iii. Cultural methods:

a. Crop rotation

b. Sanitation of field by destroying/burning crop debris

c. Removal and destruction of diseased plants or plant parts

d. Rouging

iv. Heat and chemical treatment of diseased plants

v. Soil treatment: by use of chemicals, heat energy, flooding and fallowing

4. **Protection of the host**

i. Chemical control: application of chemicals (fungicides, antibiotics) by seed treatment, dusting and spraying

ii. Chemical control of insect vectors

iii. Modifications of environment

iv. Modification of host nutrition

5. **Disease resistance**

Use of resistant varieties: Development of resistance in host is done by

i. Selection and hybridization for disease resistance

ii. Chemotherapy

iii. Host nutrition

iv. Genetic engineering, tissue culture

6. **Therapy**

Therapy of diseased plants can be done by

i. Chemotherapy

ii. Heat therapy

iii. Tree-surgery

Nature, chemical combination, classification of fungicides and antibiotics.

Fungicides – definition

The word „fungicide" originated from two latin words, viz., „fungus" and „caedo". The word „caedo" means „to kill." Thus the fungicide is any agency/chemical which has the ability to kill the fungus. According to this meaning, physical agents like ultra violet light and heat should also be considered as fungicides. However, in common usage, the meaning is restricted to chemicals only. Hence, fungicide is a chemical which is capable of killing fungi.

Fungistat

Some chemicals do not kill the fungal pathogens. But they simply arrest the growth of the fungus temporarily. These chemicals are called fungistat and the phenomenon of temporarily inhibiting the fungal growth is termed as fungistatis.

Antisporulant

Some other chemicals may inhibit the spore production without affecting the growth of vegetative hyphas and are called as „Antisporulant". Eventhough, the antisporulant and fungistatic compounds do not kill the fungi, they are included under the broad term fungicide because by common usgage, the fungicide has been defined as a chemical agent which has the ability to reduce or prevent the damage caused to plants and their products. So, some of the plant pathologists prefer the term „Fungitoxicant" instead of fungicide.

Characters of an ideal fungicide

1. It should have low phytotoxicity
2. It should have lonf shelf life
3. Stability during dilution
4. It should be less toxic to human being, cattle, earth worms , microorganisms etc.
5. It should be a broad spectrum in its action
6. Fungicide preparation should be ready for use
7. It should have compatibility with other agrochemicals
8. It must be cheaper one
9. It should be available in different formulations
10. It should be easily transportable

Classification of Fungicides

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

I. Based on mode of action

Protectant

As the name suggests, protectant fungicides are prophylactic in their behaviour.Fungicide which is effective only if applied prior to fungal infection is called a protectant, eg., Zineb, Sulphur.

Therapeutant

Fungicide which is capable of eradicating a fungus after it has caused infection and there by curing the plant is called chemotherapeutant. eg. Carboxin, Oxycarboxin antibiotics like Aureofungin. Usually chemo therapeutant are systemic in their action and affect the deep-seated infection.

Eradicant

Eradicant are those which remove pathogenic fungi from an infection court (area of the host around a propagating unit of a fungus in which infection could possibly occur). eg. Organic mercurials, lime sulphur, dodine etc. These chemicals eradicate the dormant or active pathogen from the host. They can remain effective on or in the host for some time.

II. Based on general uses

The fungicides can also be classified based on the nature of their use in managing the diseases.

1. Seed protectants : Eg. Captan, thiram, organomercuries carbendazim, carboxin etc.
2. Soil fungicides (preplant) : Eg. Bordeaux mixture, copper oxy chloride, Chloropicrin, Formaldehyde Vapam, etc.,
3. Soil fungicides : Eg. Bordeaux mixture, copper oxy (for growing plants) chloride, Capton, PCNB, thiram etc.
4. Foliage and blossom : Eg. Capton, ferbam, zineb, protectants mancozeb, chlorothalonil etc.
5. Fruit protectants : Eg. Captan, maneb, carbendazim, mancozeb etc.
6. Eradicants : Eg. Organomercurials, lime sulphur, etc.
7. Tree wound dressers : Eg. Boreaux paste, chaubattia paste, etc.

8. Antibiotics : Eg. Actidione, Griseofulvin, Streptomycin, Streptocycline, etc.,

9. General purpose spray and dust formulations.

III. Based on Chemical Composition

The chemical available for plant disease control runs into hundreds, however, all are not equally safe, effective and popular.Major group of fungicides used include salts of toxic metals and organic acids, organic compounds of sulphur and mercury, quinines and heterocyclic nitrogenous compounds. Copper, mercury, zinc, tin and nickel are some of the metals used as base for inorganic and organic fungicides. The non metal substances include, sulphur, chlorine, phosphorous etc. The fungicides can be broudly grouped as follows and discussed in detail.

Groups of Fungicides – Copper Fungicides, Sulphur Fungicides and Mercury Fungicides Copper Fungicides

The fungicidal action of copper was mentioned as early as 1807 by Prevost against wheat bunt disease *(Tilletia caries),* but its large scale use as a fungicide started in 1885 after the discovery of Bordeaux mixture by Millardet in France. The mixture of copper sulphate and lime was effective in controlling downy mildew of grapevine caused by *Plasmopara viticola* and later, late blight of potato *(Phytophthora infestans).*

Some other copper sulphate preparations later developed were Borduaux paste, Burgandy mixture and Cheshnut compound which are all very effectively used in the control of several plant diseases. In addition some preparations of copper oxy chloride preparations arev also mused. These are all insoluble copper compounds very successfully used in managing several leaf diseases and seeding diseases in nursery. Some of the important diseases controlled by copper fungicides are listed below.

I. Copper sulphate preparations

Boreaux Mixture

In 1882, Millardet in France (Bordeaux University) accidently observed the efficacy of the copper sulphate against the downy mildew of grapes caused by *Plasmopara viticola.* When copper sulphate was mixed with lime suspension, it effectively checked the disease incidence. The mixture of copper sulphate and lime was named as “Bouillie Bordelaise” (Bordeaux Mixture). The original formula developed by Millardet contains 5 lbs of CuSO4 + 5lbs of lime + 50 gallons of water. The chemistry of Bordeaux mixture is complex and the suggested reaction is:

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

The ultimate mixture contains a gelatinous precipitate of copper hydroxide and calcium sulphate, which is usually sky blue in colour. Cupric hrdroxide is the active principle and is toxic to fungal spores. In metric system, to prepare one percent Bordeaux mixture the following procedure is adopted:

One kg of copper sulphate is powdered and dissolved in 50 litres of water. Similarly, 1 kg of lime is powdered and dissolved in another 50 litres of water. Then copper sulphate solution is slowly added to lime solution with constant stirring or alternatively, both the solutions may be poured simultaneously to a third contained and mixed well.

The ratio of copper sulphate to lime solution determines the pH of the mixture. The mixture prepared in the above said ratio gives neutral or alkaline mixture. If the quality of the used is inferior, the mixture may become acidic. If the mixture is acidic, it contains free copper which is highly phytotoxic resulting in scorching of the plants. Therefore, it is highly essential to test the presence of free copper in the mixture before applied. There are several methods to test the neutrality of the mixture, which are indicated below:

(i) Field Test: Dip a well polished knife or a sickle in the mixture for few minutes. If reddish deposit appears on the knife/sickle, it indicates the acidic nature of the mixture.

(ii) Litmus paper test: The colour of blue litmus paper must not change when dipped in the mixture.

(iii) pH paper test : If the paper is dipped in the mixture, it should show neutral pH.

(iv) Chemical test: Acid a few drops of the mixture into a test tube containing 5 ml of 10% potassium ferrocyanide. If red precipitate appears, it indicates the acidic nature of the mixture.

If the prepared mixture is in the acidic range, it can be brought to neutral or near alkaline condition by adding some more lime solution into the mixture. Bordeaux mixture preparation is cumbersome and the following precautions are needed during preparation and application.

(i) The solution should be prepared in earthen or wooden or plastic vessels. Avoid using metal containers for the preparation, as it is corrosive to metallic vessels.

(ii) Always copper sulphate solution should be added to the lime solution, reverse the addition leads to precipitation of copper and resulted suspension is least toxic.

(iii) Bordeaux mixture should be prepared fresh every time before spraying. In case, the mixture has to be stored for a short time or a day, jaggery can be added at the rate of 100kg/100 litres of the mixture.

(iv) Bordeaux mixture is sometimes phytotoxic to apples, peaches, rice varieties like IR8 and maize varieties like Ganga Hybrid 3.

Bordeaux paste

Bordeaux Paste consists of same constituents as that of Bordeaux mixture, but it is in the form of a paste as the quantity of water used is too little. It is nothing but 10 percent Bordeaux mixture and is prepared by mixing 1 kg of copper sulphate and 1 kg of lime in 10 litres of water. The method of mixing solution is similar to that of Bordeaux mixture. It is a wound dresser and used to protect the wounded portions, cut ends of trees etc., against the infection by fungal pathogens.

Burgundy mixture

It is prepared in the same way as Bordeaux mixture, except the lime is substituted by sodium carbonate. So it is called as „Soda Bordeaux". It was developed Burgundy (France) in 1887 by Mason. The usual formula contains 1 kg of copper sulphate and 1 kg of sodium carbonate in 100 litres of water. It is a good substitute for Bordeaux mixture and used in copper-sensitive crops.

Cheshunt compound

It is compound usually prepared by mixing 2 parts of copper sulphate and 11 parts of ammonium carbonate. This formula was suggested by Bewley in the year 1921. The two salts are well powdered, mixed thoroughly and stored in a air tight container for 24 hours before being used. The ripened mixture is used by dissolving it in water at the rate of 3 g/litre. The mixture is dissolved initially in a little hot water and volume is made up with cold water and used for spraying.

II. Copper carbonate

preparation Chaubattia Paste

Chaubattia paste is another wound dressing fungicide developed by Singh in 1942 at Government Fruit Research Station, Chaubattia in the Almora district of Uttar Pradesh. It is usually prepared in glass containers or chinaware pot, by mixing 800g of copper carbonate and 800g of red lead in litre of raw linseed oil or lanolin. This paste is usually applied to pruned parts of apple, pear and peaches to control several diseases. The paste has the added advantage that it is not easily washed away by rain water.

III. Copper carbonate preparation

III. Cuprous oxide Preparation	Fungimar, Perenox, Copper Sandoz, Copper 4% dust, Perecot, Cuproxd, Kirt i copper.	Cuprous oxide is a protective fungicide, used mainly for seed treatment and for foilage application against blight, downy mildew and rusts.
IV. Copper oxychloride Preparation.	Blitox, Cupramar 50% WP, Fytolan, Bilmix 4%, Micop D-06, Micop w-50, Blue copper 50, Cupravit, Cobox, Cuprax, Mycop.	It is a protective fungicide, controls *Phytophthora infestans* on potatoes and several leaf spot and leaf blight pathogens in field.

Sulphur fungicides

Use of sulphur in plant disease control is probably the oldest one and can be classified as inorganic sulphur and organic sulphur. Inorganic sulphur is used in the form of elemental sulphur or as lime sulphur. Elemental sulphur can be either used as dust or wettable sulphur, later being more widely used in plant disease control. Sulphur is best known for its effectiveness against powdery mildew of many plants, but also effective against certain rusts, leaf blights and fruit diseases.

Sulphur fungicides emit sufficient vapour to prevent the growth of the fungal spores at a distance from the area of deposition. This is an added advantage in sulphur fungicides as compared to other fungitoxicants.

Organic compounds of sulphur are now widely used in these days. All these compounds, called as „carbamate fungicides‟, are derivatives of Dithiocarbamic acid, Dithiocarbamates are broadly grouped into two, based on the mechanism of action.

Dithiocarbamates

Monoalkyl Dithiocarbamates Eg. Zineb, Maneb, Eg. Thiram, Ziram, Mancozeb, Nabam, Vapam Ferbam	Dialkyl Dithiocarbamates

List of sulphur fungicides and the important diseases controlled by them are tabulated below:

Trade Name	**Diseases Controlled**	
Inorganic Sulphur 1. Elemental Sulphur (i) Sulphur dust	Sulphur dust Cosan, Wetsulf, Microsul	Sulphur is a contact and protective fingicide, normally applied as sprays or as dust. It is generally used to control powdery mildews of fruits, vegetables, flowers and tobacco. This is also effective against apple scab (Venturia inaequallis) and rusts of field crops.
2. Lime Sulphur (Calcium poly sulphide)	It can be prepared by boiling 9 Kg or rock lime and 6.75Kg of sulphur in 225 litres of water.	Lime Sulphur is effective against powdery mildews as a protective fungicide.
Organic Sulphur	Hexathane 75% WP,	It is used to protect

(Dithiocarbamates) a. Monoalkyl	Dithane Z-78, Funjeb, Lonocol, Parzate C,	foliage and fruits of a wide range of crops
dithiocarbamate 1. Zineb (Zinc ethylene bisdithiocarbamate)	Du Pant Fungicide A, Polyram.	against diseases such as early and late blight of potato and tomato, downy mildews and rusts of cereals, blast of rice, fruitrot of chilly etc.
2. Maneb (Manganese ethylene bisdithiocarbamate)	Dithane M22, Manzate WP, MEB	These two are protective fungicide used to control many fungal diseases of field crops, fruits, nuts, ornamentals and vegetables, especially blights of potatoes and tomatoes, downy mildews of vines, anthracnose of vegetables and rusts of pulses.
3.Mancozeb (Maneb + Zinc ion)	Dithane M45, Indofil M45, Manzeb.	
4. Nabam (DSE) (Di Sodium ethylene bisdithiocarbamate)	Chembam, Dithane A-40, Dithane D-14, Parzate Liquid	Nabam is primarily used for foilar application against leaf spot pathogens of fruits and vegetables. Soil

		applications were also reported to have a systemic action on *Pythium*, *Flusarium* and *Phytophthora*. It is also used to control algae in paddy fields.
5. Vapam (SMDC) (Sodium methyl dithiocarbamate)	Vapam, VPM, Chemvape, 4-S Karbation, Vita Fume.	It is a soil fungicide and nematicide with fumigant action. It is also reported to have insecticidal and herbicidal properties. It is effective against damping off disease of papaya and vegetables and wilt of cotton. It is also effective against nematode infestation in citrus, potato and root knot nematodes in vegetables.
b. Dialkyl Dithiocarbamate 1. Ziram (Zinc dimethyl dithiocarbamate)	Cuman L. Ziram, Ziride 80 WDP, Hexaazir 80% WP, Corozate, Fukiazsin, Karbam white, Milbam, Vancide 51Z, Zerlate, Ziram, Ziberk, Zitox 80% WDP.	Ziram is a protective fungicide for use on fruit and vegetables crops against fungal pathogens including apple scab. It is non phytotoxic except to zinc sencitive plants. It is highly effective against anthracnose of

		beans, pulses, tobacco & tomato, and also against rusts of beans etc.
2. Ferbam (Ferric dimethyl dithiocarbamate)	Coromat, Febam, Ferberk, Femate, Fermate D, Fermicide, Hexaferb 75% WP, Karbam Black, Ferradow.	Ferbam is mainly used for the protection of foliage against fungal pathogens of fruits and vegetables including *Taphrina deformans* of peaches, anthracnose of citrus, downy mildew of tobacco and apple scab.
3. Thiram (Tetra methyl thiram disulphide)	Thiride 75 WDP, Thiride 750, Thiram 75% WDP, Hexathir, Normerson, Panoram 75, Thiram, TMTD, Arasan, Tersan 75, Thylate, Pomarsol, Thiuram.	It is used for seed treatment both as dry powder or as a slurry. It is a protective fungicide also suitable for application to foilage to control *Botrytis spp.* on lettuces, ornamental, soft fruits and vegetables, rust on ornamentals and *Venturia pirina* on pears. It is also effective against soilborne pathogens like *Pythium, Rhizoctonia* and *Fusarium.*

Mercury Fungicides

Mercury fungicides can be grouped as inorganic and organic mercury compounds. Both the groups are highly fungitoxic and were extensively used as seed treatment chemicals against seed borne diseases. Ignorance compounds show bactericidal property also. However, due to their residual toxicity in soil and plants and their extreme toxicity nature to animal and human beings, the use of mercury fungicides is beings discouraged. In most of the countries, the use of mercury fungicides is banned and in countries like India, the use of mercury fungicides is restricted only in seed treatment for certain crops. The list of diseases against which mercury fungicides used are listed below

Common Name	Trade Name	Diseases Controlled
I. Inorganic Mercury 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.
II. Organomercurials Methoxy ethyl mercury Chloride Phenyl mercury chloride	Agallol, Aretan, Emisan, Ceresan wet (India) Ceresan Dry (India), Ceresol, Leytosan.	These are used mainly for treatment of seeds and planting materials. These fungicides are used for seed treatment by dry, wet or slurry method. For seed treatment 1% metallic mercury is applied at 0.25% concentration

Ethyl Mercury Chloride Tolyl mercury acetate	Ceresan (USA) Agrosan GN.	

Heterocyclic Nitrogen Compounds, Quinones and Miscellaneous Fungicides

Heterocyclic Nitrogen Compounds

Heterocyclic nitrogen compounds are mostly used as foliage and fruits protectants. Some compounds are very effectively used as seed dressers. Some of the commonly used fungicides are listed below.

Common Name	**Trade Name**	**Diseases Controlled**
1.Captan (Kittleson‟s Killer) (N-trichloromethyl thio-4- cyclohexence-1,2-dicarboximide)	Captan 50W, Captan 75 W, Esso Fungicide 406, Orthocide 406, Vancide 89, Deltan, Merpan, Hexacap.	It is a seed dressing fungicide used to control diseases of many fruits, ornamental and vegetable crops against rots and damping off.
2. Captafol (Cis-N-1,1,2,2-tetra chloro hexane 1,2- dicarboximide)	Foltaf, Difolaton, Difosan, Captaspor, Foleid, Sanspor.	It is a protective fungicide, widly used to control foliage and fruit diseases of tomatoes, coffee potato.
3. Glyodin	Glyoxaliadine, Glyoxide,	It has a narrow specrum of

	Glyodin, Glyoxide Dry, Glyodex 30% liquid and 70% WP.	activity. As a spray, it controls apple scab and cherry leaf spot.
4.Folpet (Folpet) [N-(trichloromethyl-thi)] phthalimide	Phartan, Acryptan, Phaltan, Folpan, Orthophaltan.	It is also a protective fungicide used mainly for foliage application against leaf spots, downy and powdery mildews of many crops.

Benzene compounds

Many aromatic compounds have important anti-microbial properties and have been developed as fungicides. Some important benzene compounds commonly used in plant disease control are listed below.

Common Name	**Trade Name**	**Diseases Controlled**
1. Quintozene (PCNB)	Brassicol, Terraclor, Tritisan 10%, 20%, 40% D and 75% WP, PCNB 75% WP.	It is used for seed and soil treatment. It is effective against *Botrytis, Sclerotium, Rhizoctonia* and *Sclerotinia spp.*
2. Dichloran	Botran 50% WP and 75% WP, Allisan.	It is a protective fungicide and very effective against *Botrytis, Rhizopus and Sclerotinia* spp.
3. Fenaminsosuplh (Sodiumpdimethylamino benzenediazosulphonate	Dexon 5% G and 70% WP	It is very specific in protecting germinating seeds and growing plants from seeds as well as soil-borne infection of

		Phythium, *Aphanomyces* and *Phytophthora* spp.
4.Dinocap (2,4-dinitro-6-octyl phenylcrotonate)	Karathane, Arathane, DNOPC, Mildex, Crotothane, Crotothane 25% WP, Crotothane 48% Liq.	Itisanon-systemic acaricide and control fungicide recommended to control powdery mildews on various fruits and ornamentals. It is also used for seed treatment.

Quinone Fungicides

Quinone areresent naturally in plants and animals and they exhibit anti-microbial activity and some compounds are successfully developed and used in the plant disease control. Quinones are very effectively used for seed treatment and two commonly used fungicides are listed below:

Common Name	**Trade Name**	**Diseases Controlled**
1. Chloranil (2,3,5,6-tetrachlora-1,4-benzoquinone)	Spergon	Chloronil is mainly used as a seed protectant against smuts of barely and sorghum and bunt of wheat.
2. Dichlone (2,3-dichloro-1,4- napthoquinone)	Phygon, Phygon XL WP.	Dichlone has been used widely as seed protectant. This is also used as a foliage fungicide, particularly against apple scab and peach leaf curl.
Organo – Phosphorous		It has a specific action

fungicide Ediphenphos (Edifenphos) (O-ethyl-SS-diphenyldithiophosphate)	Hinosan 50% EC and 2% D.	against *Pyricularia oryzae* (Rice blast). It is also effective against *Corticium sesakii* and *Cochliobolus miyabeanus* in rice.

Organo Tin compounds

Several other organic compounds containing tin, lead, etc. have been developed and successfully used in plant disease control. Among them, organo tin compounds are more popular and effective against many fungal diseases. These compounds also show anti bactericidal properties. Some of the organo tin compounds commonly used are listed below.

Common Name	**Trade Name**	**Diseases Controlled**
1. Fentin hydroxide (TPTHTiphenyl tin hydroxide)	Du-Ter WP 20% or 50% WP. Du-Ter Extra-WP, Farmatin 50 WP, Du-Terforte WP, Tubotin.	It is a non-systemic fungicide recommended for the control of early and late blight of potato, leaf spot of sugar beet, blast of rice and tikka leaf spot of ground nut.
2. Fentin acetate (TPTATriphenyl tin acetate)	Brestan WP 40% and 60% WP.	It is a non systemic fungicide recommended to control *Ramularia* spp.on celeryand sugar beet anthracnose and downy mildew It is effective against Cercospora leaf spot of

3. Fentin Chloride (TPTC- Triphenyl tin chloride)	Brestanol 45% WP, Tinmate.	sugarbeet and paddy blast

Systemic Fungicides and Antibiotics

Systemic Fungicides

Since the late 1960s there has been substantial development in systemic fungicides. Any compound capable of being freely translocated after penetrating the plant is called systemic. A systemic fungicide is defined as fungitoxic compound that controls a fungal pathogen remote from the point of application, and that can be detected and identified. Thus, a systemic fungicide could eradicate established infection and protect the new parts of the plant.

Several systemic fungicides have been used as seed dressing to eliminate seed infection. These chemicals, however, have not been very successful in the cases of trees and shrubs. On the basis of chemical structure, systemic fungicides can be classified as Benzimidazoles, Thiophanates, Oxathilins and related compounds, pyrimidines, morpholines, organo-phosphorus compounds and miscellaneous group.

I. Oxathilin and related compounds

Oxathalins were the earliest developed compounds. This group of systemic fungicide is also called as carboxamides, carboxyluc acid anillides, carboxaanillides or simply as anillides which are effective only against the fungi belong to *Basidiomycotina* and *Rhizoctonia solani*. Some of the chemicals developed are (i) Carboxin (DMOC: 5,6 - dithydra-2-methyl-1, 4-oxathin-3-carboxanillide) and (ii) Oxycarboxin (DCMOD- 2,3-dihydro-5-carboxanillido-6-methyl-1, 4 oxathilin-4, 4, dioxide). The diseases controlled by these chemicals are listed below.

Common Name	**Trade Name**	**Diseases Controlled**
1. Carboxin (5,6-dinydro- 2-methyl-1-4-oxanthin-3-carboxanlido)	Vitavax 10% D, Vitavax 75% WP, Vitavax 34% liq. Vitaflow.	It is systemic fungicide used for seed treatment of cereals against bunts and smuts, especially loose smut of wheat

2. Oxycarboxin (5,6-dihydro-2-methyl- 1,4-oxathin-3-carboxianilid-4,4- dioxide)	Plantvax 5G, Plantvax 5% liq. Plantvax 1.5 EC, 10% dust, 75 WP.	It is a systemic fungicide used for the treatment of rust diseases of cereals, pulses, ornamentals, vegetables and coffee
3.Pyracarbolid (2-methyl-5,6-dihydro- 4H-Pyran-3-carboxylic acid anilide).	Sicarol.	It controls rusts, smuts of many crops and *Rhizoctonia solani*, but is slightly more effective than carboxin

II. Benzimidazoles

The chemicals of this group show a very broad spectrum activity against a variety of fungi. However, they are not effective against bacteria as well as fungi belongs to *Mastigomycotina*. Two types of fungicidal derivates of benzimidazoles are known. The first type of derivates includes fungicides such as thiabendazole and fuberidazole. The fungicidal moiety of the second type is methyl-2-benzimidazole carbamate (MBC). The fungicides of this group may be simple MBC such as carbendazim or a complex from such as benomyl, which transforms into MBC in plant system. Some of the important diseases controlled by these compounds are shown below:

Common Name	**Trade Name**	**Diseases Controlled**
1.Benomyl (Methyl - 10 (butly carbomyl)-2 benzimidazole carbamate)	Benlate 50 WP, Benomyl. Bavistin 50 WP, MBC, Dersol, B.Sten 50, Zoom, Tagstin, Agrozim,	It is a protective and eradicative fungicide with systemic activity, effective against a wide range of fungi

2. Carbendazim (MBC) (Methyl -2-benzimidazole carbamate)	Jkenstin.	affecting field crops, fruits and ornamentals.It is very effective against rice blast, apple scab, powdery mildew of cereals, rose, curcurbits and apple and Diseases caused by *Verticillium and Rhizoctonia*. It is also used as pre-and postharvest sprays of dips for the control of storage rots of fruits and vegetables. Carbendazim is a systemic fungicide controlling a wide range of fungal pathogens of field crops, fruits, ornamentals and vegetables. It is used as spray, seedling dip, seed treatment, soil drench and as post harvest treatment of fruits. It is very effective against wilt diseases especially, banana wilt. It controls effectively the sigatoka leaf spot of banana, turmeric leaf spot and rust diseases in many crops.
3. Thiabendazole (TBZ) (2,4-thiazoyl benzimidazole)	Thiabendazole, Mertect, Tecto, Storite.	It is a broad spectrum systemic fungicide effectivel against many major fungal diseases. Pathogenic fungal control

		includes species of *Botrytis, Ceratocystis, Cercospora, Colletotrichum, Fusarium, Rhizoctonia, Sclerotinia, Septoria and Verticillium.* It is also effective for the post harvest treatment of fruits and vegetables to control storage diseases.
4.Fuberidazole (2, (2-buryl) - benzimidazole).	Voronit.	It is used for the treatment of seeds against diseases caused by *Fusarium,* Particularly *F.nivale* on rye and *F.culmorum* of peas

III. Thiophanates

These compounds represent a new group of systemic fungicides based on thiourea. They are the derivatives of thioallophanic acid. These fungicides contain aromatic nucleus which is converted into benzimidazole ring for their activity. Hence, thiophanates are often classified under benzimidazole group and the biological activity of thiophanates resembles of benomyl. Two compounds are developed under this group are discussed.

Common Name	**Trade Name**	**Diseases Controlled**
1. Thiophanate(1,2 - bis (ethyl carbonyl-2-thioureido) benzene)	Topsin 50 WP, Cercobin 50 WP, Enovit.	It is a systemic fungicide with a broad range of action, effective against

		Venturia spp., on apple and pear crops, powdery mildews, *Botrytis* and *Sclerotinia* spp. On various crops.
2. Thiophanate - methyl (1,2 bis (3 methoxycarbonyl-2-thioureido) benzene.)	Topsin-M70 WP, Cercobin-M 70 WP, Envovit-methyl, Mildothane.	It is effective against a wide range of fungal pathogens, including *Venturia spp.* on apples and pears, *Mycosphaerella musicola* on bananas, powdery mildews on apples, cucurbits, pears and vines, *Pyricularia oryzae* on rice, *Botrytis and Cerospora* on various crops.

IV.Morpholines

Common Name	**Trade Name**	**Diseases Controlled**
Tridemorph (2-6 - dimethyl-4-cyclo - tridecyl morpholine)	Calixin 75 EC, Bardew, Beacon	It is an eradicant fungicide with systemic action, being absorbed through foilage and roots to give some protective action. It controls powdery mildew diseases of

		cereals, vegetables and ornamentals. It is highly effective against *Mycosphaerella, Exobasidium*

V. Pyrimidines, Pyridines, Piperidines and Imidazole

Common Name	**Trade Name**	**Diseases Controlled**
1. Triadimefon (1-(4-chlorophenoxy)-3, 3-dimethyl-1-(1-2-triazol-1yl) butan-2-one)	Bayleton, Amiral	It is very effective against powdery mildews and rusts of several crops.
2. Triadimenol (1-(4-Chlorophenoxyl-3, 3-dimethyl-1(1,2,4-triazol-1-yl) butan-2-ol)	Baytan	It is also very effective against powdery mildews and rusts of several crops.
3. Bitertanal (B-(1-1-biphenyl-4-yloxy-a-(1-1-dimethyl-ethyl-1-H-1,2-4- triazole-1-ethanol)	Baycor	It is highly effective against rusts and powdery mildew of a variety of crops. It is also used against *Venturia* and *Monilinia* on fruits and *Cereospora* leafspots of groundnut and banana.
	Terrazole 30% WP, Terrazole 95% WP,	

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

VI. Hydroxy Pyrinidines

Common Name	Trade Name	Diseases Controlled
1. Ethirimol (5-butyl 2-ethyl amino-4-hydrop-6-methyl pyrimidine)	Milliatem 80 WDP, Milcurb Super, Milgo	It is effective against powdery mildew of cereals and other field crops. It is also effective against powdery mildews of cucumber and ornamentals.
2. Dimethirimol (5-butyl 2-dimethylamino-4-hydroxy-6-methy pyrimidine)	Milcurb	It is very effective against powdery mildews of chrysanthemum and cucurbits.
VII. Furan derivatives 1. Furcarbanil (2-5-dimethyl-3-furanilide)		It is used as seed or soil application, It systemically controlled bean rust and is being used as a seed

2. Cyclafuramid (N-cyclohexyl-2,5-dimethyl firamide) **VIII.Benzanilide derivative** 1. Mebenil (2-methyl benzanilide)		dressing fungicide against loose smut of wheat and barley. It is effective against bunts, smuts and rusts of cereals, coffee rust, blister blight of tea, smut and red rot of sugarcane, *Fusarium wilt* of tomato, *Rhizoctonia* on tomato, potato, groundnut, rice as well as *Armillaria* sp. On rubber. It is effective against yellow rust on wheat and barley *(P. striiformis)* and brown rust on barley *(P. hordei)*. It is also having direct fungitoxic activity against *Sclerotium rolfsli* and *Rhizoctonia*.

IX. Organo phosphorous compounds

Common Name	**Trade Name**	**Diseases Controlled**
1. Pyrazophos (2-0-0-	Afugan, Curamil, WP,	It is used to control

Diethylthionophosphoryl) -5- methyl-6-carbethoxy pyrazolo-(1- 5a)pyrimidine)	Missile EC.	powdery mildews of cereals, vegetables, fruits and ornamentals.
2. Iprobenphos (IBP) (S-benyzl-0-0-bisisopropylphosphorothiate)	Kitazin 48% EC, Kitazin 17G, Kitazin 2% D.	It is used to control *Pyricularia oryzae* and sheath blight of rice.
X. Piperazine 1.Triforine(N,N-bis-(1-foramido-2,2,2-trichloroethyl- piperazine)	Saprol-EG, Fungitex.	It is effective against powdery mildew, scab and other diseases of fruits and rust on ornamentals and cereals.
XI. Phenol derivative 1. Choloroneb (1-4-dichloro-2,5-dimethoxy benzene)	Demonsan 65 WP, Tersan SP, Turf fungicide	It is also active against storage diseases of fruits. It is highly fungistatic to *Rhizoctonia* spp., moderately so to *Pythium* spp. and poorly to *Fusarium* spp. It is used as a supplemental seed treatment for beans and soyabeans to control seedling disease

XIII. Other systemic fungicides

Common Name	Trade Name	Diseases Controlled
1. Metalaxyl (methyl-DLN-(2,6-dimethylphenyl-N-)2-methoxyacetyl	Apron 35 SD, Ridomil	It is a systemic fungicide and highly effective for specific use as seed dressing against fungal pathogens of the order Peronosporales.
2. Metalaxyl + Mancozeb	Ridomil MZ 72 WP (8% Metalaxyl + 64% Mancozeb)	It is a fungicide with systemic and contact action and effective against damping-off, root rots, stem rots, and downy mildew of grapes and millets.
3. Tricyclazole (5-methyl-1,2,4 triazole(3,4b)-benzothiazole)	Beam, Bim	It is a specific fungicide used against paddy blast fungus, *P. oryzae*
4. FosetylAI. (Aluminium - Trisaluminium	Alliette 80 WP	It is a very specific Fungicide for Oomycetous fungi, especially against *Pythium* and *Phytophthora*

Antibiotics

Antibiotic is defined as a chemical substance produced by one micro-organism which is low concentration can inhibit or even kill other micro-organism. Because of their specificity of action against plant pathogens, relatively low phytotoxicity, absorption through foliage and systemic translocation and activity in low concentration, the use of antibiotic is becoming very popular and very effectively used in managing several plant diseases. They can be grouped as antibacterial antibiotics and antifungal antibiotics. Most antibiotics are products of several actinomycetes and a few are from fungi and bacteria.

I. Antibacterial antibiotics

1. Streptomycin sulphate

Streptomycin is an antibacterial, antibiotic produced by streptomyces griseus. Streptomycin are streptomycin sulphate is sold as Agrimycin,-100, Streptomycin sulphate, Plantomycin, Streptocycline, Paushamycin, Phytostrip, Agristrep and Embamycin, Agrimycin - 100 contains 15 per cent streptomycin sulphate + 1.5 percent terramycin (Oxy tetracycline).

Agristerp contains 37 percent streptomycin sulphate. Phytomycin contains 20 percent streptomycin. Streptocycline and paushamycin contains 9 parts f streptomycin and 1 part of tetracycline hydrochloride.

This group of antibiotics act against a broad range of bacterial pathogens causing blights, wilt, rots etc. This antibiotic is used at concentrations of 100-500 ppm. Some important diseases controlled are blight of apple and pear *(Erwinia amylovora)*, Citrus canker *(Xanthomonas campestris p.v. citri)*, Cotton black arm *(X.c.* p.v. *malvacearum)*, bacterial leaf spot of tomato *(Pseudomonas solanacearum)*, wild fire of tobacco *(Pseudomonas tabaci)* and soft rot of vegetables *(Erwinia carotovora)*.

In addition, it is used as a dip for potato seed pieces against various bacterial rots and as an disinfectant in bacterial pathogens of beans, cotton, crucifers, cereals and vegetables. Although it is an antibacterial antibiotic, it is also effective against some diseases caused by Oomycetous fungi, especially foot-rot and leaf rot of betelvine caused by *Phytophthora parasitica var. piperina.*

2. Tetracyclines

Antibiotics belonging to this group are produced by many species of Streptomyces. This group includes Terramycin or Oxymicin (Oxytetracycline). All these antibiotics are bacteriostatic, bactericidal and mycoplasmastatic. These are very effective against seed-borne bacteria. This group of antibiotic is very effective in managing MLO diseases of a wide range of crops. These are mostly used as combination products with Streptomycin sulphate in controlling a wide range of bacterial diseases. Oxytetracyclines are effectively used as soil drench or as root dip controlling crown gall diseases in rosaceous plants caused by Agrobacterium tumefaciens.

II Antifungal antibiotics

1. Aureofungin

It is a hepataene antibiotic produced in sub-merged culture of Streptoverticillium cinnamomeum var. terricola. It is absorbed and translocated to other parts of the plants when applied as spray or given to roots as drench. It is sold as Aurefungin-Sol. Containing 33.3% Aureofungin and normally sprays at 50-100 ppm. The diseases controlled are citrus gummosis caused by several species of Phytophthora, powdery mildew of apple caused by *Podosphaera leucotricha* and apple scab (Venturia inaequalis), groundnut tikka leaf spot, downy mildew, powdery mildew and anthracnose of grapes, potato early and late blight. As seed treatment it effectively checked are *Diplodia* rot of mango, *Alternaria* rot of tomato, *Pythium* rot of cucurbits and *Penicillium* rot of apples and citrus. As a truck application/root feeding, 2 g of aureofungin-sol+1g of copper sulphate in 100 ml of water effectively reduce. Thanjavur wilt of coconut.

2. Griseofulvin

This antifungal antibiotic was first discovered to be produced by *Penicillium griseofulvum* and now by several species of *Penicillium,* viz., *P.patulum, P.nigricans, P.urticae, and P.raciborskii.* It is commercially available as Griseofulvin, Fulvicin and Grisovin. It is highly toxic to powdery mildew of beans and roses, downy mildew of cucumber. It is also used to control *Alternaria solani* in tomato *Sclerotinia fructigena* in apple and *Botrytis cinerea* in lettuce.

3. Cycloheximide

It is obtained as a by-product in streptomycin manufacture. It is produced by different species of *Streptomyces,* including *S.griseus* and S. *nouresi.* It is commercially available as Actidione, Actidione PM, Actidione RZ and Actispray. It is active against a wide range of fungi and yeast. Its use is limited because it is extremely phytotoxic. It is effective against powdery mildew of beans *(Erysiphe polygoni),* Bunt of wheat *(Tilletia spp.)* brownnot of peach *(Sclerotinia fructicola)* and post harvest rots of fruits caused by *Rhizopus* and *Botrytis* spp.

4. Blasticdin

It is a product of *Streptomyces griseochromogenes* and specifically used against blast disease of rice caused by *Pyricularia oryzae.* It is commercially sold as Bla-s.

5. Antimycin

It is produced by several species of *Streptomyces,* especially *S. griseus* and *S. Kitasawensis.* It is effectively used against early blight of tomato, rice blast and seedling blight of oats. It is commercially sold as Antimycin.

6. Kasugamycin

It is obtained from *Streptomyces kasugaensis.* It is also very specific antibiotic against rice blast disease. It is commercially available as Kasumin.

7. Thiolution

It is produced by *Streptomyces albus* and effectively used to control late blight of potato and downy mildew of cruciferous vegetables.

8. Endomycin

It is a product of *Streptomyces endus* and effectively used against leaf rust of wheat and fruit rot of strawberry *(Botrytis cinerea).*

9. Bulbiformin

It is produced by a bacterium, *Bacillus subtills* and is very effectively used against wilt diseases, particularaly redgram wilt.

10. Nystatin

It is also produced by *Streptomyces noursei.* It is successfully used against anthracnose disease of banana and beans. It also checks downy mildew of cucuribits. As a post harvest dip, it effectively reduces brown rot of peach and anthracnose of banana in stroage rooms. It is commercially marketed as Mycostain and Fungicidin.

11. Eurocidin

It is a pentaene antibiotic produced by *Streptomyces anandii* and called as pentaene G-8. It is effectively used against diseases caused by several species of *Colletotrichum* and *Helminthosporium.*

Methods of allocation of fungicides – Precautions and safety measures while handling fungicides

Proper selection of a fungicide and its application at the correct dose and the proper time are highly essential for the management of plant diseases. The basic requirement of an application method is that it delivers the fungicide to the site where the active compound will prevent the fungus damaging the plant. This is mostly achieved by spray, fog, smoke, aerosol, mist, dust, or granules applied to the growing plant or by seed or soil treatment.

In addition, some trees and shrubs can be protected by injection of fungicide liquid into the trunk or by brushing wounds with fungicide paints or slurries. In the case of sprays, mists, aerosols and fogs, the fungicide is in of droplets of water of another fluid. In the case of smokers, the solid particles of the fungicide are carried by the air. In the case of dusts and granules, the fungicide is straightly mixed with an inert carrier, impregnated into it coated on the particles, which are applied mechanically.

The object of spraying or dusting is to cover the entire susceptible surface of hostwith a thin covering of a suitable concentration of the fungicide before the pathogen has come into contact with the host. However, these practices may not effectively eradicate the inoculum present on the surface of the seeds or deep-seated in the seed. So, the application of chemicals as seed dressing is highly essential.

In addition, soil harbours several pathogens which cause root diseases in several crop plants. So treatment of soil with chemicals is also highly useful in reducing the inoculum load present in the soil. The fungicidal application varies according to the nature of the host part diseased and nature of survival and spread of the pathogen. The method which are commonly adopted in the application of the fungicides are discussed.

1. Seed treatment

The seed treatment with fungicides is highly essential because a large number of fungal pathogens are carried on or in the seed. In addition, when the seed is sown, it is also vulnerable to attack by many common soil-borne pathogens, leading to either seed rot, seeding mortality or produce diseases at a later stage. Seed treatment is probably the effective and economic method of disease control and is being advocated as a regular practice in crop protection against soil and seed-borne pathogens. Seed treatment is therapeutic when it kills pathogens that infect embroys, cotyledons or endosperms under the seed coat, eradicative when it kills pathogens that contaminate seed surfaces and protective when it prevents penetration of soilborne pathogens into the seedling. There are various types of seed treatment and broadly they may be divided into three categories (a) Mechanical, (b) Chemical and (c) Physical.

A. Mechanical method

Some pathogen when attack the seeds, there may be alteration in size, shape and weight of seeds by which it is possible to detect the infected seeds and separate them from the healthy ones. In the case of ergot diseases of cumbu, rye and sorghum, the fungal sclerotia are usually larger in size and lighter than healthy grains. So by sieving or flotation, the infected grains may be easily separated. Such mechanical separation eleminates the infected grains may be easily separated. Such mechanical separation eliminates the infected materials to a larger extent. This method is also highly useful to separate infected grains in the case of „tundu" disease of wheat. Eg. Removal of ergot in cumbu seeds.

Dissolve 2kg of common salt in 10 litres of water (20% solution). Drop the seeds into the salt solution and stir well. Remove the ergot affected seeds and sclerotia which float on the surface. Wash the seeds in fresh water 2 or 3 times to remove the salts on the seeds. Dry the seeds in shade and use for sowing.

B. Chemical methods

Using fungicides on seed is one of the most efficient and economical methods of chemical disease control. On the basis of their tenacity and action, the seed dressing chemicals may be grouped as (i) Seed disinfectant, which disinfect the seed but may not remain active for a long period after the seed has been sown and (ii) Seed protectants, which disinfect the seed surface and stick to the seed surface for sometime after the seed has been sown, thus giving temporary protection to the young seedlings against soil borne fungi. Now, the systemic fungicides are impregnated into the seeds to eliminate the deep seated infection in the seeds. The seed dressing chemicals may be applied by (i) Dry treatment (ii) Wet treatment and (iii) Slurry.

(i) Dry Seed Treatment

In this method, the fungicide adheres in a fine from on the surface of the seeds. A calculated quantity of fungicide is applied and mixed with seed using machinery specially designed for the purpose. The fungicides may be treated with the seeds of small lots using simple Rotary seed Dresser (Seed treating drum) or of large seed lots at seed processing plants using Grain treating machines. Normally in field level, dry seed treatment is carried out in dry rotary seed treating drums which ensure proper coating of the chemical on the surface of seeds. In addition, the dry dressing method is also used in pulses, cotton and oil seeds with the antagonistic fungus like *Trichoderma vitide* by mixing the formulation at the rate of 4g/kg of the seed.

Eg. Dry seed treatment in paddy.

Mix a required amount of fungicide with required quantity of seeds in a seed treating drum or polythene lined gunny bags, so as to provide uniform coating of the fungicide over the seeds. Treat the seeds atleast 24 hours prior to soaking for sprouting. Any one of the following chemical may be used for treatment at the rate of 2g/kg : Thiram or Captan or Carboxin or Tricyclazole.

(ii) Wet seed treatment

This method involves preparing fungicide suspension in water, often at field rates and then dipping the seeds or seedlings or propagative materials for a specified time. The seeds cannot be stored and the treatment has to be done before sowing. This treatment is usually applied for treating vegetatively propagative materials like cuttings, tubers, corms, setts rhizomes, bulbs etc., which are not amenable to dry or slurry treatment.

a. Seed dip / Seed soaking

For certain crops, seed soaking is essential. Seeds treated by these methods have to be properly dried after treatment. The fungicide adheres as a thin film over the seed surface which gives protection against invasion by soil-borne pathogens. Eg. Seed dip treatment in paddy.

Prepare the fungicidal solution by mixing any of the fungicides viz., carbendazim or pyroquilon or tricyclazole at the rate of 2g/litre of water and soak the seeds in the solution for 2 hrs. Drain the solution and keep the seeds for sprouting. Eg. Seed dip treatment in Wheat.

Prepare 0.2% of carboxin (2g/litre of water) and soak the seeds for 6 hours. Drain the solution and dry the seeds properly before sowing. This effectively eliminates the loose smut pathogen, *Ustilago nuda tritici.*

b. Seedling dip / root dip

The seedlings of vegetables and fruits are normally dipped in 0.25% copper oxychloride or 0.1% carbendazin solution for 5 minutes to protect against seedling blight and rots.

c. Rhizome dip

The rhizomes of cardamom, ginger and turmeric are treated with 0.1% emisan solution for 20 minutes to eliminate rot causing pathogen present in the soil.

d. Sett dip / Sucker dip

The sets of sugarcane and tapioca are dipped in 0.1% emisan solution for 30 minutes. The suckers of pine apple may also be treated by this method to protect from soilborne diseases.

(iii) Slurry treatment (Seed pelleting)

In this method, chemical is applied in the form of a thin paste (active material is dissolved in small quantity of water). The required quantity of the fungicide slurry is mixed with the specified quantity of the seed so that during the process of treatment slurry gets deposited on the surface of seeds in the form of a thin paste which later dries up.

Almost all the seed processing units have slurry treaters. In these, slurry treaters, the requisite quantity of fungicides slurry is mixed with specified quantity of seed before the seed lot is bagged. The slurry treatment is more efficient than the rotary seed dressers. Eg. Seed pelleting in ragi.

Mix 2.5g of carbendazim in 40 ml of water and add 0.5g of gum to the fungicidal solution. Add 2 kg of seeds to this solution and mix thoroughly to ensure a uniform coating of the fungicide over the seed. Dry the seeds under the shade. Treat the seeds 24 hrs prior to sowing.

(iv) Special method of seed treatment

Eg. Acid - delinting in cotton

This is follows in cotton to kill the seed-borne fungi and bacteria. The seeds are treated with concentrated sulphuric acid @ 100 ml/kg of seed for 2-3 minutes. The seeds are then washed 2 or 3 times thoroughly with cold water and shade dried. After drying, they are again treated with captan or thiram @ 4g/kg before sowing.

II. Soil treatment

It is well known that soil harbours a large number of plant pathogens and the primary sources of many plant pathogens happens to be in soil where dead organic matter supports active or dormant stages of pathogens. In addition, seed treatment does not afford sufficient protection against seedling diseases and a treatment of soil around the seed is necessary to protect them.

Soil treatment is largely curativ in nature as it mainly aims at killing the pathogens in soil and making the soil „safe" for the growth of the plant.

Chemical treatments of the soil is comparatively simple, especially when the soil is fallow as the chemical is volatile and disappears quickly either by volatilization or decomposition. Soil treating chemicals should be non-injurious to the plants in the soil adjacent to the area where treatment has been carried out because there may be standing crop in adjacent fields. The soil treatment methods involving the use of chemicals are

(i) Soil drenching, (ii) broadcasting, (iii) furrow application, (iv) fumigation and

(v) chemigation.

(i) Soil drenching

This method is followed for followed for controlling damping off and root rot infections at the ground level. Requisite quantity of fungicide suspension is applied per unit area so that the fungicide reaches to a depth of atleast 10-15 cm.

Eg. Emisan, PCNB, Carbendazim, Copper fungicides, etc.

(ii) Broadcasting

It is followed in granular fungicides wherein the pellets are broadcasted near the plant.

(iii) Furrow application

It is done specifically in the control of some diseases where the direct application of the fungicides on the plant surface results in phytotoxic. It is specifically practiced in the control of powdery mildew of tobacco where the sulphur dust is applied in the furrows.

(iv)Fumigation

Volatile toxicants (fumigants) such as methyl bromide, chloropicrin, formaldehyde and vapam are the best chemical sterilants for soil to kill fungi and nematodes as they penetrate the soil efficiently. Fumigations are normally done in nursery areas and in glass houses. The fumigant is applied to the soil and covered by thin polythene sheets for 5-7 days and removed. For example, Formaldehyde is applied at 400 ml/100 Sq.m. The treated soil was irrigated and used 1 or 2 weeks later. Vapam is normally sprinkled on the soil surface and covered. Volatile liquid fumigants are also injected to a depth of 15-20 cm, using sub-soil injectors.

(v) Chemigation

In this method, the fungicides are directly mixed in the irrigation water. It is normally adopted using sprinkler or drip irrigation system.

III. Foliar application

A. Spraying

This is the most commonly followed method. Spraying of fungicides is done on leaves, stems and fruits. Wettable powders are most commonly used for preparing spray solutions. The most common diluent or carrier is water. The dispersion of the spray is usually achieved by its passage under pressure through nozzle of the sprayer.

The amount of spray solution required for a hectare will depend on the nature of crops to be treated. For trees and shrubs more amount of spray solution is required than in the case of ground crops. Depending on the volume of fluid used for coverage, the sprays are categorised into high volume, medium volume, low volume, very high volume and ultra low volume.

The different equipments used for spray application are: Foot-operated sprayer, rocking sprayer, knapsack sprayer, motorised knapsack sprayer (Power sprayer), tractor mounted sprayer, mist blower and aircraft or helicopter (aerial spray).

B. Dusting

Dusts are applied to all aerial parts of a plant as an alternative to spraying. Dry powders are used for covering host surface. Generally, dusting is practicable in calm weather and a better protective action is obtained if the dust is applied when the plant surface is wet with dew or rain drops. The equipments employed for the dusting operation are: Bellow duster, rotary duster, motorised knapsack duster and aircraft (aerial application).

IV. Post – harvest application

Fruits and vegetables are largely damaged after harvest by fungi and bacteria. Many chemicals have been used as spray or dip or fumigation. Post harvest fungicides are most frequently applied as aqueous suspensions or solutions. Dip application has the advantage of totally submerging the commodity so that maximum opportunity for penetration to the infection sites.

Systemic fungicides, particularly thiabendazole, benomyl, carbendazim, metalaxyl, fosety-AI have been found to be very effective against storage diseases. In addition, dithiocarbamates and antibiotics are also applied to control the post-harvest diseases. Wrapping the harvested products with fungicide impregnated wax paper is the latest method available.

VI. Special method of applications

1. Trunk Application / Trunk Injection

It is normally adopted in coconut gardens to control Thanjavur wilt caused by *Ganoderma lucidum*. In the infected plant, a downward hole is made to a depth of 3-4" at an angle of 450C at the height of 3" from the ground level with the help of an auger. The solution containing 2g of Aureofungin soil and 1 g of copper sulphate in 100 ml of water is taken in a saline bottle and the bottle is tied with the tree. The hose is inserted into the hole and the stopper is adjusted to allow the solution in drops. After the treatment, the hole is covered with clay.

2. Root Feeding

Root feeding is also adopted for the control of Thanjavur wilt of coconut instead of trunk application. The root region is exposed; actively growing young root is selected and given a slanting cut at the tip. The root is inserted into a polythene bag containing 100 ml of the fungicidal solution. The mouth of the bag is tied tightly with the root.

3. Pseudostem Injection

This method is very effective in controlling the aphid vector *(Pentalonia nigronervosa)* of bunchy top of bannana. The banana injector is used for injecting the insecticide.Banana injector is nothing but an Aspee baby sprayer of 500 ml capacity. In which, the nozzle is replaced by leurlock system and aspirator needle No. 16. The tip of the needle is closed and two small holes are made in opposite direction.

It is for free flow of fluid and the lock system prevents the needle from dropping from the sprayer. One ml of monocrotophos mixed with water at 1:4 ratio is injected into the pseudostem of 3 months old crop and repeated twice at monthly intervals. The same injector can also be used to kill the bunchy top infected plants by injecting 2 ml of 2, 4-D (Femoxone) mixed in water at 1:8 ratio.

4. Corn Injection

It is an effective method used to control Panama will of banana caused by *Fusarium oxysporum* f. sp. *cubense.* Capsule applicator is used for this purpose. It is nothing but an iron rod of 7 mm thickness to which a handle is attached at one end. The length of the rod is 45 cm and an iron plate is fixed at a distance of 7 cm from the tip.

The corm is exposed by removing the soil and a hole is made at 45) angle to a depth of 5 cm. One or two gelatin capsules containing 50-60 mg of carbendazim is pushed in slowly and covered with soil. Instead of capsule, 3 ml of 2% carbendazim solution can also be injected into the hole.

5. Paring and Pralinage

It is used to control *Fusarium* wilt and burrowing nematode (*Radopholus similis)* of banana. The roots as well as a small portion of corm is removed or chopped off with a sharp knife and the sucker is dipped in 0.1% carbendazim solution for 5 minutes.

Then, the sucker is dipped in clay slurry and furadan granules are sprinkled over the corm @ 40 g/corm.

FUNGICIDES MODE OF ACTION TABLE

FRAC GROUP	MODE OF ACTION	CHEMICAL FAMILY (GROUP)	ACTIVE INGREDIENTS
1	Mitosis and cell division	benzimidazoles	thiabendazole
1		thiophanates	thiophanate-methyl
2	Respiration		iprodione vinclozolin
3	Sterol synethesis	imidazoles	Imazilil
3		piperazines	Triforine
3		pyrimidines	Fenarimol
3		triazoles	bitertanol cyproconazole difenoconazole fenbuconazole flusilazole ipconazole metconazole myclobutanil propiconazole prothioconazole tebuconazole tetraconazole triadimefon triadimenol triticonazole
4	Nucleic acid synethesis	acylalanines	metalaxyl metalaxyl-M (=mefenoxam)
7	Respiration		boscalid carboxin flutolanil
9	Protein synthesis		cyprodinil
11	Respiration	methoxyacrylates	azoxystrobin picoxystrobin
11		methoxy-carbamates	pyraclostrobin
11		oximino acetates	kresoxim-methyl trifloxystrobin
11		oxazolidine-diones	famoxadone
11		dihydro-dioxazines	fluoxastrobin
11		imidazolinones	fenamidone
12	Signaling		fludioxonil
13	Signaling		quinoxyfen
14	Lipids and membranes		chloroneb dicloran quintozene (PCNB)
14		1,2,4-thiadiazoles	etridiazole
17	Sterol synthesis		fenhexamid

FUNGICIDES MODE OF ACTION TABLE

FRAC GROUP	MODE OF ACTION	CHEMICAL FAMILY (GROUP)	ACTIVE INGREDIENTS
19	Cell wall synthesis	peptidyl pyrimidine nucleoside	polyoxin
21	Respiration	cyanoimidazole	cyazofamid
22	Cell division		zoxamide
24	Protein synthesis		kasugamycin
25	Protein synthesis		streptomycin
27	Unkown		cymoxanil
28	Cell membrane permeability		propamocarb
29	Respiration	2,6-dinitro-anilines	fluazinam
30	Respiration	tri phenyl tin compounds	fentin hydroxide
33	Unkown	ethyl phosphonates	fosetyl-Al
33			phophorous acid and salts
40	Cell wall synthesis	cinnamic acid amides	dimethomorph
40		mandelic acid amides	mandipropamid
41	Protein synthesis		oxytetracycline
P	Host plant defense induction	benzo-thiadiazole BTH	acibenzolar-S-methyl
M	Multi-site contact activity	inorganic	copper
		inorganic	sulphur
		dithiocarbamates and relatives	ferbam mancozeb maeb metiram thiram ziram
		phthalimides	captan
		chloronitriles (phthalonitriles)	chlorothalonil
		guanidines	dodine
NC	Not classified	diverse	mineral oils, organic oils, potassium bicarbonate

Mode of action and formulations of fungicides

A fungicide's formulation has a big impact on a fungicide's activity. For example the more finely ground the sulfur particles, the more effective as a powdery mildew fungicide but also the more likely that phytotoxicity can occur! Unfortunately, pesticide formulations can be almost as confusing as pesticide classes, to know what pesticide formulation will work best for your specific purposes you should know the characteristics, advantages, and disadvantages of the different formulations and adjuvants.

What is a formulation: The pesticide formulation is a mixture of the active and inert ingredients in the pesticide. The active ingredients are the chemicals that affect the target pest. The inert ingredients are all other ingredients in the pesticide, and are also called inactive ingredients. Inert ingredients are used to dilute the active ingredient or make it safer, easier to handle, and more effective. Some formulations are ready to use, others must be further diluted by air (air-blast sprayer), water, or a petroleum-based solvent. A single active ingredient is often sold in multiple formulations - you must choose the formulation that works best for you.

How to choose the formulation: There are several questions that you must answer while choosing the formulation.

1. Do you have the equipment needed for this type of formulation?
2. Can the formulation be applied safely under the conditions of the application area?

3. Will the formulation reach the target and stay there long enough for control?

4. Is there a possibility the formulation will harm the surface on which it is applied? To answer these questions, you must know the characteristics of the formulations and the advantages and disadvantages of each type. The most common formulations found in grape disease control are:

<u>Liquid Formulations</u>

Emulsifiable Concentrates (EC or E) – contains a liquid active ingredient, one or more petroleum-based solvents, and an agent that allows the product to be mixed with water to form an emulsion. An emulsion is a mixture of two or more liquids that are not soluble in one another. Each gallon of EC usually contains 25 to 75% (2 to 8-lbs) active ingredient.
These are among the most versatile formulations and are adaptable to many application equipment types from small, portable sprayers to hydraulic sprayers, low- volume ground sprayers, and mist blowers.

Advantages:

- Relatively easy to transport, handle, and store.
- Little agitation required (will not settle or separate when equipment is running).
- Non-abrasive.
- Does not plug nozzles or screens.
- Little visible residues on treated surfaces.
- Highly concentrated, making it easy to over- or under-dose by mixing and calibration errors.
- May cause phytotoxicity.
- Easily absorbed through skin.
- Solvents may damage rubber or plastic hoses, gaskets, pump parts, and metal or painted surfaces.
- May cause pitting or discoloration of painted surfaces.
- Flammable – must be stored away from open flame or heat.
- May be corrosive.

Solutions (S) – pesticide active ingredients that readily dissolve when mixed with a solvent such as water or a petroleum-based solvent. These formulations form a solution that will not settle out or separate once mixed. Solutions usually contain the active ingredient, the solvent, and one or more inert ingredients. Solutions may be used in any Type of sprayer.

Advantages:

- Relatively easy to transport, handle, and store.
- Little agitation required (will not settle or separate when equipment is running).

Disadvantages:

- Easily absorbed through skin.

Concentrate solutions (C or LC) – solutions sold as concentrates that must be further diluted with a liquid solvent. The solvent may be water but more often is refined oil or petroleum-based.

Advantages:

- No agitation

needed. Disadvantages:

- Less formulations of this type.

Other advantages and disadvantages vary depending on the solvent used, the concentration of the active ingredient, and the type of application.

Flowables (F or L) – finely ground active ingredients (in this case, soluble solids) are mixed with liquid along with inert ingredients to form a suspension. A suspension is a substance that contains undissolved particles mixed throughout a liquid. Flowables are mixed with water for application and are similar to EC or WP formulations for case of handling and use.

Advantages:

- Seldom clogs nozzles.
- Easy to handle and apply.

Disadvantages:

- Requires moderate agitation to maintain solids in suspension.
- May leave a visible residue.

Dry Formulations

Dusts (D) – ready to use formulations containing a low percentage of active ingredient (0.5 to 10%), combined with a fine, dry inert carrier made from talc, chalk, clay, nut hulls, or volcanic ash. The size of the dust particle is variable. A few dust formulations are available as concentrates, containing a high percentage of active ingredient, which must be mixed with inert carriers before they are applied. Dusts easily drift onto non-target areas.

Advantages:

- Usually ready to use with no mixing involved.
- Effective where moisture from a spray may be harmful.
- Requires simple equipment.

- Easily drifts off target during application.
- May irritate eyes, nose, throat, and skin.
- Does not stick to surfaces as well as liquid formulations do.
- Difficult to achieve even distribution of particles on surfaces.

Granules (G) – similar to dust formulations except granules have larger and heavier particles. These coarse particles are composed of absorptive materials such as clay, corn cobs, or walnut shells. The active ingredient either coats the outside of the granules or is absorbed into them. The amount of active ingredient in this formulation is relatively low, typically ranging from 1 to 15%. Granular pesticides are most often applied to control weeds, nematodes, and soil insects.

Advantages:

- Ready to use with no mixing involved.
- Drift hazard is low because heavier particles quickly settle.
- Fewer hazards to the applicator (no spray, little dust).
- Requires simple application equipment such as seeders or fertilizer spreaders.
- May break down more slowly than WP's or EC's by slow release coating.

Disadvantages:

- Does not stick to foliage or other non-level surfaces.
- May need to incorporate into soil.
- May require moisture to start pesticide action.
- May be hazardous to nontarget species that mistake granule for grain or seed.

Pellets (P or PS) similar to granular formulations, the terms are often used interchangeably. However, in a pellet formulation all the particles are the same weight and shape. This uniformity allows pellets to be applied by precision applicators such as those used for precision planting of pelleted seed.

Wettable Powders (WP or W) – dry, finely ground formulations that look like

dusts. Wettable powders are usually mixed with water for application as a spray. A few products are available that may be applied as dusts or as a spray. Wettable powders contain 5 to 95% active ingredient (usually 50% or more). The powder particles do not dissolve in water, and settle out quickly unless constantly agitated. This is one of the most widely used pesticide formulations, useable for most pest problems and with most types of spray equipment if agitation is available.

Advantages:

- Easy to transport, store, and handle.
- Less likely to cause phytotoxicity than EC's and other petroleum-based pesticides.
- Easily measured and mixed.
- Less skin and eye absorption than EC's and other liquid formulations.

Disadvantages:

- Inhalation hazard when handling the concentrated powder.
- Requires good and constant agitation (usually mechanical agitation in the spray tank).
- Abrasive on many pumps and nozzles.
- Difficult to mix in hard or alkaline water.
- Often clogs nozzles and screens.
- Residues may be visible.

Soluble Powders (SP or WSP) – looks like wettable powders; however, when mixed with water dissolves readily and forms a true solution. After soluble powders are mixed thoroughly no additional agitation is necessary. The amount of active ingredient in soluble powders ranges from 15 to 95% (usually 50% or more). Soluble powders have all the advantages of wettable powders and none of the disadvantages except an inhalation

hazard while mixing. Few pesticides are available in this formulation because few active ingredients are water soluble.

Water-Dispersible Granules or Dry Flowables (WDG or DF) – like wettable powders except the active ingredient is prepared as granule-sized particles. Water-dispersible granules must be mixed with water to be applied. In the water, the granules break into fine particles. This formulation requires constant agitation to keep the solids in suspension. Water-dispersible granules have the same advantages and disadvantages of wettable powders except that WDGs are more easily mixed and measured and have less

inhalation hazard to the

Form ulation A bbreviations

A	=	Aerosol
AF	=	Aqueous Flowable
AS	=	Aqueous Solution of Aqueous Suspension
B	=	Bait
C	=	Concentrate
CM	=	Concentrate Mixture
CG	=	Concentrate Granules
D	=	Dust
DF	=	Dry Flowable
DS	=	Soluble Dust
E	=	Em ulsifiable Concentrate
EC	=	Em ulsifiable Concentrate
F	=	Flowable
G	=	Granules
H/A	=	Harvest Aid
L	=	Flowable
LC	=	Liquid Concentrate or Low Concentrate
LV	=	Low Volatile

Adjuvants

An adjuvant is a chemical added to the pesticide formulation or tank mix to increase the safety or efficacy of a pesticide. Most pesticide formulations are composed of a small percentage of adjuvants. Common adjuvants are:

- Surfactants or surface active [redacted] [redacted] ingredients – alter the dispersal, spreading, and wetting properties of spray droplets.

- Wetting agents – allow wettable powders to be mixed with water.
- Emulsifiers – allow petroleum-based pesticides (EC’s) to mix with water.
- Invert emulsifiers – allow water-based pesticides to be mix with a petroleum carrier.
- Spreaders – allow pesticides to form a uniform layer on the treated surface.
- Penetrants – allow the pesticide to get through the outer surface to the interior of the treated area (e.g. a leaf).
- Stickers – allow pesticides to stay on the treated surface.
- Foaming agents – reduce drift.
- Thickeners – reduce drift by increasing droplet size.
- Safeners – reduce toxicity of a pesticide formulation to the handler or treated surface.
- Compatibility agents – aid in combining pesticides.
- Buffers – allow pesticides to be mixed with diluents or pesticides of different acidity or alkalinity.
- Anti-foaming agents – reduce foaming of spray mixtures that require vigorous agitation.

M	=	Microencapsulated
MTF	=	Multiple Tem perature Form ulation
P	=	Pellets
PS	=	Pellets
RTU	=	Ready To Use
S	=	Solution
SD	=	Soluble Dust
SG	=	Soluble Granule
SP	=	Soluble Powder
ULV	=	Ultra Low Volum e
ULW	=	Ultra Low W eight or Ultra Low W ettable
W S	=	W ater Soluble
W SG	=	W ater-Soluble Granules
W SL	=	W ater-Soluble Liquid
W	=	W ettable Powder
W SP	=	Soluble Powder