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B.Sc. BOTANY

FIRST YEAR

PAPER – II : FUNGI, BACTERIA, VIRUSES, LICHENS AND PLANT PATHOLOGY

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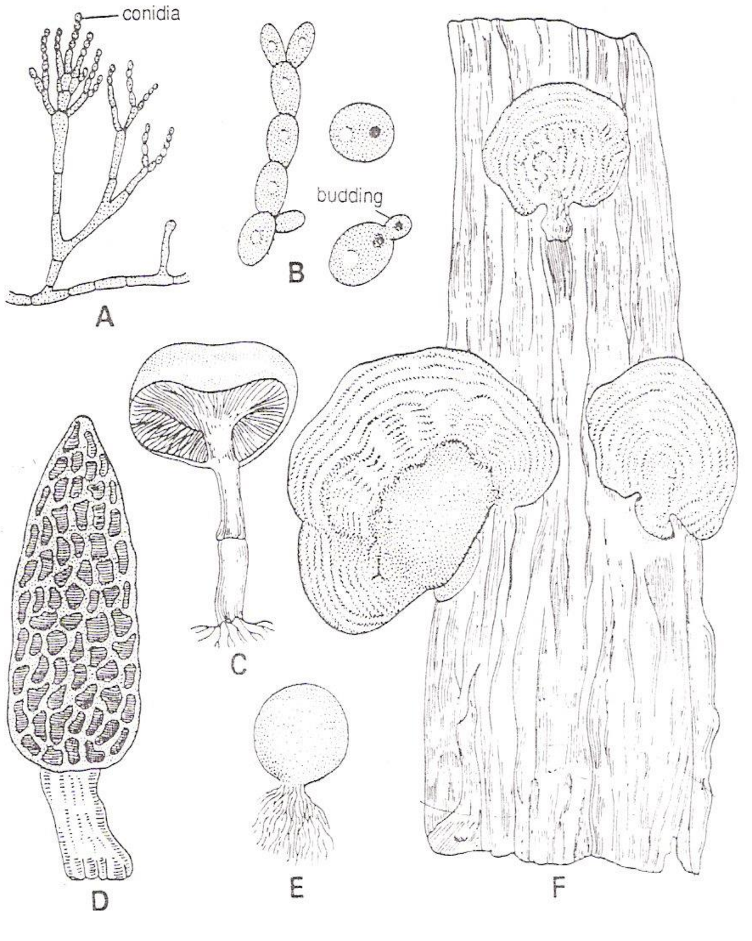
UNIT - I

GENERAL CHARACTERS OF FUNGI

The fungi constitute a large and diverse group of plank kingdom. They resemble algae in many respects and therefore, included in the large group Thallophyta. There are about 50,000 to 100,000 known species of fungi in the world. According to one estimate, there are 4,300 genera and 50,000 species of fungi (Ainsworth, 1961), but this number is constantly increasing because of the never ending search for these organisms, throughout the world. In the five kingdom system of classification, the fungi are treated as a separate kingdom.



Fungi and their bodies. A, ***Penicillium;*** B, yeast, C, ***Agaricus*** (mushroom); D, ***Morchella*** (morel); E, ***Lycoperdon*** (puff ball); F, fruiting bodies of bracket fungi on a tree trunk.

They lack chlorophyll and other photosynthetic pigments and cannot synthesize their food from carbon dioxide and water in the presence of sunlight and their mode of nutrition is either saprophytic, parasitic or symbiotic. When fungi live as saprobes they bring about the decay of organic materials, and when they act as parasites they attack living protoplasm and cause diseases of plants, animals and human beings.

The body of fungi is very simple, and in majority of cases consists of a network of branches filaments called the **hyphae.** The tangled mass of hyphae is the **mycelium.** In few cases the mycelium is completely lacking, *e.g., **Synchytrium*** and in the other cases the plant body may be unicellular, ***e.g., Saccharomyces.***

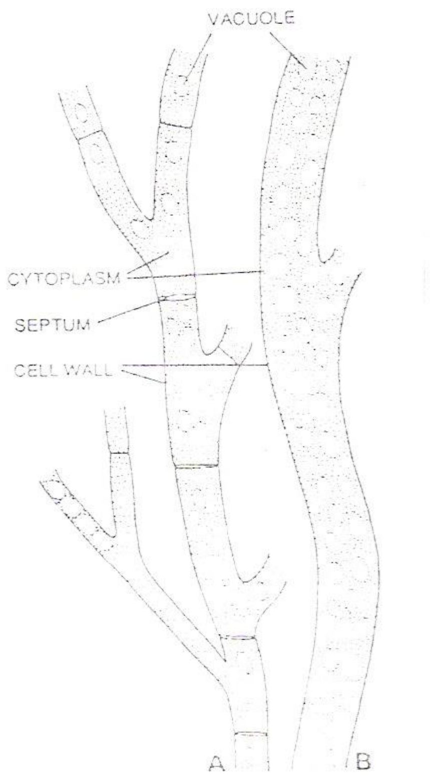
The cell wall of the mycelium does not consist of true cellulose. It either consists of chitin or fungal cellulose along with other substances.

The chief food reserves are glycogen and oils. As they are devoid of chlorophyll the starch is not found.

Occurrence and distribution

The fungi are most diversified in their habitat. They are found in almost all possible types of habitats. They are devoid of chlorophyll and may be saprophytes, parasites or symbionts. Many species of Phycomycetes, are found in the water and are called the **aquatic fungi.** Some fungi are commonly found upon algae and other aquatic plants in epiphytic state. Some species are found on the dead organic materials present in the water. Some species are sub-terranean and found under the surface of the earth.

Many species of the fungi are recognizable only with the naked eye and even from the distance such as mushrooms, morels, puff balls, bracket fungi, cup fungi etc. Whereas on the other hand they are microscopic and may be recognized with great care by the experts of the subject with the help of compound microscope.



The fungi : vegetative hyphae. A, portion of a septate hypha; B, portion of non-sepate hypha.

The parasitic fungi are commonly found upon the hosts, i.e., vascular plants where they cause various diseases and do great harm to the host plants.

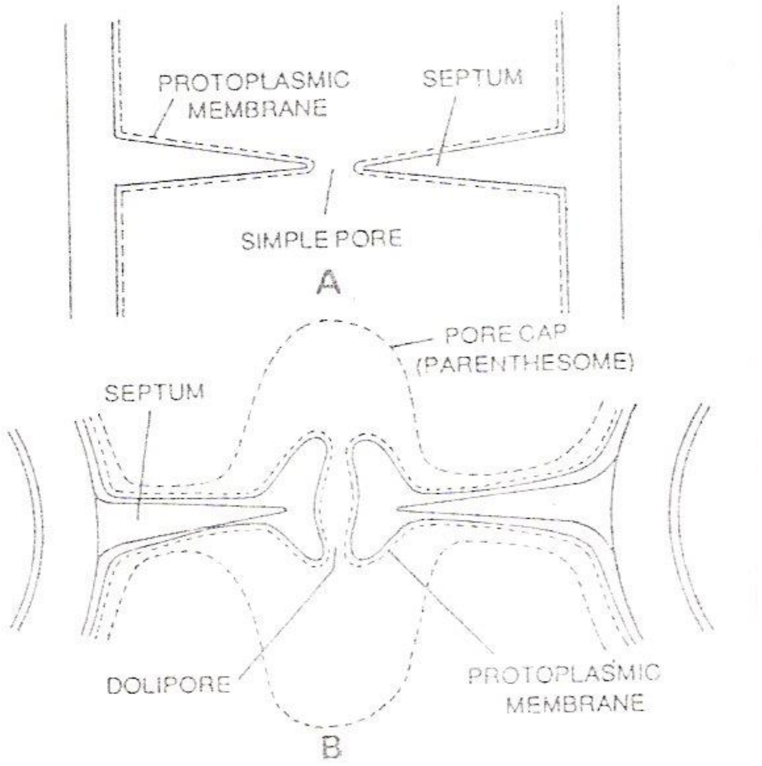
Some fungi are found in the alimentary canals of mammals and human beings where they cause the stomach disorders. Some froms cause the skin diseases. In this way we see that fungi are much diversified and accustomed to unusual habitats.

Vegetative Structure

Ainsworth (1971) has divided the fungi kingdom into two large divisions – 1. Myxomycota and 2. Eumycota. The Myxomycota includes the class Myxomycetes. In Myxomycetes (the slime molds) the thallus is a naked amoeboid mass of protoplasm. this may be a **plasmodium** (i.e., single large multinucleate protoplast) or a **pseudoplasmodium** (i.e., an aggregation of many small unincleate protoplast that retain their individuality).

In the division Eumycota (i.e., true fungi), the thallus has a definite cell wall. In certain fungi the thallus is unicellular (e.g., ***Saccharomyces, Blastocladiella)*** and the entire surface of the cell is responsible for the absorption of food. The plant body which consists of a single cell, and doesn't bear any additional structures for sucking the food from the substrate or for reproduction, is called **holocarpic.** When a part of the thallus is meant for reproduction, it is **eucarpic.** This eucarpic multicellular vegetative body of the fungus consists of a network of much branched thin filaments called the **hyphae** and the tangled mass of the hyphae is called **mycelium.** The hypae grow by apical elongation. the hyphae may be segmented or non-segmented. The segmented hyphae possess cross walls in them at regular intervals called the **septa.** The mycelium having septa is called the **septate.** Usually each septum bears a small pore in its centre for the communication of the cytoplasm from one cell to another. The mycelium without septa is called the **aseptate.** The aseptate mycelium possesses many nuclei embedded in the cytoplasm and called the **coenocytic** mycelium. The cells of the septate mycelium may be uninucleate, binucleate, or multinucleate.

The septa in the higher fungi (i.e., Ascomycotina, Basidiomycotina and Deuteromycotina) possess one or more small perforations in the centre to maintain protoplasmic continuity between adjacent cells. This pore is a simple pore is most of higher fungi (All Ascomycotina) but in some (many Basidiomycotina excluding rusts) it is a complex structure called **dolipore.** The electron microscope reveals a curved double membrance on each side of the septum. Because this membrance structure looks like a parenthesis in sectional view, it is known as **parenthosome.**



septa pores in fungi.A, simple pore; B, dolipore in many Basidiomycetes (a after Talbot 1971; B after Burnett, 1968).

Some fungi lack mycelium altogether, e.g., ***Synchytrium.***

The cell wall of fungi consists of a chemically different substance from normal cellulose called the **fungal cellulose.** The constituents of the fungal cellulose appear to be carbohydrates, cellulose, pectose, callose and related compounds mixed with other substances. In higher fungi the walls consist of chitin, the deposits of calcium carbonate and some other salts have also been reported from the cell wall of some fungi. The composition of the cell wall is not a constant feature and changes according to the age of mycelium, temperature, composition and the pH of the media.

The cells of a mycelium, as a whole are filled up with colourless cytoplasm. In coenocytic mycelium numerous nuclei are embedded. Many irregular vacuoles are also found. The glycogen fungi on living plants secrete certain enzymes which dissolve the host cell walls.

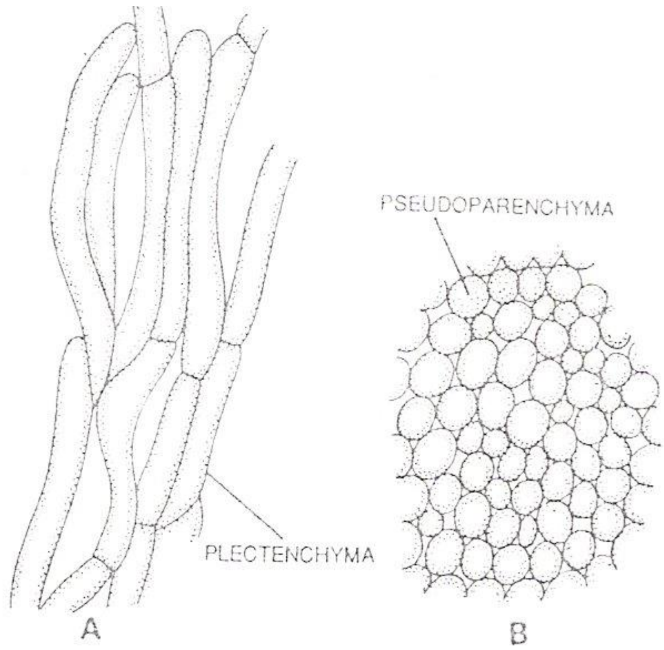
Most of the fungi possess hyaline mycelium but some of them possess various coloured pigments. These may be yellow, green, smoky green, orange, brown and red. Certain fungi are named after the colour of their spores, e.g., black molds, green molds and blue green molds. These pigments are nothing to do with the metabolic activity of the fungi.

The mycelium of the lower fungi is aseptate and coenocytic whereas of higher fungi it is always septate and the cells may be uni, bi or multinucleate. In lower fungi the septation takes place only at the time of the formation of sex organs.

There are certain modifications of the mycelium, which are as follows :

1. Plectenchyma

Sometimes the normal hyphae are so compactly interwoven that the whole mass becomes felt like and called the **Plectenchyma.** If the hyphae of the mass retain their individuality and do not fuse, the mass is called the **Prosenchyma or proso-plectenchyma.** And, if the hyphae are completely fused to each other and lost their individually and the whole mass looks like the parenchyma of the **higher plants, it is then called the** Pseudoparenchyma or paraplectenchyma.



Fungai tissues. A, plectenchyma; B, pseudoparenchyma.

2. Sclerotia

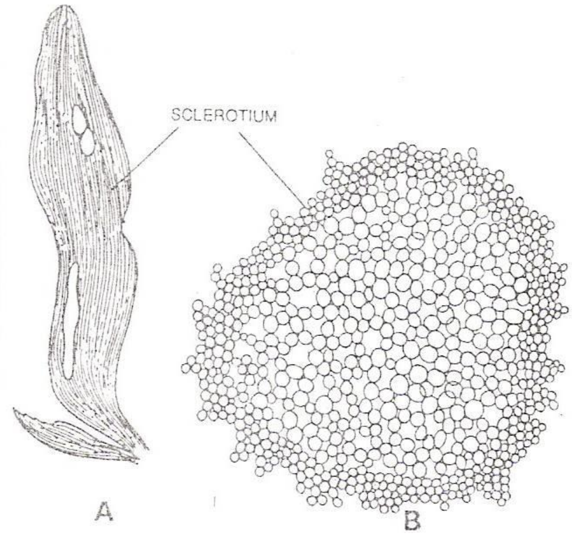
This is amother important modified form of the mycelium may also be called a specialized form of plectenchyma. Here the interwover hyphae of the mycelium become so much compact that the mass becomes rounded and cushion-like. These cushion – like compact masses are termed **sclerotia.** These bodies vary in size. They may be as small as a pin head and as a litre's flask. The outer face of the sclerotium becomes dark brown to black and crust –like. The inner cells are coloured and isodiametric, *e.g.,* ***Sclerotinia scleriotiorum.***

3. Rhizomorph

Sometimes in some of the fungi the hyphae fuse to each other forming rope-like structures running parallel to each other. These thick, gelatinous, dark brown and rope-like coiled structures are called the **rhizomorphs.** They resemble the finer roots of the trees. These structures are perennating and face the adverse condition. They may survive even for several years. On the approach of favourable conditions these structures may give rise to new mycelia.

4. Sporophores

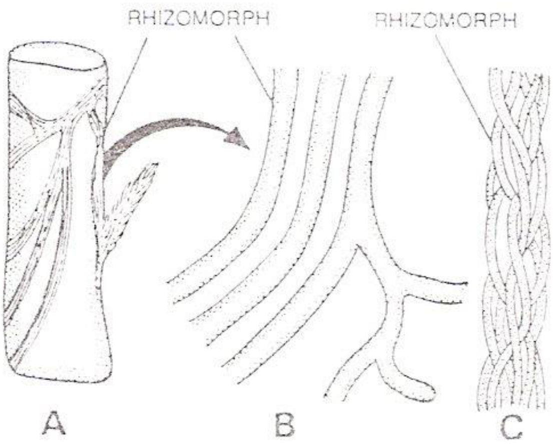
The sporophores bear spores on them. These are the modified forms of the mycelium. Usually the sporophores are erect and aerial. They arise from the prostrate hyphae. The sporophores may be branched (***e.g., Peronospora)*** or unbranched ***(e.g., Albugo)***. The bear sporangia ***(e.g., Albuga)*** or conida ***(e.g., Pernospora)*** on them. the sporophore bearing sporangia is called the **sporangiophore** and bearing conidia the **conidiophore.** Sometimes the sporophores are found in group and from **pycnia, sporodochia, hymenia and acervuli** in various fungi.



Sclerotium. A, complete sclerotium; B, cross section of sclerotium**.**

5. Stroma

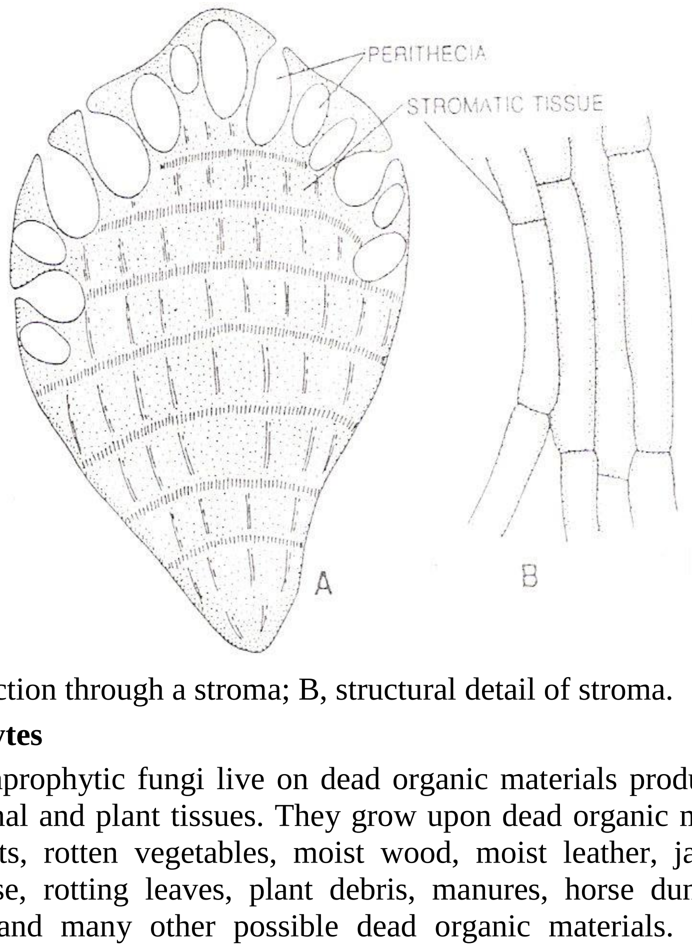
They are flat, cushion-like pesudoparenchymatous structures from which usually the sporophores arise.



Rhizomorph. A, as seen on root; B, parallel hyphae of rhizomorph; C, rope like structure.

Nutrition

The fungi are chlorophyll-less plants and cannot synthesize their own food unlike green plants from carbon dioxide and water in the presence of sunlight. They are so simple in structure that they cannot obtain inorganic food directly from the soil, and therefore they are always dependent for their food on some dead organic material or living beings. The fungi which obtain their food from dead organic materials are called the **saprophytes,** whereas the fungi obtaining their prepared food from living plants or animals are called the **parasites.** The living beings on which the fungi parasitize are called the **hosts.** Some grow in the association of other plants and are mutually beneficial. This association is called the **symbiosis** and the participants are **symbionts.** From the point of view of their nutrition the fungi may be classified as saprophytes, parasites, symbionts and predacious fungi. They are **heterotrophic** and never autotrophic.

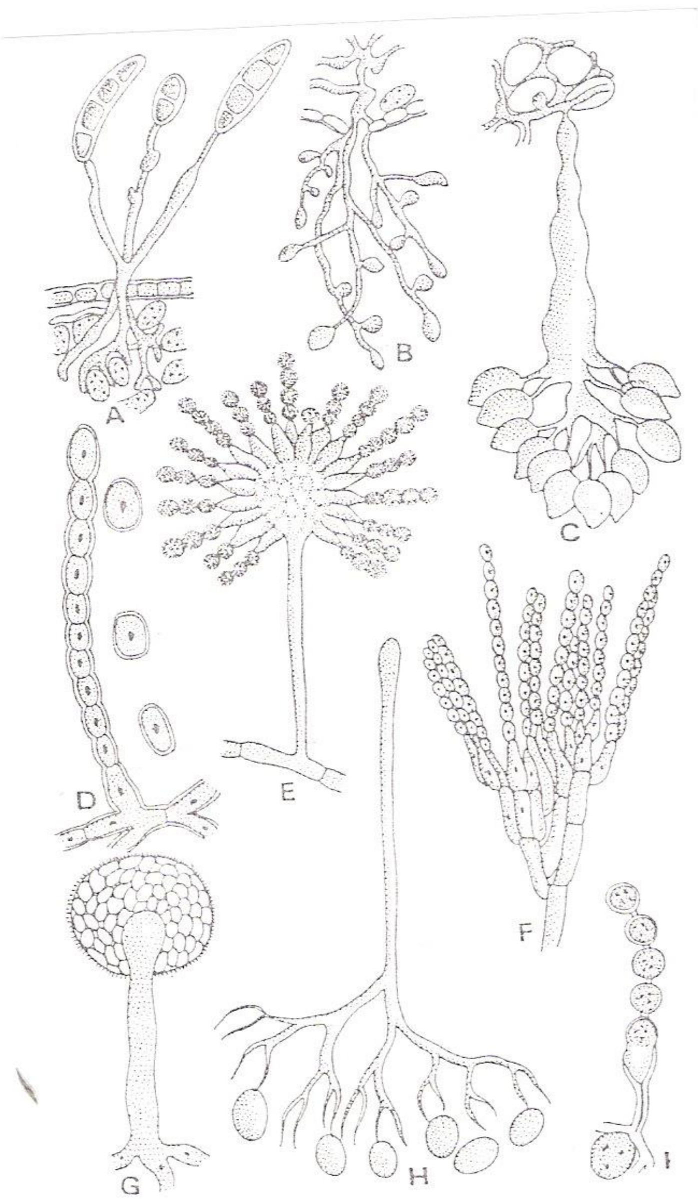


Stroma. A, section through a stroma; B, structural detail of stroma.

(a) Saprophytes

The saprophytic fungi live on dead organic materials produced by the decay of animal and plant tissues. They grow upon dead organic matters such as rotten fruits, rotten vegetables, moist wood, moist leather, jams, jellies, pickles, cheese, rotting leaves, plant debris, manures, horse dung, vinegar, moist bread and many other possible dead organic materials. ***Sprolegnia, Mucor, Rhizopus, Penicillium, Morchella, Aspergillus, Agaricus*** and many others are good examples of saprophytic fungi.

The saprophytic fungi absorb their food from the substratum by ordinary vegetative hyphae which penetrate the substratum, ***e.g., Mucor mucedo***. In other cases of the saprophytic fungi such as ***Rhizopus*** and ***Blastocladiella*** the rhizoids develop which penetrate the substratum and absorb the food material. In the case of saprophytic fungi the mycelium may be ectophytic or endophytic. In the case of ***Rhizopus*** the mycelium is ectophytic whereas the rhizoids remain embedded in the substratum and said to be endophytic.



The fungi. Various types of sporophores. A, conidiophores and conidia of *Helminthosporium;* B, sporangiophore and sporangia of *Phytophthora;* C, sporophore and sporangia of *sclerospora;* D, conidiophore and conidia of *Erysiphe;* E, conidiophore and conidia of *Aspergillus;* F, conidiophore and conidia of *Penicillum;* G, sporangiophore and sporangium of *Mucor;* H, condiophore and conidia of *Peronospora;* I, sporangiophore and sporangia of *Albugo.*

(b) Parasites

The parasitic fungi absorb their food material from the living tissues of the hosts on which they parasitize. Such parasitic fungi are quite harmful to their hosts and cause many serious diseases. These fungi cause the great losses to the human beings directly or indirectly. Many diseases of the important crops are caused by parasitic fungi. the rusts, smuts, bunts, mildews and many other plant diseases are important examples of fungi diseases of crops. Their mode of life is parasitic and the relation of host and parasitic is called the **parasitism.**

The parasitic which survive on living hosts and only on living hosts are called the **obligate parasites.** Such parasites cannot be grown upon dead organic culture media, ***e.g., Puccinia, Peronospora, Melampsora*** etc. The parasitic fungi which usually live on living hosts and according to their need they adopt saprophytic mode of life for some time are called the **facultative saprophytes**, ***e.g., Taphrina deformans*** and some smuts. Some paraitic fungi usually pass saprophytic mode of life, but under certain conditions they parasitize some suitable host and are called the **facultative parasites,** *e.g.,* ***Fusarium, Pythium*** etc.

The parasitic fungi absorb their food from the hosts in different ways. The fungus having the mycelium outside the host is called the **ectoparasite,** ***e.g., Erysiphe,*** whereas the fungus having the mycelium embedded in the host tissue is called the **endoparasite.** In the former type certain cushion-like **apporessoria** develop on the surface of the host and from each appressorium a peg-like structure develops which penetrates the host epidermal cell giving rise to a branched or unbranched absorbing organ called the **haustorium.** The haustoria may also develop from the mycelium of endoparasites. The haustoria vary in their shapes. They may be small, rounded, button-like as in ***Albugo,*** branched and convolute as in ***Peronospora*** and hhghly branched as in ***erysiphe.***

Reproduction

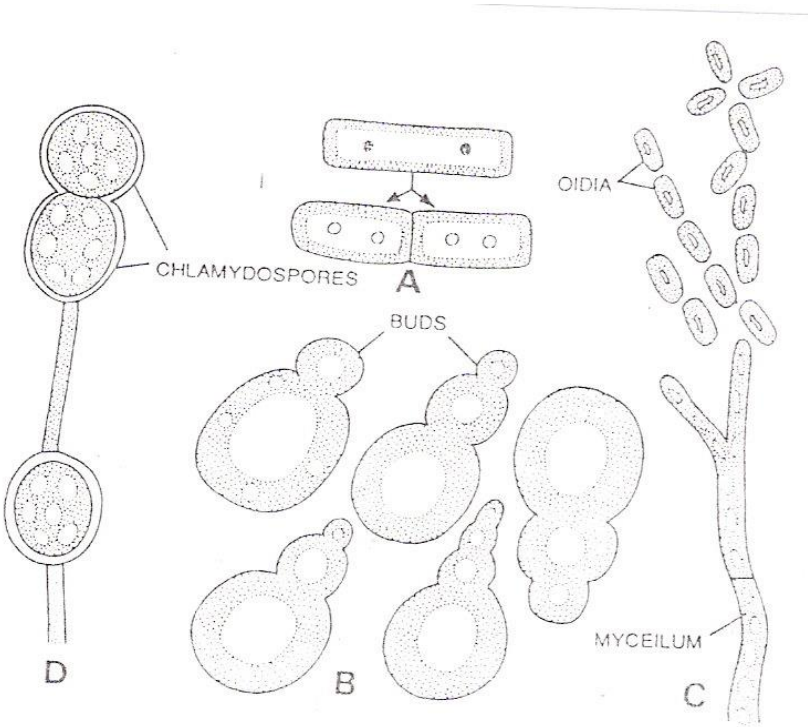
The fungi reproduce by means of vegetative, asexual and sexual methods.

1. Vegetative reproduction

The most common method of vegetative reproduction is **fragmentation.** The hypha breaks up into small fragments accidentally or otherwise. Each fragment develops into a new individual. In the laboratory the 'hyphal tip method' is commonly used for inoculation of saprophytic fungus.

In addition to above-mentioned common method of vegetative reproduction the fungi reproduce vegetative by other means, such as **fission, budding, sclerotia, rhizomorphs** etc.

In fission, the cell constricts in the centre and divides into two giving rise to new individuals.



Asexual reproduction. A, transverse cell division (fission); B, budding in yeast cell; C, hypha fragmenting into olidia or arthrospores in *Collybia conigena;* D, chalamydospore formation in *Fusarium.*

The budding is commonly found in ***Saccharomyces.*** The buds arise from the protoplasm of the parent cells and ultimately become new individuals.

The sclerotia are resistant and perennating bodies. They survive for many years. Each sclerotium is cushion-like structure of compact mycelium. They give rise to new mycelia on the approach of favourable conditions.

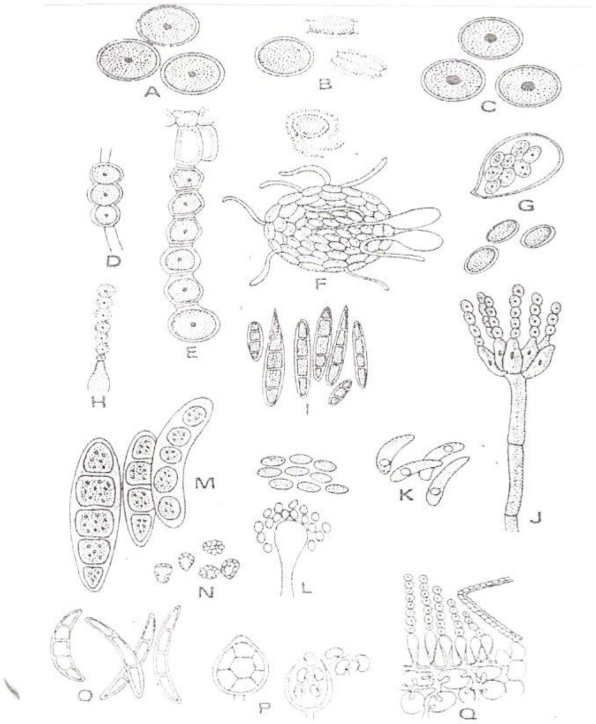
As mentioned under the modified mycelium, the rope-like rhizomporphs are also resistant to unfavourable conditions and give rise to new mycelia even after several years on the approach of favourable conditions.

2. Asexsual reproduction

The asexual reproduction takes place by means of spores. Each spore may develop into a new individual. The spores may be produced asexually or sexually an thus named (a) asexual spores and (b) sexual spores. Under asexual reproduction, only asexual spores will be considered.

Asexual spores

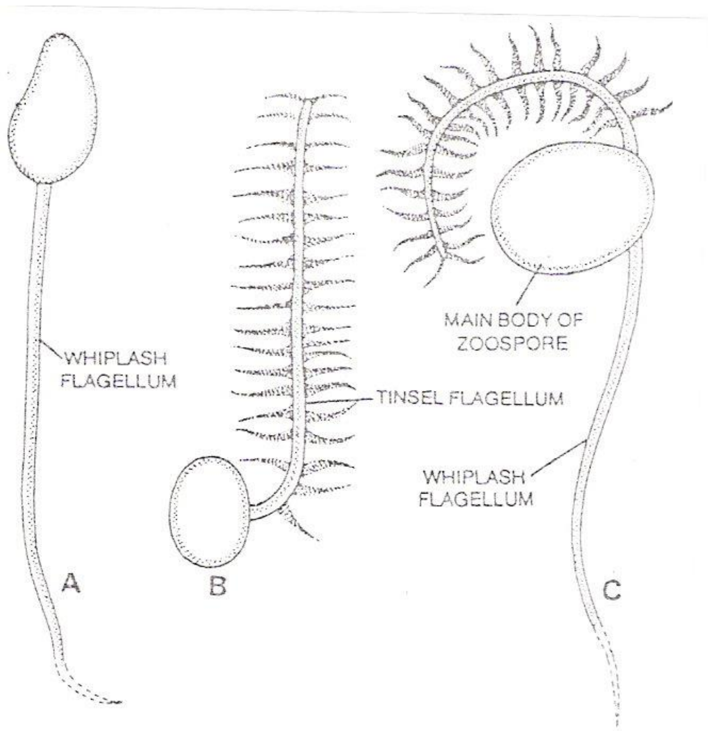
They are innumerable and produced on the haplont mycelium in Phycomycetes and Ascomycetes. In Basidiomycetes they are produced on the diplont mycelium. The spores are of diverse type and borne upon special strcuture called the **sporophores.** These spores are produced asexually and called the asexual spores. Usually the spores are uninucleate and nonmotile but multinucleate and motile spores are also found. The fungus producing more than one type of spores is called the **plemorophic or polymorphic.** the spores produced inside the sporangia are termed the **endogenous spores** and the spores developing exogenously on the terminal ends of sporophores are called the **exogenous spores.**



The fungi. Various types of spores. A,chlamydospores of *Ustilago hordei;* B, ascocpores of *Aspergillus;* C, chlamydospores of *Ustilago tritici;* D, chlamydospores of *Fusarium;* E, ascospores of *Erysiphe;* F, cleisothecium of *Erysiphe;* G, ascus and ascospores of *Erysiphe;* H, conidia of *Aspergillus;* I, conidia of *Cercospora;* J, conidiophore and conidia of *Penicillium;* K, conidia of *Colletotrichum* sp; L, aplanospores of *Mucor;* m, conidia of *Helminthosporium;* N, aplanospores of *Rhizopus;* O, conidia of *Fusarium* sp; P, sporangium and zoospores of *Phytophthora*sp; Q, sporangiospores and sporangia of *Albugo.*

Endogenous spores

The endogenous spores are product within the special spore producing cell the **sporangium.** The sporangia may be terminal or intercalary in their positions. The sporophores which bear the sporangia on their apices are called the **sporangiophores.** They may be branches or unbranched. The spores produced inside the sporangia are called the endospores or endogenous spores. They may be motile or non-motile. The motile spores are called the **zoospores** and the non-motile **aplanospores.** The zoospores are produced inside the zoosporangia. The protoplasm of the sporangium divides into uninucleate or multinucleate protoplasmic bits and each bit metamorphoses into a spore.



Zoospores. A, posteriorly uniflagellate with a whiplash flagellum; B, anteriorly uniflagella with a tinsel flagellum; C, biflagellate with an anterior tinsel posterior whiplash flagellum. (after Couch, 1941).

The endogenously produced zoospores are uni or biflagellate. Each spore is without any cell wall, uninucleate and vacuolate. They can move with the help of their flagella. They are usually kidney –shaped or reniform and the flagella are inserted posteriorly or laterally on them. Such zoospores have been recorded from ***Albugo, Pythium, Phytophthora*** and many other lower fungi.

The aplanospores are non-motile, without flagella and formed inside the sporangia. They may be uni or multinucleate ***(e.g., Mucor, Rhizopus).*** These spores lack vacuoles and possess two layered cell walls. The outer thick layer is **epispore or exospore** which may be ornamented in many cases. The inner thin layer is **endospore.**

Exogenous spores

The spores producing externally or exogenously are either called the exogenous spores or **conidia.** They are produced externally on the branched or unbranched **conidiophores.** The conidiophores may be septate or aseptate. The conida bome upon the terminal apices of the conidiophores or the ends of the branches of the conidiophores. the conidia may be produced singly on each sterigma or in chains. The conidial chains may be **basipetal or acorpetal** in succession. The conidia are diverse in their shape and size. They may be unicellular or multicellular, uninucleate or multinucleate. Different genera may be recognized only by the presence of various shaped and various coloured conidia. The conidia of Fungi Imperfecti shaped, whereas the conidia of ***Aspergillus*** and ***Penicillium*** are smoky green coloured and the fungi are called 'The blue-green molds'.

In other type of exospores, the sporophores develop in groups and form the specialized structure called the **pustules, pycnia, aecidia, acervuli,** and **sporodochia.** The pycnia are flask-shaped producing **pycniospores** in them. The acervuli are saucer-shaped widely open bodies having developed conidia in them on small conidiophores. In mushrooms the sporophores are compactly arranged and form an umbrella-like fructification. The terminal expanded portion bears **gills.** In each gill there are hundreds of sporophores called the basidia bearing basidiospores. the sporophores (basidia) are arranged in hymenia.

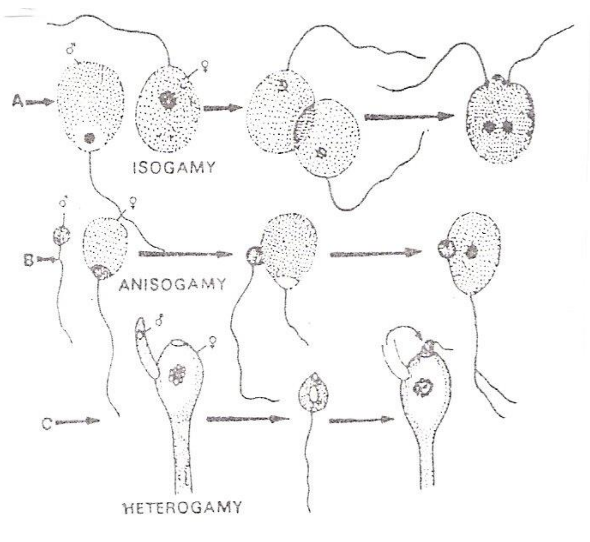
3. Sexual reproduction

A large number of fungi reproduce sexually. However, the members of 'Fungi Imperfecti', or 'Deuteromycetes' lack sexual reproduction.

Usually two phases are found in the life cycle of the plants. these phases are called haploid and diploid phases respectively. the haploid phase possesses the (x) number of chromosomes in the nucleus, whereas this number becomes (2x) in the diploid phase. the gametes are always haploid (x) and by a sexual fusion they result in diploid (2x) sexual spores, such as **zygospores, oospores** etc. To bring haploid (x) phase once again in the life cycle the reduction division (meiosis) takes place and the number of chromosomes becomes half.

The gametes taking part in sexual fusion may be morphologically or physiologically different. Such two gametes taking part in fusion are of opposite sexes or strains, which may be called male and female sex organs or plus and minus strains. When both the sex organs or stains ossur on the same mycelium, the fungus is said to be **monoecious or homothallic,** and when the male and female sex organs of plus and mines strains occur separately mycelia the fungus is said to be **dioecious or heterothallic.**

The gametes taking part in fusion are usually formed in the cells of sacs called **gametangia** (singular-gamentangium). The morphologically identical male and female gametes are called the **iaogametes.** The morphologically dissimilar male and female gametes called the **heterametes.**



Sexual reproduction in fungi. A, isogamy-as seen in *Synchytrium;* B, anisogamy-as seen in *Allomyces;* C, heterogamy-as seen in *Monoblepharis.*

In such cases the male gametes are called the **antherozoids** and the female ones are the **eggs.** The fusion of the plasma of the gametes is called the **plasmogamy,** which is usually followed by the nuclear fusion i.e., **karyogamy.** The whole process is called the **fertilization.**

Sometimes, in some of the fungi, e.g., Phycomycetes and Ascomycetes, the entire contents of the two gametangia fuse with each other, the process is called the **gametangial copulation.** In the members of Physomycetes and Ascomycetes the gametangia taking part in gametangial copulation are called the **autheriadia** (singular-autheridium) and the **oogonia** (singular-oogonium).

In the lower fungi, there is complete fusion of the nuclei of the two different strained gametes in the sexual union, i.e., karyogamy, whereas in the higher fungi, e.g., Ascomycetes and Basidiomycetes, the fusion of the two nuclei of different strains is delayed and the pairs of the nuclei called the **'dicaryons'** are formed. The mycelium having such pairs of nuclei is called the **'dicaryotic mycelium'.** In the opposite cases the **monocaryotic mycelium.**

The most common methods of sexual reproduction involves the fusion of two :

1. Planogametic copulation

This type of sexual reproduction involves the fusion of two naked gametes one or both of them are motile. The motile gametes are known as planogametes. The most primitive fungi produce isogamous planogametes***, e.g., Synchytrium, Plasmogametes***, etc. The anisogamous planogametes are only found in the genus ***allomyces*** of order Blastocladialesd. In ***Monoblepharis*** (order Monoblepharidales) the unique condition is present; here the female gamete is non-motile whereas the male gamete is motile. The male ganete enters the oogonium and fertilizes the egg.

2. Gametangial contact

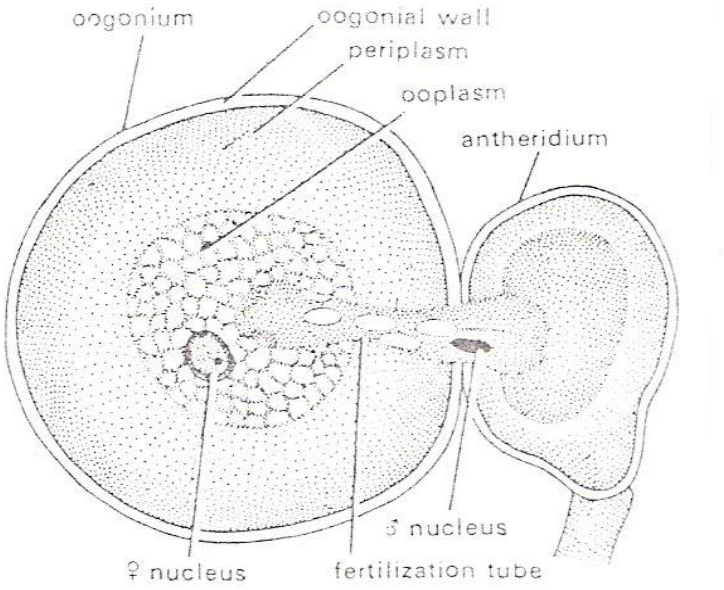
This method of reproduction is found in many lower fungi (class Phycomycetes). In this method two gametangia of opposite sex (oogonium and antheridium) come in contact and one or more gamete unclei migrate from the male gametangium (autheridium) to the female gametangium (oogonium). In no case the gametangia actually fuse. The male nuclei in some species enter the female gametangium through a pore developed by the dissolution of the wall of contact ***(e.g., in Aspergillus, Penicillum*** etc.); in other species the male nuclei migrate through a fertilization tube ***(e.g., Pythium, Albugo, Pernospora*** etc.). After the migration of the nuclei the autheridium eventually disintegrates but the oogonium continuous its development in various ways.

3. Gametangial copulation

In this method of sexual reproduction the fusion of the entire contents of two contacting compatible gametangia takes place ***(e.g., Mucor, Rhizopus, Entomophthro*** **etc).**

4. Spermatization

The sexual reproduction in ***Neurospora*** **(**Class-Ascomycetes) and other fungi takes place by means of this method. The minute, uninucleate, spore-like male structures are known as spermatia. They are produced in several ways. The spermatia are carried by outer agencies to the receptive hyphae (trichogynes) of female gametangia, to which they become attached. A pore develops at the wall of contact and the contents of spematium pass into the female gametangium through the recertive hypha.



Sexual reproduction. Gametangial contact by means of fertilization tube in *Pythium aphanidermatum.*

5. Somatogamy

The sex organs are not produced. The somatic cells take part in sexual fusion, ***e.g., morchella***, many higher fungi.

Reduction in sexuality

In the series Flagellatae of Phycomycetes (sub-division Mastigomycottina, Ainsworth, 1971) the sex organs are quite conspicuous and called the antheridia (male) and the oogonia (female). The resultants of fusion are oospores. In the series Aplanatae (sub-division Zygomycotina, Ainsworth 1971) the gamentangial copulation takes place. The gametangia are represented by + and-signs. The resultants of gametangial union are zygospores. In Ascomycetes (sub-division Ascomycotina, Ainsworth 1971), the sex organs are not so prominent and there is a regular phenomenon of reduction of sexuality. In Ascomycetes, the phenomenon of nuclear fusion is not sompletely understood as yet. In some of the Ascomycetes (sac fungi) ***(e.g., Morchella)*** no sex organs are produced and the somatic cells take part in sexual fusion. This process is called the **somatogamy.** In the Basidiomycetes (sub-division

Basidiomycotina, Ainsworth 1971) there is further reduction of sexuality. In this class of fungi there are no sex organs and only the fusion of the nuclei of a dicaryon represents the process of sexuality. In the members of Fungi Imperfecti or Deuteromycetes (sub-division Deuteromycotina, Ainsworth 1971) the sexual process is altogether absent and they reproduce asexually by conidia.

CLASSIFICATION OF FUNGI

C.J. ALEXOPOULOS (1962)

Division – MYCOTA

Sub – divisions

MYXOMYCOTINA **EUMYCOTINA**

Classes

1. Myxomycetes

1. **Chytridiomycetes**
2. **Hyphochytridiomycetes**
3. **Plasmodiophoromycetes**
4. **Oomycetes**
5. **Trichomycetes**
6. **Zygomycetes**

From –class- Deuteromycytes

7. **Ascomycetes**
8. **Basidiomycetes**

DIVISION – MYCOTA (The Fungi) : Devoid of chlorophyll; the plant body varies from a microscopic unicell to an extensive mycelium; true nuclei with nuclear membrances, uncleoli present; cell walls contain chitin or cellulose, or a mixture of both, and other complex polysaccharides; reproduction asexual and sexual; progative units- spores, two sub-divisions-

1. Myxomyxotina and 2. Eumycotina.

Sub – division – MYXOMYCOTINA; They definite cell walls are absent from their amoeba-like bodies; somatic structure. a free –living plasmodium, *i.e.,* a multinucleate mass of protoplasm without definite cell walls, the entire plasmodium whose nuclei are diploid (2n), is consumed in the formation of fructifications which bear haploid (n) spores resulting from meiosis; spores are provided with firm walls, flagellated cells are characteristically produced; single class- Myxomycetes.

Sub-division-RUMCOTINA : They are true fungi, the organisms, only with few exceptions provided with cell walls and are typically filaments (some unicellular); reproduction –sexual and asexual; there are eight classes and one form –class.

1. **Class-Chytridiomycetes :** They are posteriorly uniflagellate fungi, motile cells (zoospores or planogametes) produced, each with a single posterior, whiplash flagellum; various types of thalli; 3 orders – 1. Chytridiales, 2. Blastocladiales and 3. Monoblepharidales.
2. **Class- Hyphochytridiomycetes :** Aquatic fungi; motile cells possess a single anterior tinsel flagellum; parasitic on algae and fungi or saprobic on plant and insect debris in the water; single order-Hypochytriales.
3. **Class – Oomycetes :** Fungi with –developed coenocytic mycelium; they reproduce asexual by menas of flagellate zoospores, each bearing one tinsel flagellum directed forward and one whiplash flagellum directed backward. zoospores formed in sporangia of various types; perfect spores – oospores; 4 orders – 1. Saprolegniales, 2. Leptomitales, 3. Lagenidiales and 4. Peronosporales.
4. **Class – Plasmodiophoromycetes :** Obligate endoparasitic fungi of vascular plants, algae and fungi; non-cellular (without cell walls), multinucleate thalli living in the cells of their hosts, motile cells possess two unequal, anterior whiplash-type flagella; resting spores produced in masses, but not in distinct fruiting bodies, single order-Plasmodiophorales.
5. **Class – Trichomycetes :** Fungi possessing simple or branched filamentous coenocytic thallus, attached to the digestive track or the external cuticle of living arthropods; mycelium not immersed in host tissues; 5. orders.
6. **Class- Zygomycetes :** Saprobic or parasitic fungi, well developed coen cocytic or septate mycelium; sexual reproduction resulting in the formation of a resting spore formed by the fusion of two usually equal gamentangia; no motile cells formed; 3 orders – 1. Mucorales, 2. Entomophthorales and 3. zoopagales.
7. **Class – Ascomycetes :** Somatic body consists of a sepate mycelium, in some one-celled; never producing motile spores or gametes; sexually produced spores, ascospores formed inside sac-like structure, the ascus; 3. sub-classes-1. Hemiascomycetidae, 2. Euascomycetidae and 3. Loculoascomycetidae.
8. **Class – Basidiomycetes :** Sexually produced spores, basidiospores, formed exogenously on a specialized organ, the basidium, in which karyogamy and meiosis occur; 2. sub-classes-1. heterobasidiomycetidae 2. Homobasidiomycetidae.

Form – Class – Deuteromycetes : This form – class is also known as Fungi Imperfecti; sexual reproduction lasking; a parasexual cycle may be present; 4 orders – 1. Sphaeropsidales, 2. Melanconiales, 3. Moniliales and 4. Mycelia Sterilia.

Class – MYXOMYCETES

Sub-classes

Ceratiomyxomycetidae

(Spores borne externally on individual stalks)

Myxogastromycetidae

(Spores borne internally in fructifications)

Orders

1. Ceratiomyxales.

1. Liceales
2. Echinosteliales
3. Trichiales
4. **Stemonitales**
   (described in next)
5. Physarales.

Class – CHYTRIDIOMYCETES

Orders

1. Chytridiales (True mycelium lacking, rhizomycelium present in some species).

2. Blastocladiales (true mycelium present, sexual reproduction of fungi by planogametes, thickwalled resistant sporangia characteristically

3. Monoblepharidales (True mycelium present, sexual reproduction by fusion of a male planogamete, with a female aplanogamete, no resistant sporangia).

Class – HYPHOCHYTRIDIOMYCETES

Single order

Hypochytriales
(Aquatic fungi, motile cells anteriorly uniflagellate possessing a flagellum of the tinsel type)

Class – OOMYCETES

Orders

1. Saprolengniales 2. Leptomitales 3. Lagenidiales 4. Peronosporales

Order – **Saprolengniales :** Holocarpic or eucarpic thallus, zoospores always formed within the sporangium, diplanetic, monoplanetic or rerely aplanetic; oogonium not differentiated into ooplasm and periplasm; aquatic; saprophytic exxept few; 3. families – 1. Ectrogellaceae, 2. thraustochytriaceae and 3. **Saprolegniaceae.**

Order – **Peronosporales :** Eucarpic thallus, monoplanetic; oogonium differentiated into ooplasm and periplasm, terrestrial, parasitic on higher plants, 3 families – 1. **Pythiaceae, 2. Albugunaceae, 3. Peronosporaceae.**

Class – PLASMODIOPHOROMYCETES

Single order

Plasmodiophorales

Always parasitic assimilative phase a multinucleate thallus within host cells of plants (mostly vascular); sporulating in place and often causing hypertrophy, both flagella of zoospores of whiplash type, single family P**lasmodiophoreaceae.**

Class – ZYGOMYCETES

Orders

1. Mucorales

2. Entomophthorales (Two families :
1. Entomophthoraceae
2. Basidiobolaceae)

3. Zoopagales (Single family Zoopa-gaceae)

Order – **Mucorales :** Chiefly saprobic, some weakly parasitic on plants, afew endoparasitic in vertebrates; asexual reproduction by sporangia containing one to many aplanospores, sometimes by conidia; 9-11 families, **Mucoraceae and Pilobolaceae** described in the next.

Class – TRICHOMYCETES

Class – ASCOMYCETES

Sub-classes

1. Hemiascomycetidae (Asci naked; no ascocarps; no ascogenous hyphae).

2. Euascomycetidae (Asci usually unitunicate; borne in a cleistothecium, perithecium or apothecium).

3. Loculoascomycetidae (Asci bitunicate; ascocarp an ascostroma).

Orders :

1. **Endomycetales**
2. **Taphrinales**
3. Hysteriales

Series

Orders :

1. Myriangiales
2. Microthyriales
4. Pleosporales

Dothideales

1. Plectomycetes
   Orders –
   1. **Eurotiales**
   2. Microascles

2. Pyrenomycetes
   1. **Erysiphales**
   2. Meliolales
   3. Onygenales

3. Discomycetes
   1. Ostropales
   2. Helotiales
   3. Chaetomiales
   4. **Clavicipitales**
   5. **Sphaeriales**
   6. Diaporthales
   7. Hypocreales
   8. Coryneiales
   9. Coronophorales

4. Laboulobeniomycetes
   1. Laboulbeniales
   3. **Pezizales**
   4. Tuberales

Order – **Endomycetales :** Asco arising directly from zygotes each derived from the copulation of two cells, or parthenogenetically from single cells; 4 families – 1. Ascoideaceae; 2. Endomycetaceae; 3. Spermophthoraceae and **4. Saccharomycetaceae.**

Order – **Taphrinales :** Product of sexually a dikaryotic thallus; asci arising directly from cells of this thallus; single family – **Taphrinaceae.**

Order – **Eurotiales :** Ascocarp sessile and without an ostiole; 3 families – 1. Ascosphaeri-aceae, 2. Gymnoascaceae **3. Euriotiaceae.**

Order – **Erysiphales :** Ascovarp closed (cleistothecium), typically black or dark coloured, wall appendaged, mycelium largely superficial, single family –

Erysiphaceae.

Order- **Clavicipitales :** Asci persistent; ascospores thread-like; ascocarp a perithecium with an ostiole; periphyses present; asci with enlarged thickened by apical cap penetrated by a narrow thread –like aoical pore; single family- **Clavicipitaceae.**

Order – **Sphaeriales :** Ascocarps and stomata, if present, dark, membranous or carbonous; perithecia, typically white to bright coloured; periphyses and apical paraphyses present; mature asci attached to the inner perithecial wall; 4 families – 1. **Sordariaceae, 2.** Phyllachoraceae, 3. Diatrypaceae and **4. Xylariaceae.**

Order – **Pezizales :** Ascocarp an open apothecium or a modified form of it; apothecia above ground (epigeous); asci operculate or sub-operculate; 3, families – 1. Sarcoscyphaceae, **2. Pezizaceae** and 3. **Helvellaceae.**

Class – BASIDIOMYCETES

Sub-classes

1. Heterobasidiomycetidae
(Basidium septate)
Orders :
1. Tremellales
2. **Uredinales**
3. **Ustilaginales**

2. Homobasidiomycetidae
(Basidium non-septate)

1. Exobasidiales
Series – hymenomycetes
2. **Polyporales**
3. **Agaricales**
Series –Gasteromycetes
4. Hymenogastrales
5. **Lycoperdales**
6. Sclerodermatales
7. Phalles
8. **Nidulariales**

Order – **Uredinales :** Basidiocarp absent; basidium (promycelium) arising from a thick-walled probasidium, a telautospore; plant parasites; basidiospores produced on sterigmata, forcibly discharged; 3 families – 1. **Pucciniaceae, 2. Melampsoraceae** and 3. Coleosporiceae.

Order – **Ustilaginales :** Basidiocarp lacking; mostly parasitic on vascular plants; teleutospores formed in a manner similar to that of chlamydospores; basidiospores sessile, not forcibly discharged, 3 families- 1. **Ustilaginaceae, 2. Tilletiaceae** and 3. Graphiolaceae.

Order – **Hymenomycetes :** Basidiocarp present; hymenium present and exposed before the spores are mature.

Order – **Polyporales :** Basidiocarp present ; hymenium present; hymenium gymnocarpic texture of basidiocarp not spft and putrescent; 6 families- 1. Thelephoraceae, 2. Clavariaceae, 3. Cantharellaceae 4. Hydnaceae, 5. Meruliaceae and **6. Polyporaceae.**

Order – **Agaricales :** Basidiocarp present; hymenium borne on lamellae (gills), or if lining the interior of pores then basidiocarp soft and putrescent; 5 families – 1. Boletaceae, 2. Paxillaceae, 3. Russulaceae, 4. Hygrophoraceae and **5. Agaricaceae.**

Series – **Gasteromycetes :** Hymenium present or absent, basidiocarps remaining closed at least until the spores have been released from the basidia (i.e., angiocarpic).

Order – **Lycoperdales :** Gleba powdery; global chambers not separating from peridium; hymenium present in early stages; spores mostly lightcoloured, small; 3 families – 1. Arachniaceae, **2. Lycoperdaceae** and 3. Geastraceae.

Order – **Nidulariales :** Gleba waxy; glebal chambers forming waxy peridioles, or entire gleba separating as a unit from the peridium; 2 families – 1. Sphaerobolaceae and **2. nidulariaceae.**

Form – Class- DEUTEROMYCETES

(The Imperfect Fungi)

Orders

1. Shaeropsidales (Reproduction by means of conidia borne in pysnidia). Form-Families 1. Sphaeropsidaceae 2. Zythiaceae 3. Leptostromataceae 4. Excipulaceae	2. Melanoconiales (reproduction by means of condia borne in acervuli). 1. Melanconiaceae Genus - C*olleto richum*	3. Moniliales (reproduction by means of conidia borne otherwise; by oidia or by budding). 1. Moniliaceae 2. Dematiaceae *Helminthosporium, Alternoria, Cerospora,* 3. Stillbellaceae 4. Tuberculariceae Genus - *Fusarium*	4. Mycelia Sterlia (No reproductive structures known). Important form genera *Rhizoctonia ;* and Sclerotium

ECONOMIC IMPORTANCE OF FUNGI

The fungi are related to both the useful and harmful activities to which the man is directly concerned. Several fungi are directly used as foodstuffs. Many mushrooms are edible and served as delicious dishes. The fungi, like yeasts are responsible for fermentation. The baking industry is dependent on the enormous budding of the yeast cells. Contrary to the useful activities the fungi act as great enemy to the human beings. Some of the mushroom-like fungi are highly poisonous and known as toadstools. If somehow, or other they are eaten as mushrooms, the death is sure. Many saprophytic fungi cause the sufficient damage and decay to the foodstuffs. Several fungi attack the paper wood pulp and give a death blow to the paper industry. Some fungi directly attack the book paper and cause sufficient damage. Many fungi cause the sufficient damage to the woolen and cotton textiles. Some fungi are the greatest enemy of the timbers, and cause the decay of the same. As we know, many of the parasitic fungi are responsible for hundreds of diseases of economic plant. Several fungi cause several human and animal diseases. Conclusively, this can be said very safely that the fungi are our friends on one side and the greatest foes on the other side.

USEFUL ASPECTS

Direct utilization of fungi as food

Many agaricales and Helvellales are directly used as food. There is a non-poisonous edible toadstool, i.e., ***Coprinus*** sp. found in lawns in the rainy season. ***Agaricus campestris*** is edible mushroom and cultivated for its fructifications. the fruiting bodies are quite freshly and eaten directly as vegetable or with rice as **'pulao'.** These mushrooms are being successfully cultivated in South India. ***Morchella esculenta*** is another important edible fungus. It is found in Kashmir, Himachal and Punjab plains. Its local name is '**guchi**' and sold as costly as rupees two thousand or more per kilogram. ***Torulopsis utilis,*** is used for the large-scale production of yeast for food purposes. ***Saccharomyces cerevisiae*** is used in bread making industry.

Used as manures

The fungi with bacteria take part in the decay of organic plant and animal waste which is very essential for removing derides from our environments, for supplying carbon dioxide necessary for photosynthesis by green plants, and for providing humus, an important soil constituent for healthy plant growth.

Processing of food

A few species of ***Penicillium*** are being used in processing of food. ***Penicillium camemberti*** involved in ripening of Camembert cheese and ***P.roqueforti*** in ripening of roquefort cheese. Danish blue cheese and the Italian Gorgonzola are also ripened with ***Pencillium.*** In Javam ***aspergillus wentii*** is employed in processing soybeans, because of its ability to loosen the hard tissues of the bean.

Production of antibiotics

Pensillium is best known to the non-botanist because it is the source from which the antibiotic pencillium is extracted. Pencillium was first discovered in ***Pencillium notatum*** Westling and for a time this was the species from which pencillium was extracted. Later investigation has shown ***P.chrysogenum*** thom to be better for this purpose, and irradiation of it with X-rays and ultraviolet light has induced mutants with an even higher content of pencillin. In India at Pimpri and Rishikesh these are big factories of antibiotics.

Beer and wine

Strains of ***Saccharomyces cerevisiae*** are commonly used in the manufacture of beer. **Taette** is an alcoholic beverage prepared from milk. Yeasts cause the characteristic changes in flavour **sake** is widely used alcoholic beverage of Japan. It is a yellow rice wine containing 14 to 24 percent of alcohol. An alcoholic fermentation ensues in which several yeasts may be active. ***saccharomyces sake, S. tokyo and S. yeddo*** and some of the yeasts characteristic of sake. In Japan ***aspergillus oryzae*** is used to make sake, and to manufacture various fermented foods.

Preparation of medicines

The famous drug, ergotine, which has long been used as a drug for obsteric purposes to include uterine constractions in cases of delayed childbirth; ergot is obtained from ***Claviceps purpurea***, the casual organism of plant disease, ergot of rye. This is found in Nilgiris and South India. The other fungi, ***ashbya gosypii and Eremothecium ashbyii*** are used in the synthesis of vitamin B-riboflavin. ***Saccharomyces cerevisiae*** are employed in the synthesis of yeast tablets, rich in vitamins. ***Saccharomyces cerevisiae,*** are used in alcoholic fermentation.

Preparation of various acids

Aspergillus niger is however, employed in the production of gallic acid. the same fungus has also been employed in the production of citric and gluconic acids. Molliard (1922), found that gluconic acid was synthesized along with citric acid and oxalic acids by ***aspergillus niger. Aspergillus itaconicus*** is used in the synthesis of itaconic acid, ***Aspergillus terreus*** also produces itaconic acid along with fumaric, succinic and oxalic acids. Kojic acid is obtained from the mycelium of ***Aspergillus oryzae, A. glaucus, A. tamarii*** **and *A.flavus***. Many species of *Pencillium* are capable of producing organic acids, such as citric, fumaric, oxalic, gluconic and gallic.

Synthesis of enzymes

Many important and useful enzymes have been synthesized from various fungi. The enzyme tyrosinase is obtained from ***Neurospora crassa. Saccharomyces cerevisiae*** synthesizes invertase enzyme. ***Aspergillus oryzae*** has been employed in active enzymes preparation. A. niger produces starch digesting enzymes, ***Aspergillus versicolor*** synthesizes an enzyme capable of destroying tartrates and recommended its use in the commercial preparation of grape juice.

Production of esters

According to Brikinshaw and others (1931), the ethyl acetate was synthesized by ***Pencillium digitatum.***

Production of pigments

A maroon coloured pigment, **fumigatin** is produced by ***Aspergillus fumigatus.*** The red pigments, **catenarin** is produced by ***Helminthosporium*** sp. Another importance blue-purple pigment, **spinulosin** is produced by ***Penicillium spinulosum.*** A number of pigments have been isolated from yeasts, particularly from species of ***Rhodotorula and Cryptococcus.***

HARMFUL ASPECTS

Plant pathogens

Various parasitic fungi act as casual organisms and infect hundreds of species and varities of plants of the economic value. A list of few important diseases of the plants of economic importance, with their casual organisms is given below.

Name of Disease	Name of Crop	Casual organism
1. Club root	Cabbge	*Plasmodiophora brassicae*
2. Wart disease	Potato	*Synchytrium endobioticum*
3. Damping off	Various seedlings	*Pythium sp*
4. Late blight	Potato	*Phytophthora infestans*
5. While rust	Crucifres	*Albugo candida or Cystopus candidus*
6. Downy mildew	Peas	*Peronospora pisi*
7. Downy mildew	Grapes	*Plamopara viticola*
8. Powdery mildew	Graphes	*Uncinula necator*
9. Powedery mildew	Peas	*Erysiphe polygomi*
10. Powdery mildew	wheat	*Erysiphe graminis*
11. Powdery mildew	Wheat	*Ustilago tritici*
12. Loose amut	Barley	*U. hordei*
13. Covered smut	Barley	*U.nuda*
14. Loose smut	Oats	*U. kolleri*
15. Covered smut	Oats	*U.avenae*
16. Whip smut	Sugarcane	*U.scitaminea*
17. Grain smut	Jowar	*Sphaceloheca sorghi*
18. Smut of	Bajrs	*Tolyposporium pencillariae*
19. Black rust	Wheat	*Puccinia graminis trittici*
20. Brown rust	Wheat	*P. recondita*
21. Yellow rust	Wheat	*P. striiformis*
22. Rust of	Linseed	*Melamspora lini*
23. Early blight	Potato	*Alternaria solani*

24. Tikka disease	Groundnut	*Cercospora personata*
25. Red rot	Sugarcane	*Colletotrichum falacatum*
26. Flag smut	Wheat	*Urocystis trittici*
27. Leaf curl	Pearch	*Taphrina deformans*

Besides, there are hundreds of other diseases which cause heavy losses to the pulses, vegetables, cereals, fruits and other important crops.

Decay of timber

Many species of ***Polyporus*** and other Basidiomycetes cause the damage and decay to the timber wood and sufficient losses are caused.

Destruction of textiles

According to Prindle (1935), the species of the genera ***alternaria, Penicillium*** etc. are especially destructive to woollen textiles. According to Duske (1943), the rayon is destroyed by the genera of ***Aspergillus*** *and* ***Penicillium.*** According to Hardy (1943), the cheif destroyed fungi to the textiles are ***Mucor, Aspergillus, Fusarium and Trichoderma.*** The deterioration of cotton is storage is caused cheifly by a species of ***Stachybotrys*.** He also investigated that the greatest amount of damage to textile materials is due to ***Chaetomium globosum.***

Destruction of paper industry

Many fungi cause damage to the paper pulp-wood, e.g., ***Polyporus adustus, Polysticus hirsutus*** etc. Many species of Basidiomycetes cause wood decay if suitable environmental conditions prevail. Many fungi destroy the paper of books and newspapaers in moist condition. the fungi such as ***chaetomium, Aspergillus, Cephalothecium, Stachybotrys, Alternaria, Fusarium, Cladosporium, Stemphyllium, Dematium*** cause sufficient damage to paper industry.

Spilage of footstuffs

Pencillium digitatum is responsible for the rotting of citrus fruits. According to Thom and Ayers (1916), many fungi, such as ***Mucur, Aspergillus, Penisillium, Oidium and Fusarium,*** cause damage to the milk and milk products. To avoid this damage to the milk normal pasteurization (i.e., heating milk to 1450F) is necessary before distribution to the consumer. ***Oidium lactis*** develops the fishy odour of the butter and causes the damage to the butter. ***Mucor mucedo and Aspergillus*** are responsible for the bread spoilage.

Spoilage of meat

Many fungi are reported from the meat which cause sufficient spoilage to it, usually in tropical conditions. According to Yesair, ***Mucor*** sp., ***Penicillium*** sp., ***Neurospora*** sp., ***Fsarium*** sp., ***oidium*** sp., and ***Aspergillus*** sp., are commonly met with on meat and cause damage to it.

Medical mycology

Several important human diseases are caused by different species of fungi. ***Asperigillus fumigatus*** and ***A. glaucus*** are responisble for the lung disease 'aspergillosis'. The disease 'mycosis' and 'tokelan' are caused by other species of ***Aspergillus.*** Several other animal and human diseases are caused by various fungi.

The dermatophytes are fungi which cause diseases of the skin of man. the diseases they cause are grouped under the general term **dermatomycoses** and are commonly known as ringworm, athlete's foot etc. ***epidermophyton flocossum*** causes chronic infections commonly called athlete's personnel ***tinea capitis.*** The form germs ***Trichophytom*** also a cause of athlete's foot and other skin diseases is the largest of the form genera of dermatophytes. Several form-genera of the Moniliaceae which include serious human pathogens are ***Blastomyces, Histoplasma, Geotrichum and Sporotrichum. Blastomyces deematitidia*** causes North American **blastomycosis.** South america and some parts of Central america. It is confined to the skin and mucous membranes around and in the mouth. Certain form species of ***Geotrichum*** are known to be pathogenic to man. Four forms geotrichosis have been described-oral, intestinal, bronchial and pulmonary. ***Sporotrichum schenkii*** is the cause of **sporotrichosis** to man and animals.

NOTES

UNIT - II

ALBUGO OR CYSTOPUS (30 species)

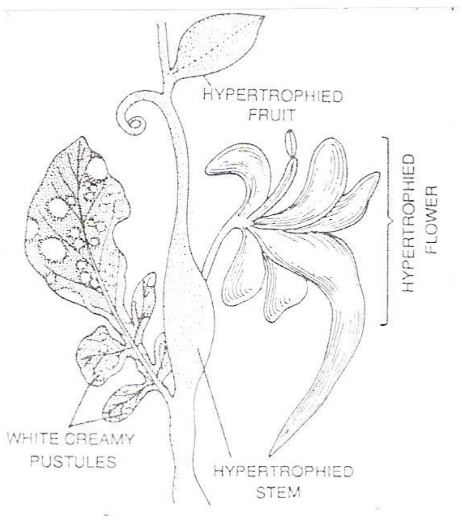
Habitat and habitat

The genus ***Albugo or Cystopus*** is an obligate parasite and belongs to family Albuginaceae. ***Albugo candida*** causes the important disease of crucifers known as the 'white rust'. This species infects ***Brassica campestris, B. oleracea, B. nigra, B. napus, Raphanus sativus and Eruca sativa***. Besides this genus also infects the members of Capparidaceae, Convolvulaceae and Amarnataceae.

Every part of the host plant is inflected expect the roots. White or cream coloured pustules develop on the surface of the leaf. Many pustules merge with each other and irregular patches are develpoed. These pustules are sub-epidermal. Due to the production of sporangia in abundance, the epidemis of the host bursts and powder like substance is exposed. In normal conditions the pustules appear on the lower surface of the leaf, but in several conditions of the disease the symptoms appear on both the surfaces. The leaves of some crucifers become thick, fleshy and curled. In several conditions the leaves remain undeveloped and the plants become dwarf. the stem becomes hypertrophied and the floral parts become withered. The sepals and petals become fleshy and leaf-like. The ovary and stamens become flat, leaf like and sterile. The whole infected flower becomes hypertrophied and several times bigger than the normal size.

Structure of mycelium

The mycelium is endophytic, branched, aseptate, coenocytic, hyaline, intercellular and with knob-like haustoria for the absorption of food material from the host cells.



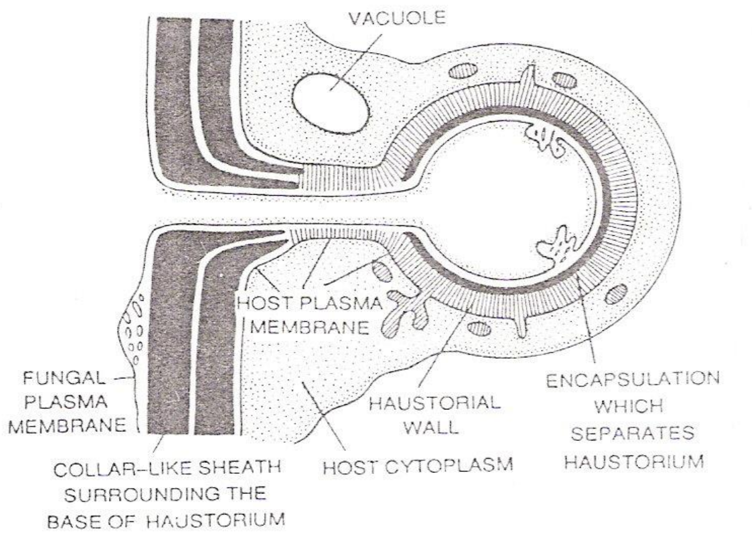
Albugo candida. white rust of crucifers-infected twig, leaf with white creamy pustules, hypertrophied stem, hypertrophied flower and fruit.

Reproduction

The reproduction takes place by means of asexual and sexual methods.

1. Asexual reproduction

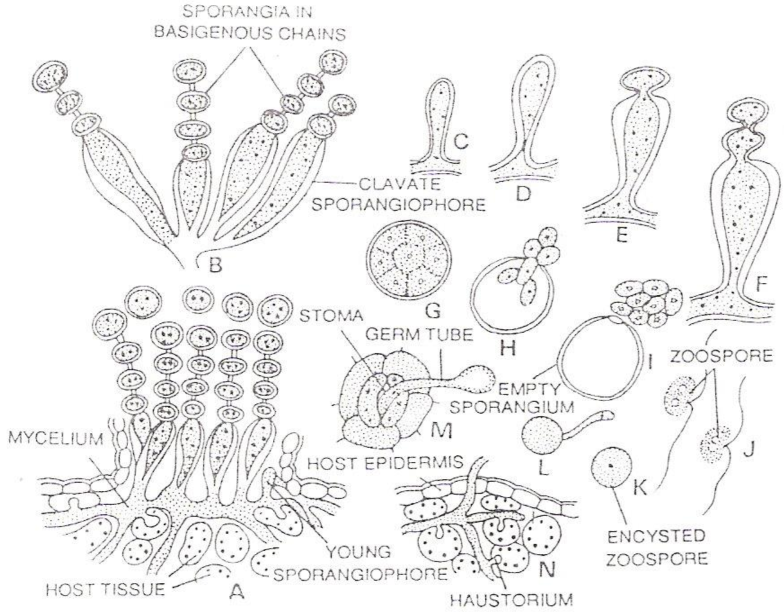
The asexual reproduction takes place by means of asexual methods. Zoospores formed inside the sporangia. In the very begining the hyphae accumulate just beneath the epidermis of the infected leaf. From these hyphae, certain thick-walled, clavate aerial sporangiophores come out. In each such sporangiophore becomes constricted and sporangium cuts off. This sporangium contains 5-8 nuclei and cytoplasm. Successively the sporangia develop by constriction method, in basigenous chains. In between each two sporangia a gelatinous pad develops acting as a separator of two sporangia from each other. The sporangium is smooth, double –walled and rounded. When the sporangia are formed in abundance on innumerable sporangiophores, the pressure is caused, the host epiderma is ruptured and hundreads of sporangia are seen on the surface of the host in the form of white creamy powder forming pustules. The sporangia are transferred from one place to another by various agencies such as wind, insects, water etc.



Albugo candida. Knob-like haustorium as seen with electron microscope.

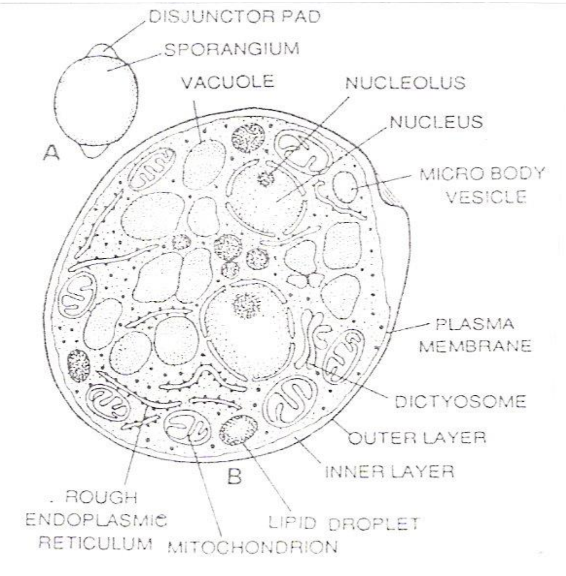
(After Berlin and Bowen, 1964).

On the maturation of the sporangium the protoplast is cleaved into uninucleate protoplasts. Each protoplast metamorphoses into a naked, biflagellate, uninucleate, reniform and vacuolate zoospore. The sporangium bursts anteriorly and the zoospores liberate in the film of water. the flagell are withdrawn and the zoospore becomes encysted. Each encysted protoplast germinates, producing a germ tube on the surface of the suitable host. The germ tube enters through stoma, develops into mycelium and ramifics in the intercellular species of the host tissue.



Albugo candida. white rust of crucifers-asexual reproduction of *Albugo*-A, section of infected host leaf showing mycelium, haustoria, sporangiospores and sporangia; B, branching of sporangiophores with basigenous chains of sporangia; C-F, development of sporangiospore and sporangia, G-I, germination of sporangium and formation of zoospores; J, biflagellate zoospores; K, encysted zoospores; L, germinating encysted zoospores; M, infection; N, intercellular mycelium and rounded within host tissue.

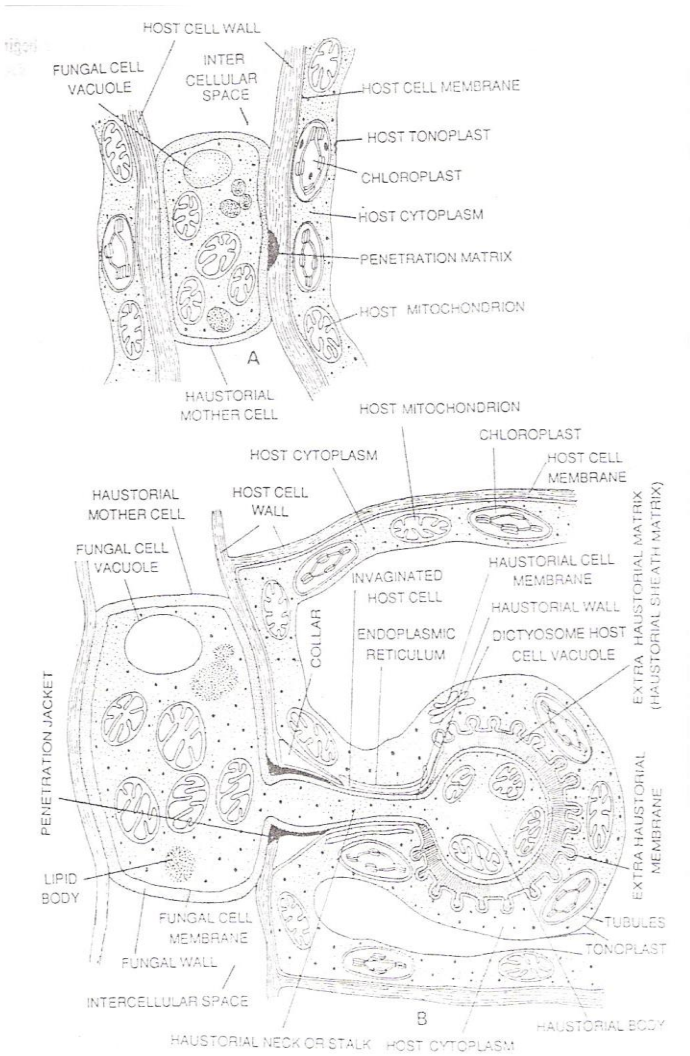
Sometimes the sporangia behave as conidia and germinate directly producing germ tubes. The sonidia may germinate from 3^0C to 25^0C temperature.



Albugo candida. a, sporangium; B, ultrastructure of sporangium (diagrammatic)

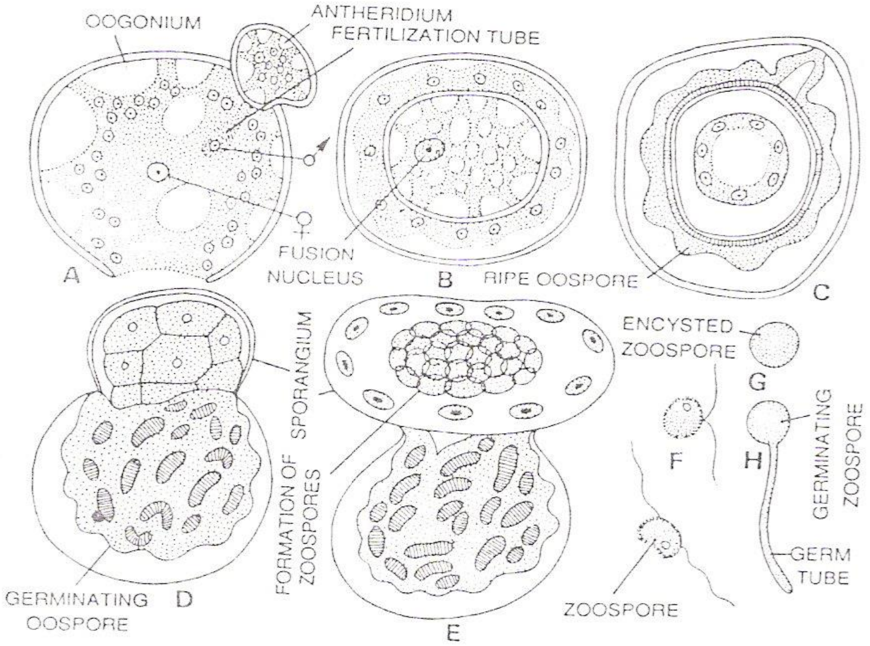
2. Sexual reproduction

the sexual reproduction is **oogamous.** The sex organs develop on the hyphal ends in the intercellular spaces of the deeper tissues of petioles and stems. The female sex organs are oogonia and the male sex organs are autheridia. The oogonium is rounded and the autheridium club-shaped. The developing oogonia and autheridia are separated from rest of the mycelium by septa. The cytoplasm, vacuoles and nuclei are uniformly distributed in the young oogonium. On the maturation of the oogonium the protoplasm of the oogonium differentiates into two regions. The outer region is called the **Periplasm** containing thin cytoplasm, many nuclei and many vacuoles. The central protoplasm with denser consistency surrounded by periplasm is called the **oosphere** or the **egg.** The dense cytoplasm of the development of the oogonium there are many nuclei, which degenierate soon leaving one functional female nucleus.



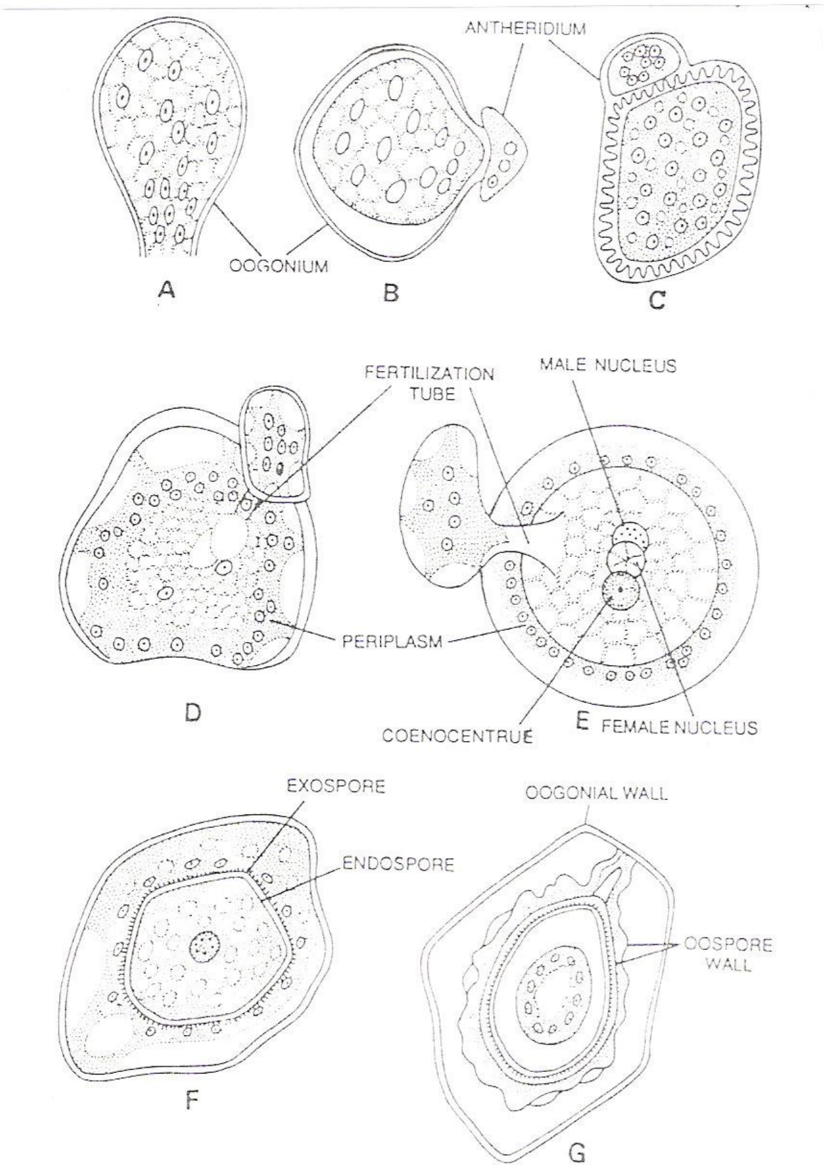
Albugo candida. A, part of intercellular mycelium; B, haustorium developed from intercellular mycelium in host cell as revealed under electron microscope.

The antheridium develops on the terminal end of another hypha lying very close to the oogonium. The hyphal end swells, becomes club-shaped and separates from rest of the mycelium by a septum. This swollen multinucleate club-shaped portion is called the antheridium. The antheridium attaches itself to the oogonial wall and at the point of contact a **fertilization tube** develops from the antheridium. The fertilization tube penetrates the oogonial wall and reaches the oosphere through the periplasm. One functional male nucleus transfers through the tube, reaches the egg, fuses with the female nuclei and the rest of the nucleal of the autheridum degenerate.



Albugo candida. white rust of crucifers. A, oogonium and autheridium with fertilization tube; B, the oospores wallhas began to form, the fusion nucleas seen; C, the mature oospore in cross section; D-E, germination of oospore; F, biflagellate zoospores; G, encysted zoospores; H, germinating zoospore (A-C, after Wager, D-H, after De Bary)

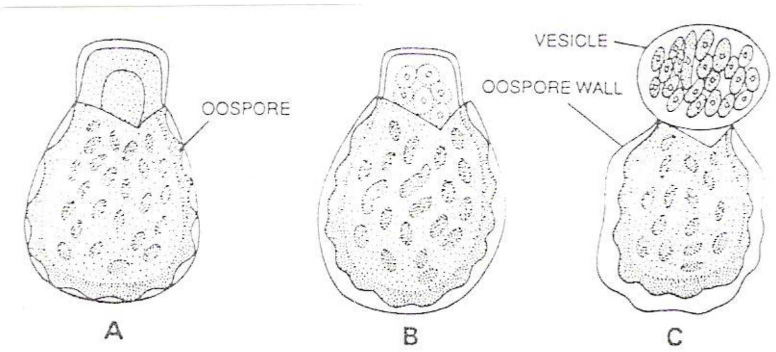
The **oospore** is thick-walled and three-layered. the outermost thick layer of the wall is warty in ***albugo candida***. The oospore contains a large diploid (2x) nucleas. The reduction division (meiosis) is not yet seen in *Albugo candida* but it has been observed in the other species of *albugo.* Priot to germination the zygote nucles divides repeatedly producing 32 nuclei. The first division is meiotic.



Albugo candida. A, oogonium with many nuclei; B, formation of the respective spot towards the attached autheridium; C, nuclei in autheridium and oogonium; D, formation of fertilization tube and migration of the nuclei of oogonium in the peripheral region leaving single female nucleus in the centre of oogonium; E, fusion of male and female nuclei; F, oospore formation and karyogamy; G, mature oospore.

Germinating of oospore

The oospores are pernnating bodies and survive in adverse conditions. The 32 nucleate oospore undergoes a period of rest and germinates on the approach of favourable conditions of moisture and temperature. The outer warty wall of oospore bursts and a thin membrance of sessile vesicle comes out of the oospore. Prior to extrusion of the contents in the vesicle the nuclei undergo the mitotic division repeatedly and a large number of uninucleate bits of protoplast are produced. Each bit metamorphoses into a biflagellate, reniform, naked, uninucleate and single vacuolate **zoospore.**



A-B, germination of oospore; C, the zoospores are being formed in the vesicle.

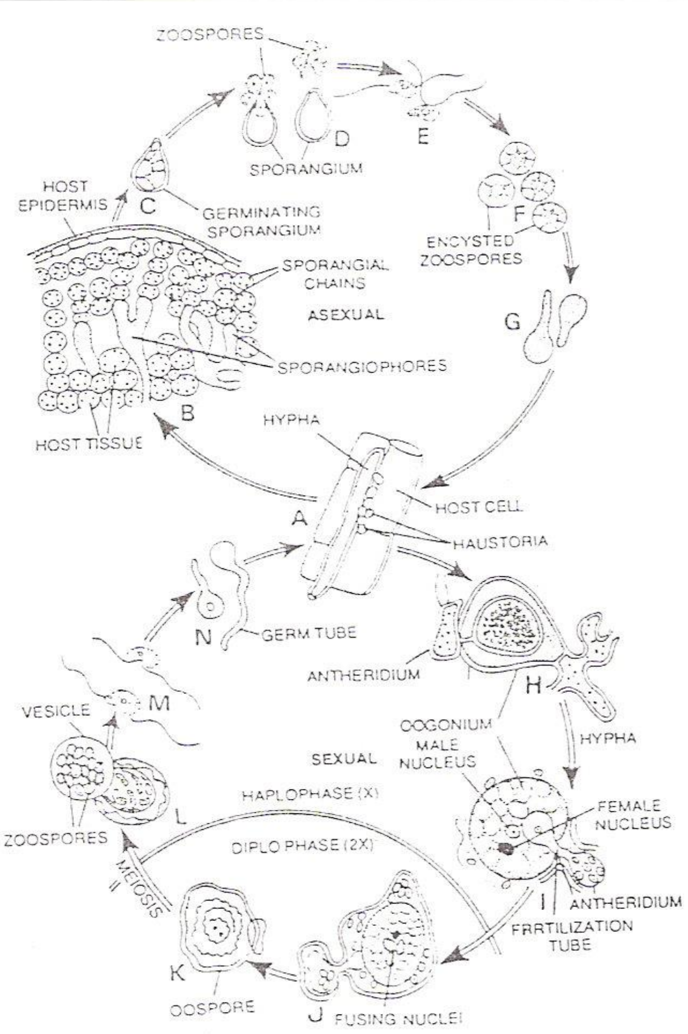
Each oospore products forty to sixy zoospores. After extrusion from the oospore, the vesicle bursts and the zoospores librate in the film of water where they move about with the help of their flagella. They swim about, encyst and germinate producing the germ tubes on the suitable host. The germ tube enters through the stoma and develops into the new mycelium which ramifies in the intercellular spaces of the host tissue.

The oospores remain dormant in the soil and infect the plants next year.

The disease may be controlled by the following methods :

1. By crop rotation
2. By eradicating infected plants.

By spraying fungicides such as Bordeaux mixture.

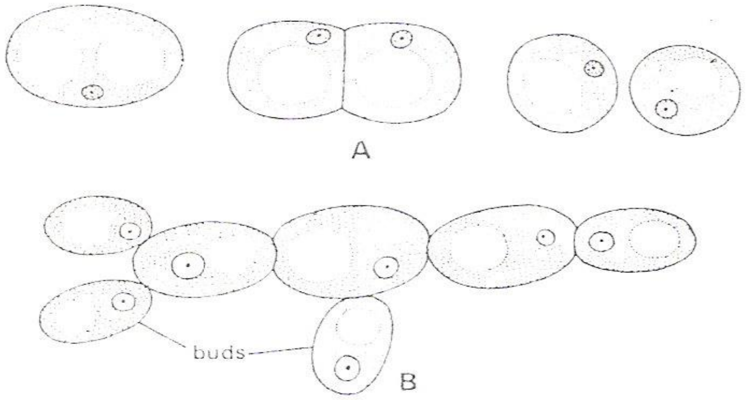


Albugo. Diagramatic life-cycle. A, hypha with in host cell showing globular haustoria; B, infected leaf in vertical section showing sporangiospores and sporangial chains; C, germinating sporangium; D, sporangia releasing zoospores; E, zoospores; F, encysted zoospores; G, germination of encysted zoospores; H, antheridum and oogonium; I, plasmogamy; J, karyogamy; K, oospore; L, germination of oospore producing zoospores within vesicle; M, zoospores; N, germination of encysted zoospore.

SUCCHAROMYCES (30 species)

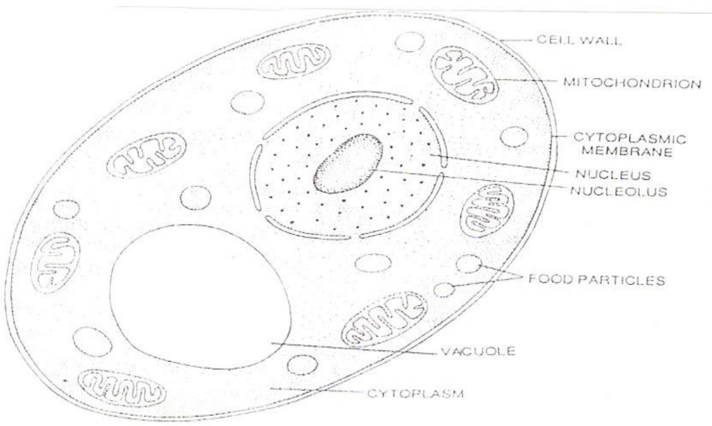
Occurence and habit

Usually the yeasts grow in such organic materials where the sugar is found in abundance. They grow in toddy juice, grape juice and sugarcane juice very easily.



Yeast

The yeasts convert the sugars into alcohol by fermentation and only because of this quality they are used in making alcohols, wines and beer etc. they are used in the bakeries to produce loafs. The spongy nature of the loaf is because of the presence of carbon dioxide. This carbon dioxide is released during fermentation.

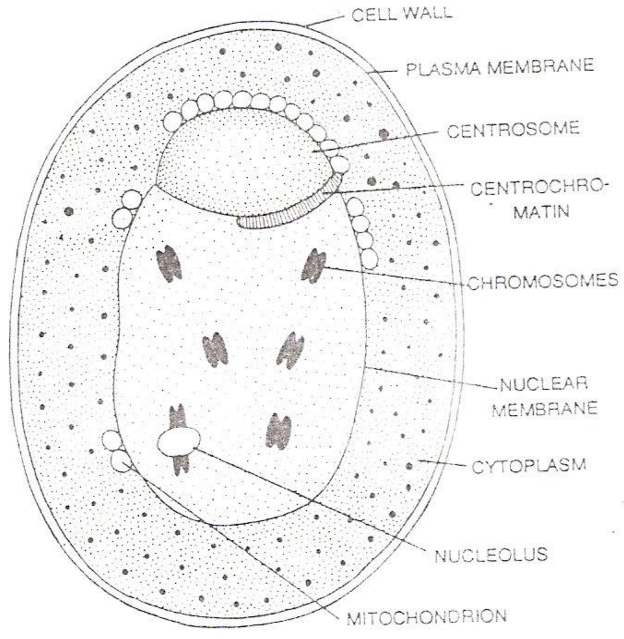


Electron micrograph of single yeast cell.

some yeasts occur as parasites, e.g., *Monosporella* is parasitic on the intestines of *Daphnia,* a crustacean; species of *Nematospora* are found to be parasitic on tomato, beans etc. Certain yeasts are found in symbiotic relationship with certain bacteria and moulds, e.g., to prepare the sake wine in Japan, the fermentation is brought about by ***saccharomyces sake*** (yeast) in association with ***Aspergillus oryzae*** (mould).

Structure

The yeast organisation are unicellular. all the metabolic activities are furnished by this single cell. These cells are microscopic and may be seen under the high power lens of the microscope as pin heads.



A yeast cell. (After Lindgren).

Each yeast cell is oval or spherical. The cell wall consists of a hard substance, the chitin. The cytoplasm is filled up in the cell. In the most common species ***Saccharomyces cerevisiae*** there is large rounded colourless area lying towards a pole of the cell. According to Lindgren (1949) and others this has been considered as a nucleus, but according to De Lamater (1950) this is the vacuole and the nucleus is the smaller body which lies on the side of the vacuole. If the former view is correct, the nucleus contains a big vacuole. the nuclear vacuole possesses a chromatin network and a small nucleus situated on one side. The glycogen granules, the oil droplets and the compounds of proteins are found embedded in the cytoplasm.

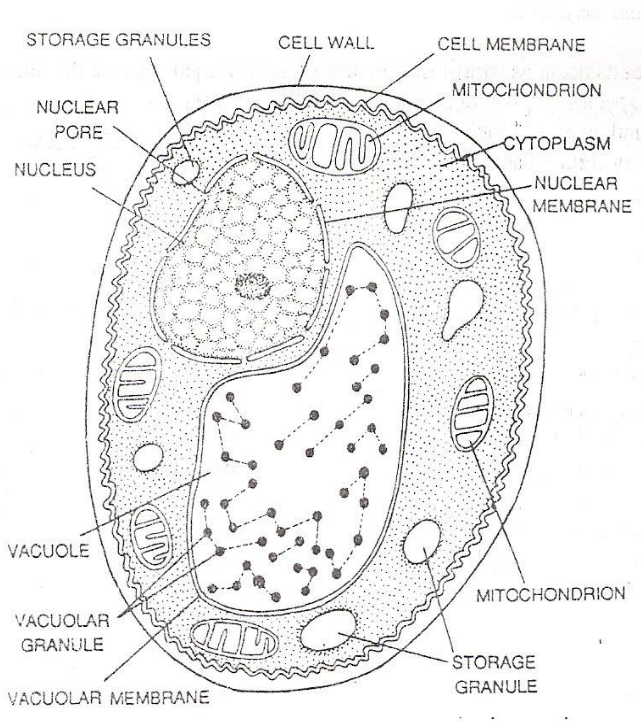
The cytology of yeast cells remained a topic of controversy for many years. Dangeard, janssens, Le Blance and others showed some nucleus like bodies to be present in the cell. This was assumed that a **diffused nucleus** of dispersed particles was present within the cells. Eischenscitz reported that these grains were abundantly found in the vacuole. This concept was recognized by Wagner (1898) and again by Wagner and Peniston (1910). These scientists describe the nucleus as **vacuole nuclear,** i.e., a vacuole filled up with chromatin particles and carrying a distinct nucleus towards its outside. Now this account is of historical value only.

Electron Microscopic Structure

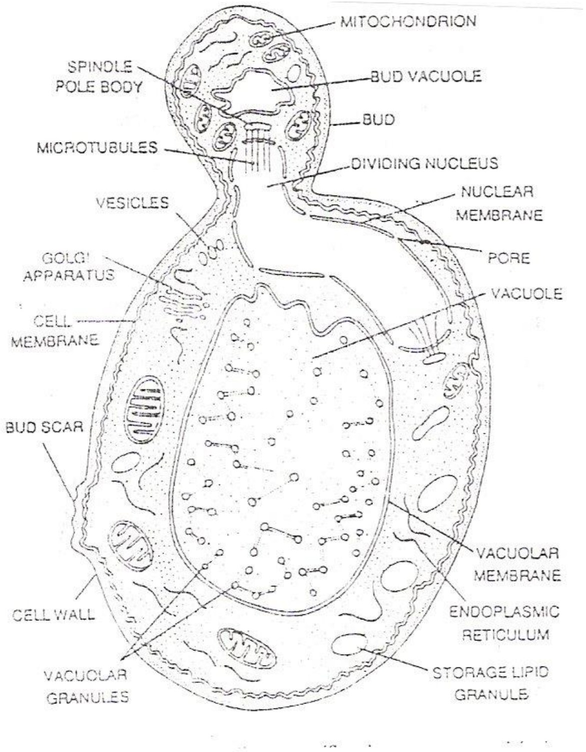
The electron microscope has now revealed astonishing details within the yeast cell : Yotsuyanagi, Y. (1959), Hashimoto, T. (1960), Naylor, H.B., Conti, S.F. and Thyagarajan, T.E. (1962).

The detailed electron microscopic structure of the yeast cell is as follows.

The cell remains surrounded by a definite two-layered cell wall. the cell wall consists of chitin and some other substances. just beneath the cell wall there is cytoplasmic membrane. There is a distinct nucleus within the cell. the nucleus is spherical to ovoid and remains surrounded by a double membrance which is interrupted by 'pores'. A distinct nucleolus is also present within the nucleus. the nucleus is a spherical dense body and remains surrounded by its own membrance. Certain vacuole-like areas of lesser density are also found within the nucleolus. The granular and homogeneous nucleoplasm is filled up within the nucleus. There occur some irregular areas within the nucleus, which contain fibrils and corresponed to the chromosomes of yeast cell. there is a distinct vacuole found within the cell that remains filled with a granular material, the volutin and is separated from the remaining cell by a membrane of its own. As assumed earlier the vacuole is not integral part of nuclear apparatus. The other cytoplasmic inclusions are mitochondria, endoplasmic reticulum and ridosomes. The number of mitochondria within a cell is 4-20. Certain other inclusions such as food particles of lipids, proteins, glycogen etc., are also found.



saccharomyces cerevisiae. Cell structure as seen under electron microscope**.**



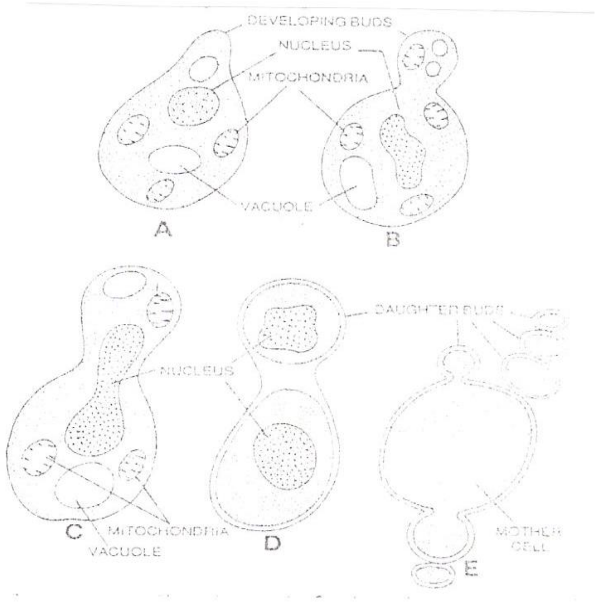
Ultra structure of a budding yeast *(Saccharomyces cerevisiae).*

Reproduction

The reproduction of yeasts takes place by means of 1. vegetative, 2. asexual and 3. sexual methods.

Vegetative reproduction

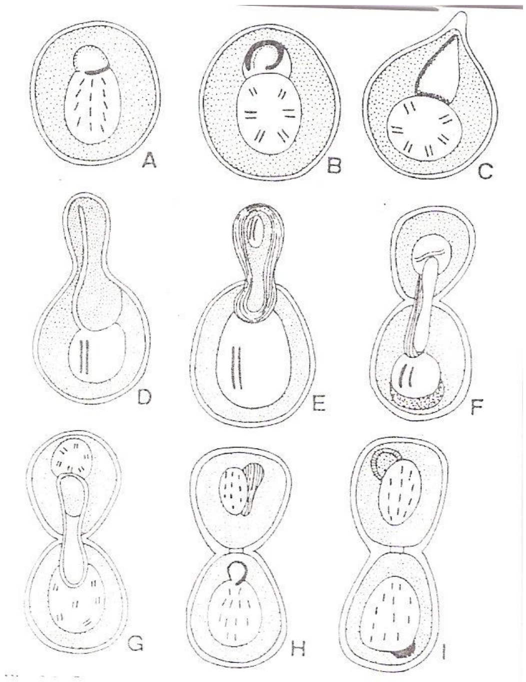
The vegetative reproduction takes place by means of ‘ budding’. This method of reproduction takes place in favourable conditions when the yeast cells grow in sugar solution. From each yeast cell one or more small outgrowths are given out, which gradually enlarge in size, detached from the mother cells and act as independent individuals. the nucleus of the mother cells divides amiitotically and transfers to the daughter cell. Several other outgrowths develop from the newly formed outgrowths, and sometimes, the chains of the cells are seen. Very soon the yeast cells are detached from each other and act as new independent individuals.



Saccharomyces sp. Vegetative reproduction. Successive stages of budding (A-E).

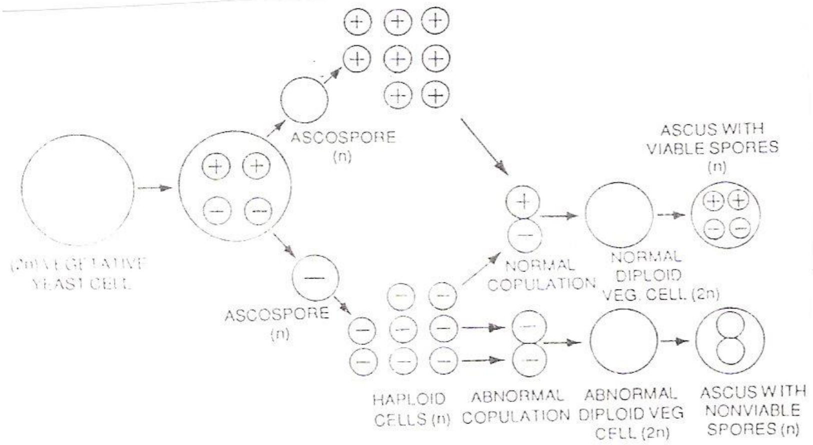
Asexual reproduction

This type of reproduction probably takes place in adverse conditions, especially when there is scarcity of nutrients and abundance of oxygen. the yeast cell enlargesin size and called the'ascus'. The nucleus of the ascus divides twice producing four nucleus. Now around each nucleus the cytoplasm deposits and the four ascospores are formed.



***Saccharomyces* sp. (yeast). A-I, process of budding.**

Sometimes eight ascospores may also be produced. Each ascospore is surrounded by a thick wall. These spores are perennating bodies. They remain dormant in adverse conditions. On the approach of favourable conditions they germinate. The ascus wall bursts and the ascospores liberate in the atmosphere. They are dispersed by wind from one place to another. On getting suitable media and approprite weather conditions the ascospores germinate and the new individuals are formed by budding.

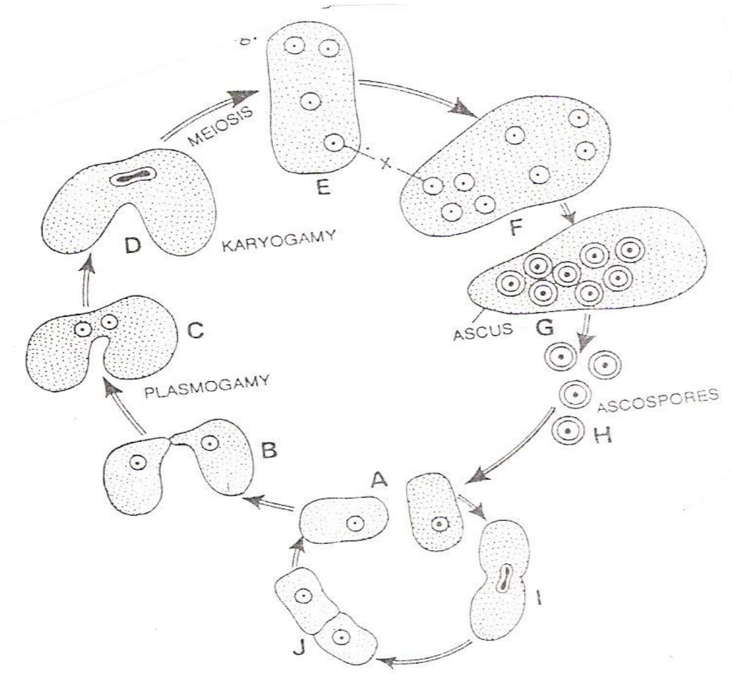


Saccharomyces cerevisiae. Diagrammatic representation of heterothallic behaviour.

Sexual repreoduction

The sexual reproduction takes place very rarely in some of the species of yeasts. This takes place by conjugation. Two individuals come close to each other and the beak-like outgrowths are given out from them. these outgrowths fuse with each other. the nuclei of both individuals come in these beaks, the wall of contact dissolves and ultimately the nuclei fuse with each other giving rise to a zygote, which soon converts into an ascus. the diploid nucleus(2x) of asucs divides thrice producing eight nuclei. the first division is reductional to bring haploid (x) condition again. Around each nucleus the cytoplasm is deposited, they become walled and called the ascospores. On burshing the wall of ascus the ascospores are liberated. On getting suitable conditions they germinate and the new individuals are produced by budding.

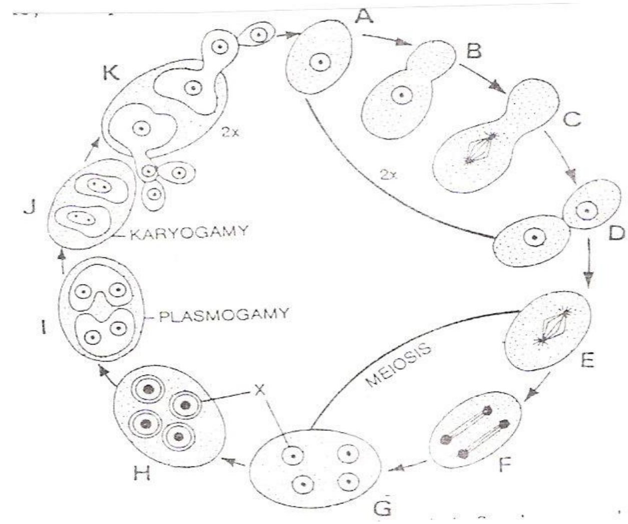
Gulliermond (1940) has recognized three main types of life cycles in the yeast. these life cycles are known as – 1. haplobiontic, 2. diplobiontic and 3. haplo-diplobiontic.



Haplobiontic type of life-cycle in *Schizosaccharomyces octosporus*

1. Haplobiotictype

This type of life cycle is found in ***Schizosaccharomyces*** and some other yeasts. In these yeasts the vegetative stage is predominantly haploid and the diploid stage is very short. the diploid stage is represented by the zygote cell only which undergoes meiosis immediately after nuclear fusion. Here each somatic cell acts as a potential gemetangium. During sexual union two cells fuse (plasmogamy) and this is followed by the fusion of the two nuclei (karyogamy). the fusion or zygote nucleus divides thrice of which the first dicisions is meiotic one. Now the zygote cell becomes ascus containing eight ascospores. After their liberation from the ascus the ascospores behave as vegetative cells.



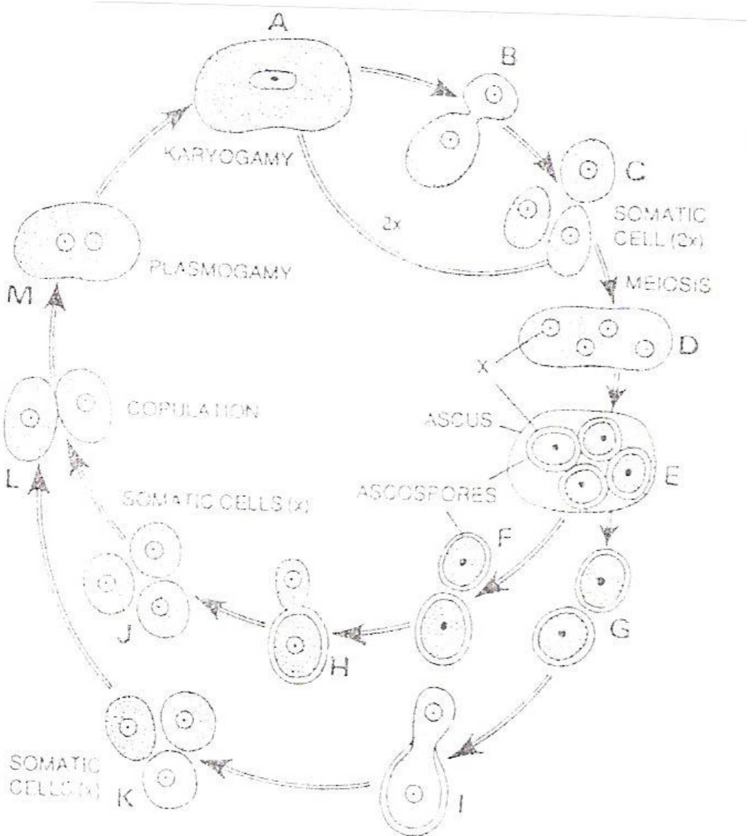
Diplobiontic type of life-cycle in *Saccharomycodes ludwigii.*

2. Diplobiontic type

This type of life-cycle is found in *Saccharomycodes ludwigii* and some other yeasts. In these yeasts the vegetative stage is predominantly diploid and the haploid stage is very short. In this type the ascorspores are not liberated from the ascus but they copulate within the ascus. The zygotes found within the ascus bud out diplobiontic vegetative cells.

3. Haplo-diplobiontic type

This type of life cycle is found in *Saccharomyces cerevisiae* and some other yeasts. In these yeasts the vegetative cells consist of both haploid and diploid phases. The haploid cells copulate and form a diploid cell (zygote). The zygote nucleus divides thrice of which the first division is meiotic one, producing eight nuclei which metamorphose into eight ascospores. Only the diploid cells produce the ascospores which give rise to haploid vegetative cells by budding.



Haple-diplobiontic type of life-cycle in *Saccharomyces cerivisiae.*

Some more types of copulation methods are also found in yeasts. In certain yeasts there is copulation between two adjoining sister cells; this is known as **adelphonogamy.** Here the cells involved in copulations do not separate after fusion and remain united to form short chains, e.g., ***Schizosaccharomyces mellacei*** and ***S. pombe***. Another type of copulation takes place between the mother and the daughter cells formed by budding; this method is known as **pedogamy.** In this type the daughter bud remains continuous with the mother cell and the nucleus from the daughter bud is being transferred into the mother cell. Both the nuclei fuse together forming diploid (2x) nucleus. The fusion nucleus divides meiotically forming 4 nuclei, three of which degenerate and remaining one develops into an ascospore. This process shows anisogamy and occurs in a few yeasts such as ***Nadsonia and Debaryomyces.***

In certain yeasts the asci are formed without copulation of two cells, e.g., in species of ***Zygosaccaromyces, Saccharomyces, Schizosaccharomyces***. This process is known as **parthenogamy.**

The number of ascospores per ascus varies from genus to genus, e.g., the asci of ***monospora*** and ***Nadsonia*** are monospores; 2-4 ascosres per ascus in ***Debaryomyces*** and ***Hensenula;*** 4 in ***Saccharomyces*** and 8 in ***Schizosaccharomyces.*** The ascus in ***Kluyveromyces polyspourus*** contains several spores.

The shape and structures of the ascospores is also variable. e.g., the ascospores of ***Sacharomyces*** and ***Schizosaccharomyces*** are globose or ovoid; rough and warty of ***Debaryomyces;*** hat-shaped and flat on one side of ***Hansenula;*** needle-like and tapering at one end of ***Nematospora.***

PUCCINIACEAE (3,000-4000 species)

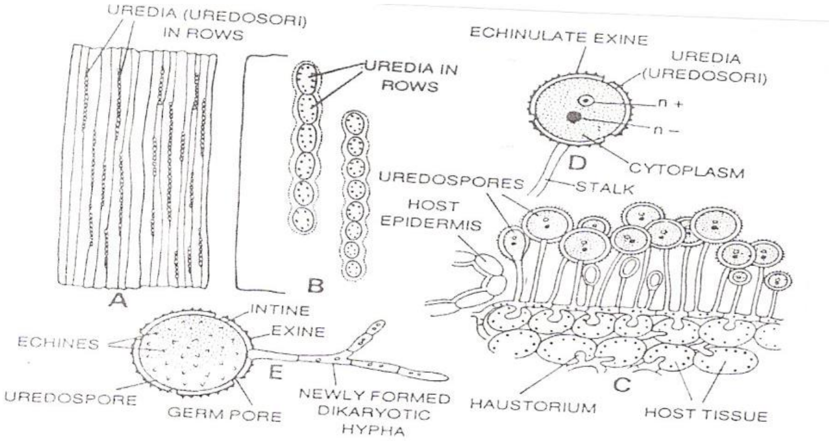
(*Puccinia graminis)*

The different species of ***Puccinia*** cause the diseases known as the rusts on various host plants. ***Puccinia*** is an obligate parasite which survives only on living host plants. the rusts are known as **rati, ratwa, gerua, gerui, gherir, tombora** in local languages in the different appearence on the surface of the host plants.

In our country the wheat crops are highly infected by the different species of ***Puccinia.*** The black or stem rust of wheat is caused by ***Puccinia graminis tritiil;*** the yellow or stripe rust of wheat is caused by ***Puccinia striiformis;*** the brown, orange or leaf rust of wheat is caused by ***Puccinia recondita.***

Symptoms

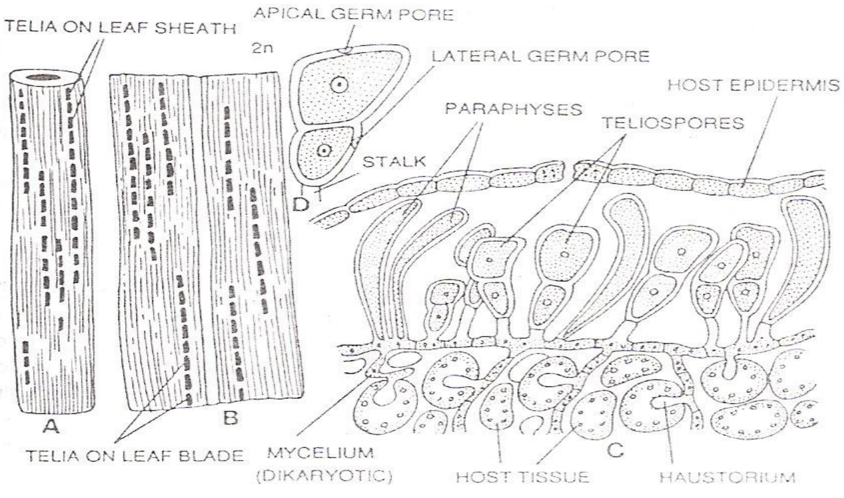
The stmptoms of the black or stem rust of wheat *(Puccinia gramminis tritici)* are commonly found on the stem but the symptoms also on the leaf sheath, leaf blade and even on the ears. The uredia developed by *P. graminis tritici* are oblong and reddish brown whish unite to each other. these uredosori or uredia represent the uredial stage of the black rust. On maturity the uredia are repured and the uredospores are liberated in the form of brown powder. In the end of the season when it is somewhat hot the irregular elongated, dark brown or black, crusts like pustules develop on the stems. They are telia or teleutosori. On maturation the teleutosori rupture and the brown coloured teleutospores come out of them.



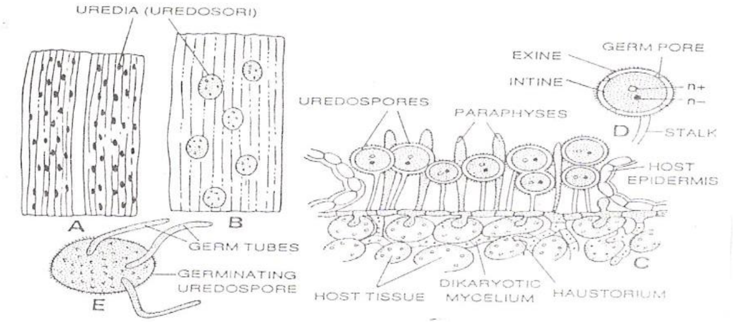
Yellow or stripe rust of wheat. Uredial stage *(Puccinia striiformis).* A, part of infected leaf showing uredia arranged in rows; B, enlarged part of A;C, V.S. of infected leaf through uredium showing mycelium, haustoria and stalked uredospores, D, single uredospore; E, germinating uredospore.

The symptoms of black rust may be accounted on its alternate host. The group of picnia are found on the upper surface of ***Berberris*** leaves, whereas on the lower surface the groups of aecidia are found. The stage represented by pycnia is called the 'pycnial stage' and by aecidia the 'aecidial stage'. The pycnia are flask-shaped and the aecidia cup-like.

The symptoms of yellow rust caused by ***Puccinia striformis*** are somewhat different. sually the symptoms appear on the leaves, but somewhat they appear upon leaf sheath, glumes, awns and even on the stem. The uredia are yellow coloured and arranged in parallel stripes, giving the name to the disease the 'yellow or stripe rust' of wheat. They are very close to each other but do not fuse. The green colour around the uredosori becomes faint, and yellow coloured parallel stripes are found on the leaf. In the end of the season dark brown and black telia appear on the leaf blade and leaf sheath. The telia are subepidermal and not exposed. The telia and elongated and arranged in parallel rows like uredia.



Yellow of stripe rust of wheat *(Puccinia striiformis).* A, telia on leaf sheath; B, telia in stripes on leaf blade; C,V.S. of infected leaf through telium showing its subepidermal state, teliospores, paraphyses, mycelium and haustoria; D, single teliospore.



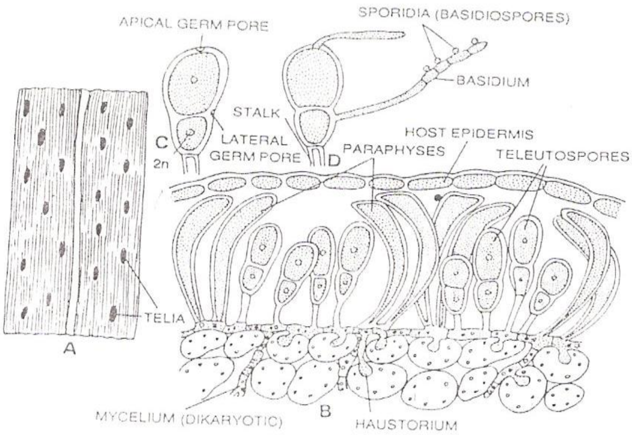
Orange, brown or leaf rust of wheat. *(Puccinia recondia).* A, a part of infected leaf with scattered uredia; B, magnified part of same; C, V.S. infected leaf through uredium showing stalked uredospores, paraphyses, mycelium and haustoria; D, single uredospore; E, germinating uredospore.

The symptoms of brown, orange or leaf rust caused by *P.recondia* appear exclusively on the leaf balde and the disease is called the 'leaf rust'. Rarely the uredia are found on the leaf sheath and stem. The uredia are rounded or oblong and brown or orange in colour. On maturation they rupture and the uredospores come out in the form of brown powder. Usually a fringe is seen around each ruptured uredium. The uredia are developed on both the surfaces of the leaf. The uredia represent the uredial stage. The telial stage is rarely found in the conditions of our country. whenever the telia present, they are small oval or somewhat elongated and sub-epidermal.

Structure of mycelium

The mycelium is localized, endophytic, intercellular, branched, sepate and well developed. There is a single central septal pore in each septum for the communications of the cytoplasm from one cell to another. In certaia phases of the fungus the mycelium is **monokaryotic** whereas in other phases it is **dikaryotic.** To abosorb food material from host cells the haustoria are developed which may be knob-like, finger-like or conbolute. In rare cases the hyphae penetrate the cell walls and the mycelium becomes intercellular.

The dikaryotic or secondary mycelium is confined to primary hist, i.e., wheat and the monokaryotic or parimary mycelium is found on the secondary or alternate host, such as *Berberris* sp., in the case of black rust, and *Thalicurum* sp., in the case of brown rust. The alternate host of yellow rust has not been discovered so far. Such fungi which complete their life cycles on two different hosts, not related to each other in any way, called the **heteroecious** fungi and the phenomenon **heteroecism.** The black rust is hereeosecious rust and complete its life-cycle on two different hosts called primary and alternate hosts such as wheat and barberry bushes respectively which are not at all related to each other in any way.



Orange, brown or leaf rust of wheat-telial stage *(Puccinia recondita).* A, a part of infected leaf showing telia; B. V.S. of infected leaf through telium showing teliospores, paraphyses, mycelium and haustoria; C, single teliospore; D, germinating teliospore.

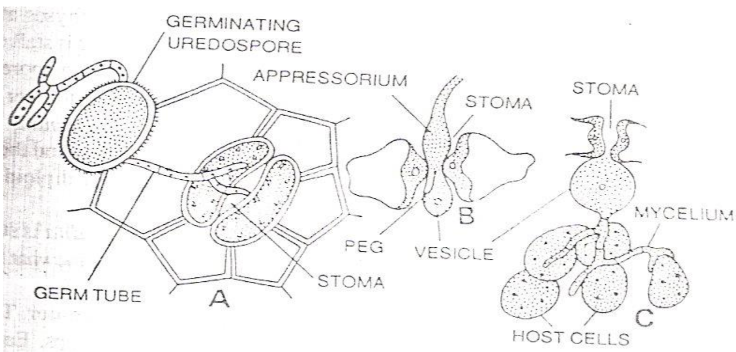
Spores

Several types of spores are found in the life history of *Puccinia graminis tritici.* They are pycniospores, pycnidospores or spermatia, aeciospores or aeciospores, uredospores, urediospores or uredeniospores; teliospores or teleutospores and; basidiospores. *Puccinia graminis* is said to be a **polymorphic** fungus, because of the prsence of several types of spores and the phenomenon is called the "polymorphism".

Uredospores

The mycelium of *Puccinia* is dikaryotic in the primary host, i.e., wheat. The hyphae accumulate in abundance just beneath the host epidermis. Many vertical hyphae arise from this accumulatedmycelium. The terminal cell of each vertical hypha swells and becomes rounded or elliptical. These vertical hyphae are called the sporophores. The terminal cells develop into uredospores. The uredospores always develop in groups or sori called the uredosori. On maturity of the uredospores the host epidermis ruptures due to the pressure externed by sporophores, and the uredospores liberate outside the uredosori. The uredospores are displayed by wind and other agencies.

Each uredospores of *Puccinia graminis tritici* is stalked, oblong or elliptical. The exosporium of the spore is echinulate, thick and brown. The four equidistant germpores are arranged on the equator of it. The endosporium is thin and smooth. Each uredospore is dikaryotic (xx).



Black or stem rust of wheat *(Puccinia gramins tritici).* A, germination of uredospore on host surface; formation of appressorium and vesicle; C, development of mycelium.

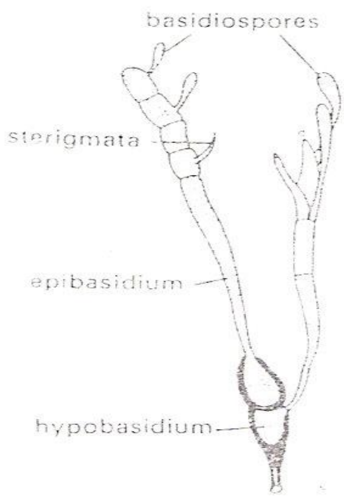
The uredospores of ***Puccinia striiformis*** causing yellow rust of wheat are stalked, yellow, rounded or somewhat oval. The exospore of the spore is hyaline, thick and echinulate. Six to ten germ spores are found scattered on the exospore. The endospore in thin and smooth. As usual the spore is dikaryotic (xx).

The uredospores of ***Puccinia recondita*** causing brown or leaf rust of wheat are stalked, brown and approximately rounded in structure. The exospore is thick, echinuclate and brown. About six germpores are scattered over it. The spore is dikaryotic (xx).

On getting suitable conditions of moisture and temperature for germination, they germinate producing germ tubes. the uredospore germinates on the epidermis of the host. More than one germ tubes come out of the germpores from a single spore. On approaching the stomata there germ tubes from appressoria. From the centre of the appressorium a peg-like strcuture develops and enters the stoma. The terminal portion of this peg swells into a vesicle. Many branched hyphae arise from this vesicle and ramify in the intercellular spaces of the host tissue, giving rise to normal knob-like or branched haustoria for the absorption of the nutrition from the host cells. The uredial stage is several times repeated prior to the development of teliospores (tclial stage) in the same season.

Teletospores

After the formation of the uredospores for sufficiently a long period on the dikaryotic mycelium, the teleutospores develop in the same sori. These spores are called the **teleutospores,** the stage, **telial stage** and the sori in which the spores develop, the **teleutosori or teliosori.** In the transitional stages both the uredospores and teliospores are found in the same sori. But later on the telia develop independently having only teleutospores in them. The telia are dark brown or black coloured.



Puccinia germinis; a, germinating telispore.

The telia of black rust ***(P.graminis tritici)*** are exposed, irregular, elongated, dark brown or balck. The crust-like pustules develop on the stems. On maturation, the teleutosori rupture and brown coloured teleutospores are released. Each teletospore is stalked, dark brown and double celled. The exospore is thick and dark brown in colour. The apex of the teleutospore is either rounded or pointed. there is one germpore at possesses alateral germpore. In each cell of mature teleutospore, there is a conspicuous diploid nucleus (2x).

In ***Puccinia striiformis*** (yellow rust) the telia are sub-epidermal. They are somewhat elongated and arranged in parallel rows like uredia. The telium is divided into several chambers by the paraphyses attached to the base of it. As usual each teleutospore is stalked, elongated, brown and bicelled. The apex of the spore is either flat or oblique. The wall of the apex is thinner than the wall of the apex of the spore of ***P.graminis tritici.*** There are two usual germpores, one apical and the other lateral. Each cell of the spore contains a diploid (2x) nuclear in it.

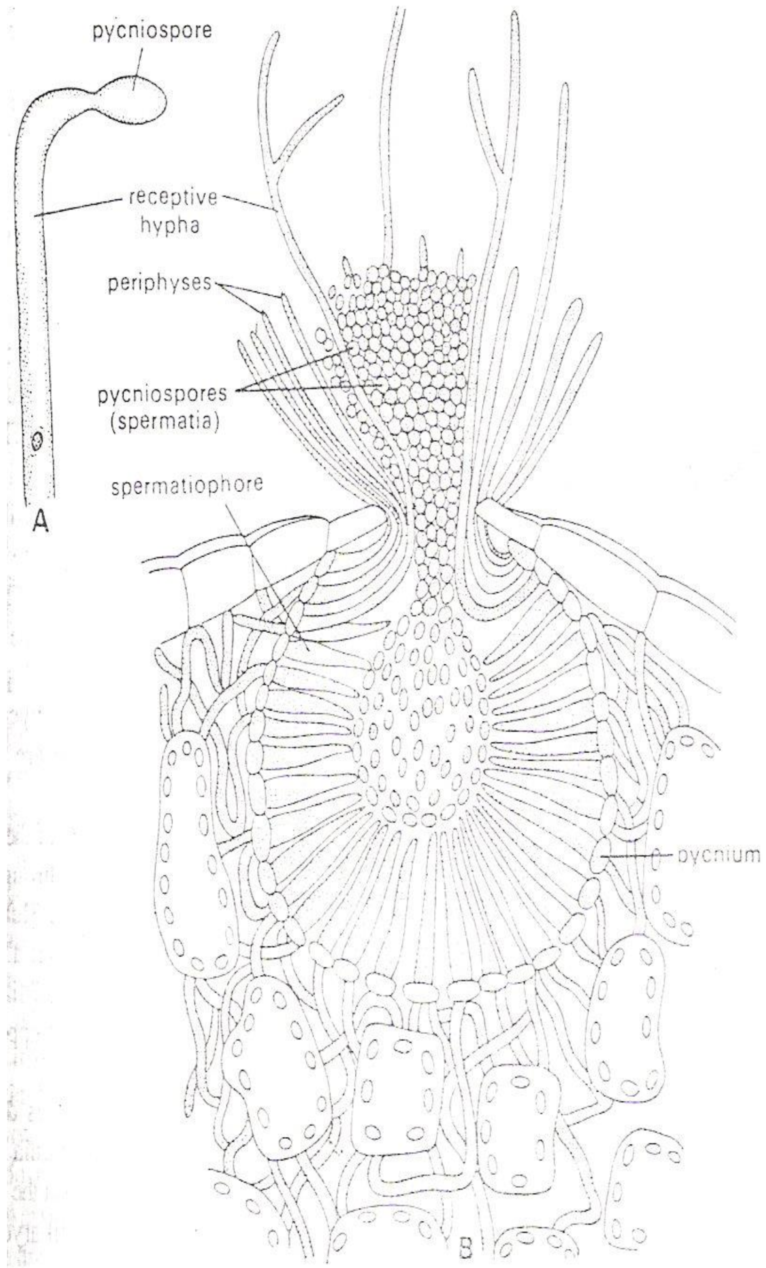
The teleutospore of ***P.recondia*** is stalked, oblong or cunciform, bicelled, brown and somewhat flat or rounded at its apical end.

The fully matured teleutospores are thick-walles and dark brown in colour. The two nuclei of a dikaryon of each cell, fuse, and in each cell a diploid nucleus develops. Each cell of the mature teleutospore contains a diploid nucleus. After the formation of the teleutospores they need a dormancy period to their germination. This is the resting period.

After the harvest, the teleutospores scattered in the soil undergo a period of rest. Prior to germination of the teleutospore the freezing temperature for a long period is essentially an important factor. The teleutospores germinate producing promycelia or basidia on which basidiospores are developed.

On the approach of the favourable conditions, the dormant protoplasm of the resting teleutospores becomes activated and the tubular promycelia or basidia came out of the germpores of each cell of the teliospore. The diploid nucleus is transferred in the basidum where it divides twice giving rise to four haploid nuclei. The first division is reductional. Each basidium becomes segmented forming four uninucleate cells. A sterigna comes out from each of the cells. In the lower three cells, the sterigmata arise just beneath the septa, and in the upper cell at the apex. On the terminal end of the sterigma a small, rounded sporidium or basidiospore develops. A single basidiospore develops on each sterigma and four basidiospores are produced on the basidium, 2 of + strain and two of – strain. The promycelial cells become depleted after the formation of basidiospores. Usually the oppisite strained nuclei of the basidium are arranged alternately in the segments. *Puccinia* is a heterothallic fungus.

After detaching from the sterigmata of the basidium, the basidiospores are carried over to the alternate host, where they germinate, producing monokaryotic mycelia. The + strained spores give rise to + mycelia and the – to – mycelia. The alternate host of *Puccinia graminis tritici* causing black rust of wheat is *Berberris* sp., and of *Puccinia recondia* causing brown rust of wheat is *Thalictrum* sp. The alternate host of *P.striformis* causing yellow rust is still unknown. Sometimes when suitable alternate host is not available, these spores give rise to secondary basidiospores which also germinate in the smae way. A germ tube comes out from the basidiospore, swells at its terminal end, the nucleus along with cytoplasm transfers to this swelling and the secondary basidiospore develops.



Puccinia graminis. A, pycniospore attached to respective hypha; B, V.S. of *Berberris* leaf through pycnium.

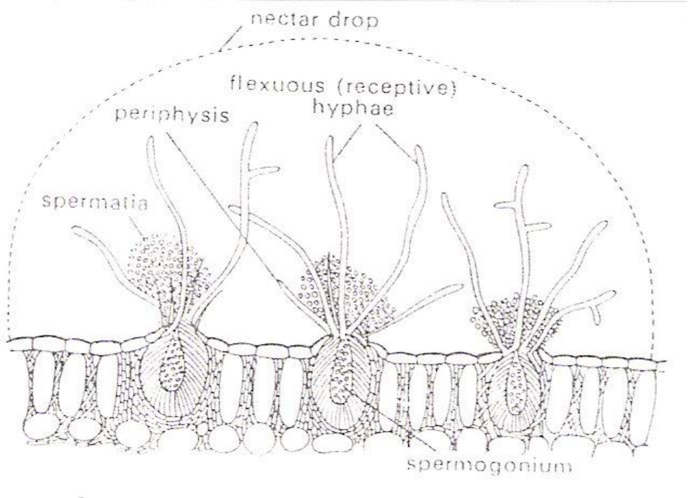
Germination of basidiospore

After reaching the host surface, the basidiospores germinate producing germ tubes. The germ tube directly penetrates the epidermis, enters the host tissue, develops into monokaryotic mycelium which ramifies in the intercellular spaces of the alternate host. The mycelium is sepate, branched and with haustoria for the absorption of food. Usually the opposite stained (+ and -) basidiospores germinate on the surface of the same host leaf and produce monokaryotic mycelia of both strains very close to each other.

The basidiospores are destroyed in the absence of suitable alternate host. About four days later after the germination of the basidiospore the pycniospores are produced on the monokaryotic mycelium.

Pycnispores, pycnidiospores or spermatia

The monokaryotic mycelium accumulates beneath the epidermis of the alternate host and develops into a flask-like structure called **pycnium.** A hymenial layer of vertical hyphae develops at the base of the pycnium. Each vertical hypha of this hymenium is called the pyconiosporohore. From the terminal ends of the pycniosporophores, round, oval, haploid and uninucleate pycniospores develop in basigenous chains. the pycinispores detach from the pycniospotophores and accumulate in the middle of the pycnium. The pycina open outside the host epidermis by small opeinings called the ostioles. Some of the sterile hyphae called the paraphyses are found in the neck region of the pycnium. Some vertical fertile hyphae called the flexuous hyphae also come out through the ostiole. They are of the same strain as that of the mycelium on which they are developed. Only one strained (+ or -) pycniospores and flexuous hyphae are produced in one pycnium.



Puccinia graminis. Pycnia relation to nuctar drop on the upper surface of barberry leaf.

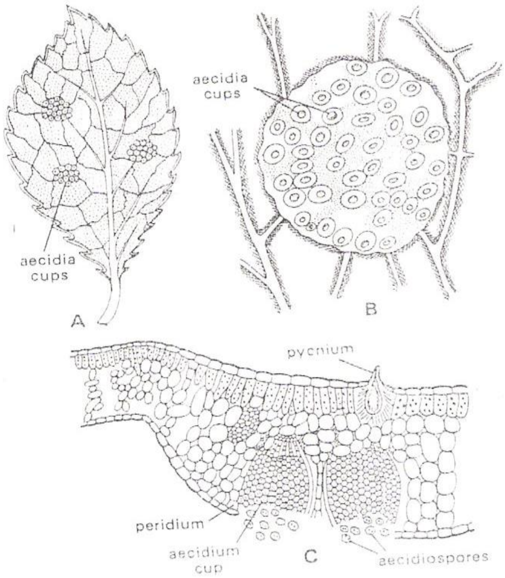
On the maturity of the pycnium, the nectar oozes out through ostiole in the form of drops. Hundreds of pycniospores come out along with the nectar. The pin head-like yellow pycnia are found on the upper surface of the infected leaf.

The pycniospores developed in the flask-like pycnia and the flexuous hyphae convert the monokaryotic phase of the mycelium of the fungus into dikaryotic phase by the process of diakryoutization. On this dikaryotic mycelium, the aeciospores are produced.

Dikaryotization or diploidization

The insects visit the mature pycnia in the search of nectar oozing out through the ostioles. the pycniospores found around the ositoles stick to their legs and proboscia and are transferred from one pycnium (+) to another (-). When the opposite strained pycniospores and the flexuous hyphae come in contact, the wall of contact dissolves and the nucles of pycniospore moves downward in the flexuous hypha through septal pores.

Simultaneouly, just beneath the pycnium, on the lower surface of the same leaf, the monokaryotic mycelium accumulates in the substomatal chamber and intercellular space. the aecidia are produced from this mycelium, after dikaryotization, and thus called the aecidial primordia or protaecia. The nuclei of the pycniospores, after passing through the pores reach in the cells of the protaecia and dikaryotize all of them.



Puccinia graminis. A, aecial cups on lower surface of barberry leaf; B, aecial cups; C, V.S. of barberry leaf through pycnium and aecial cups.

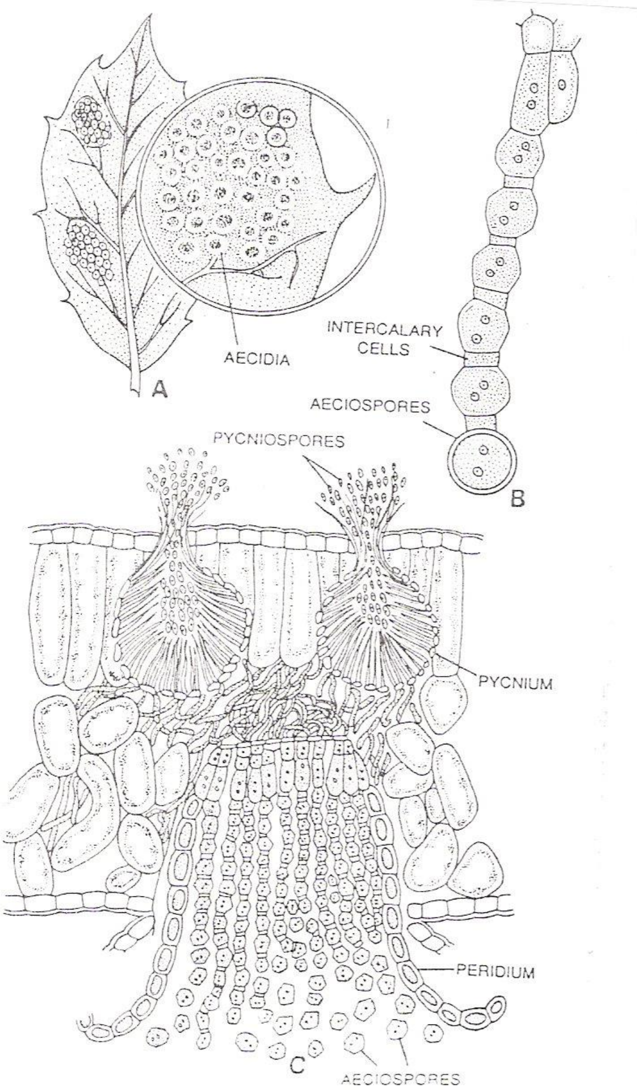
Besides this phenomenon, sometimes the pycniospore fuse with the sterile paraphyses. Sometimes, the opposite strained monokaryotic hyphae found in the intercellular spaces fuse with each other and the dikaryotization takes place. the nuclei of the cells of one hypha are transferred into the adjacent cells of opposite strained another hypha. The great mycologist, A.H.R. Buller observed in *Puccinia helianthi*, that the dikaryotization takes place by the fusion of monokaryotic hypha with the dikaryotic one. The walls of contact dissolve, and the nuslei lacking in the monokaryotic hypha are being transferred from the adjacent cells of the dikaryotic hypha, and dikaryotization takes place. this special process of dikaryotization is known as **Buller phenomenon.**

Aeciospores or aecidiospores

Just after dikaryotization the hyphae of protaecia form a stromatic layer. the cells of the stroma become dikaryotic. they are surrounded by the monokaryotic hyphae and a pseudoparenchymatous strcuture is developed. The based cells of this pseudosparenchymatous structure are somewhat longer than the lower cells. All the cells are monokaryotic.

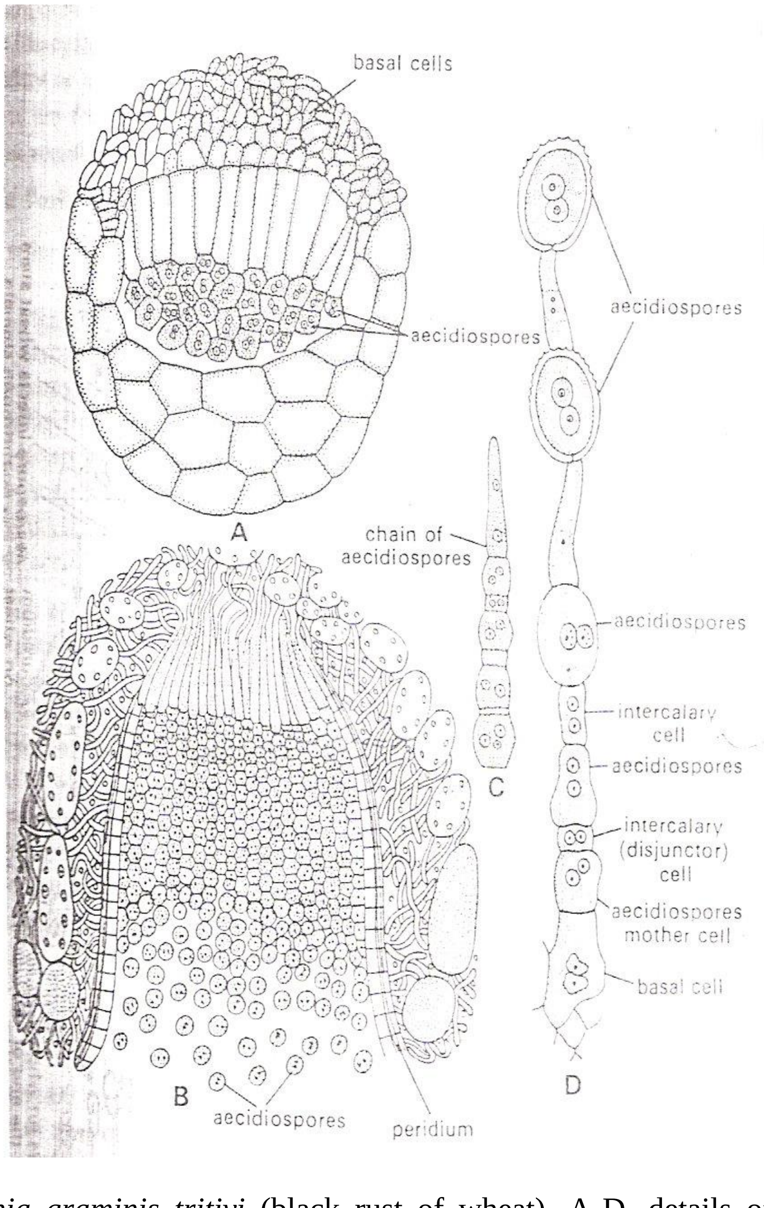
The dikaryotic cells surrounded by pseudoparenchyma develop verically elongated downwards in a thick stromatic layer, called the

hymenium. the hymenium consists of aeciospore mother cell. the aeciospores develop first the cells of the central regions and afterwards from peripheral region of the hymenium. From the outermost mother cells of the hymenial periphery several cells are developed. The lateral walls of these cells fuse to each other and the peridium in developed. The cells of the peridium divide continuously in the transverse plane, increasing the height of the peridium. The aeciospore cells elongate and divide at their apical ends giving rise to a layer of the cells at their apices. The terminal cella separtes from the aeciospore mother cell by septum and two cells develop one larger in size and the other smaller. The terminal large cell develops into the aeciospore whereas the smaller cell acts as intercalary or disjunctor cell. The intercalary cells are sterile. The nucleus of aeciospore mother cell divides again and again giving rise to the basigenous chain of aeciospores and intercalary cells. On the maturation of the aeciospores, the intercalary or disjunctor cells degenerate and the aeciospores become free.



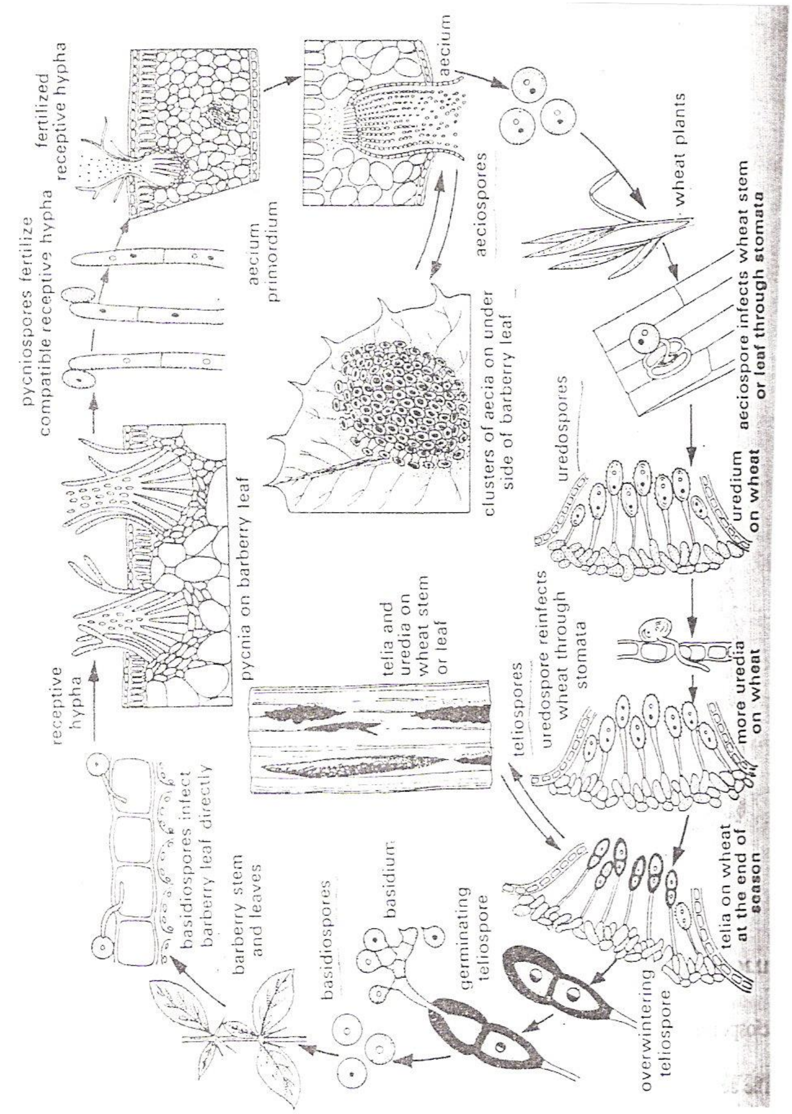
Puccinia graminis tritici on *Berberries.* Black rust of wheat. A, infected leaf of *Berberris* showing aecidia; B, a chain of aeciospores; C, V.S. of infected *Berberries* leaf through pycnia and aecidium.

The aeciospores develop first in the centre and thereafter in the peripheral region, and, therefore, the hymenial layer is thicker in the central region than the periphery and a domeshaped structure covered by peridium is formed. Very soon the peridium ruptrues, due to the pressure exerted by the aeciospores and the whole structure called aecidium looks like a bell. The aeciospores are dispersed by wind, insects, water and other suitable agencies.



Puccinia graminis tritivi (black rust of wheat). A-D, details of aecial stage found in barberry leaf.

Each aeciospores is rounded, unicellular, dikaryotic (xx) and double walled. The exospore is smooth or sometime echinulate. One or more germ pores are found on it. They are orange coloured and become polygonal because of mutual pressure.



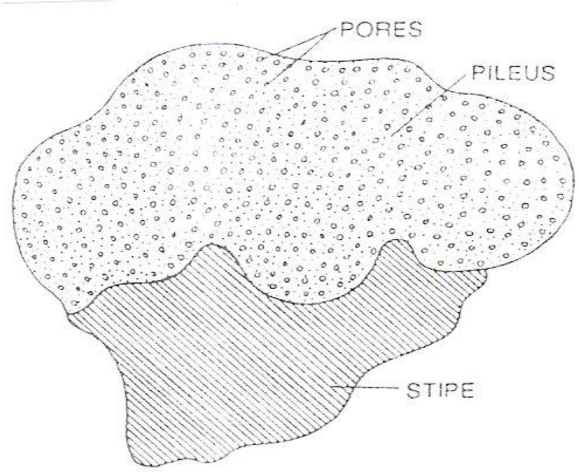
Diease-cycle of black or stem rust of wheat caused by *Puccinia graminis tritici.*

The aeciospores do not infect the host on which they are produced. They infect the primary host. In the case of ***Puccinia graminis tritici*** aeciospores produced on ***Berberris*** sp., infect the wheat plants and not ***Berberris*** in any case. The aeciosportes germinate producing producing a germ tube which comes out through the germ pore and enters the stoma of host leaf where it develops, into new mycelium. The mycelium ramifies in the intercellular spaces of the host tissue. It is dikaryotic and branched. This is secondary mycelium, this dikaryotic mycelium produces uredospores and teleutospores in usual way.

The life-cycle of ***Puccinia graminis tritici*** completes on two different hosts called primary and secondary or alternate hosts and therefore, this is a heteroesious fungus. the uredial and telial stages are found on the primary host, the basidiospores are found in the soil, and the pycnial and aecidial stages are found upon the alternate host.

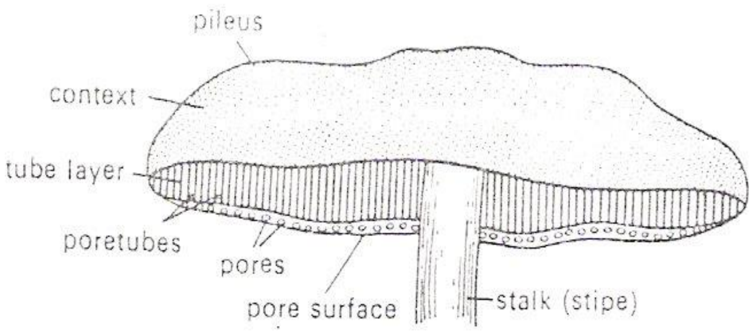
POLYPORUS (250 species)

The germs include a large number of species of pore fungi. All species may cause decay of timber, some of being especially destructive to beans, floor and lumber piled in yards. They possess shelving or stalked frucifications.



Polyporus. Fruit body (basidiocarp).

The fruit bodies are fleshy when young but become hardened, leathery or corky at maturity. The pore layer is usually quite different in texture and colour from remainder of the pileus.



Polyporus sp. Basidiocarp with pileus and stipe.

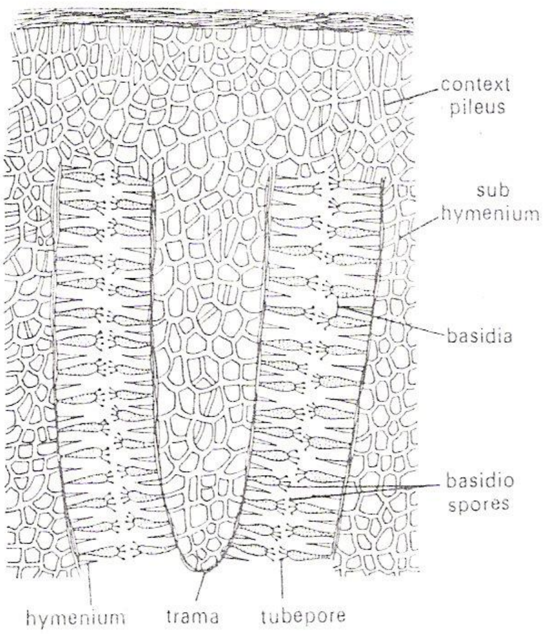
The most common members of this genusare ***Polyporus versicolor*** and ***Polyporus paragamenus***. They cause decay of many species of deciduous woody plants. ***Polyporus sulphureus*** occurs at the base of deciduous trees, especially okas. It produces large, fused imbricated shelves that are conspicuous because of their bright sulphur-yellow to orange colour. ***Polyporus cinnabarinus*** produces bright, cinnabar-coloured brackets, especially on decaying oak branches. ***Polyporus sapurema*** from Brazil and ***Polyporus mylittiae*** from Australia produce giant sclerotia.

Somatic structure (mycelium)

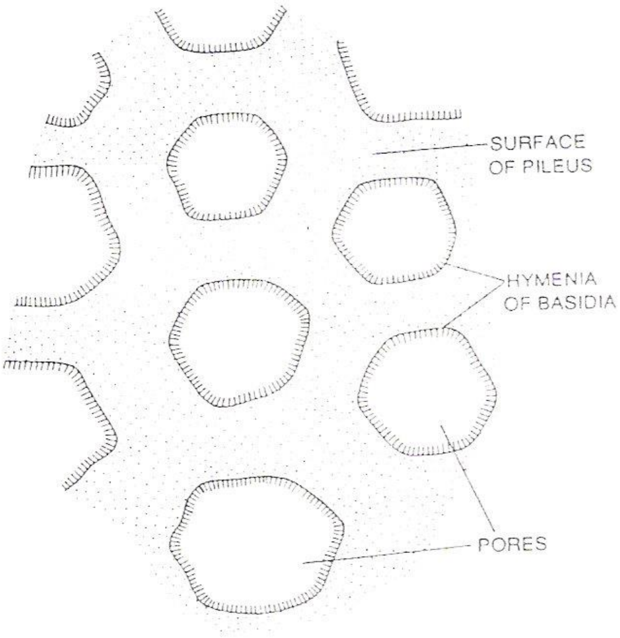
On germination the basidiospores give rise to primary mycelium. In the beginning the myceliumdevelops in the soil near the host roots. Very soon it atacks the roots and develops benath the bark. the mycelium is inconspicuous and subterrancean. The primary mycelium cosists of uninucleate cells. Eventually the cells become dikaryotic by the process of dikaryotization. The newly formed dikaryotic cells elongate and divide by the formation of clamp connections. the secondary mycelium is dikaryotic. On the severity of the parasitism the mycelium forms a complete, thick layer of hyphae around the central woody cylinder.

Fruit body (basidiocarp)

The basidiocarp develops from the secondary (dikaryotic) mycelium. in the beginning it appears to be a rounded button – like structure of hyphae. It develops from the subterranean mycelium. The knot of hyphae grows in size and bursts through the bark. Later on it differentiates into a short stalk also known as **stipe** and a rounded cap-like structure, the **pileus.** On maturation the soft basidiocarp becomes woody, corky or leathery.

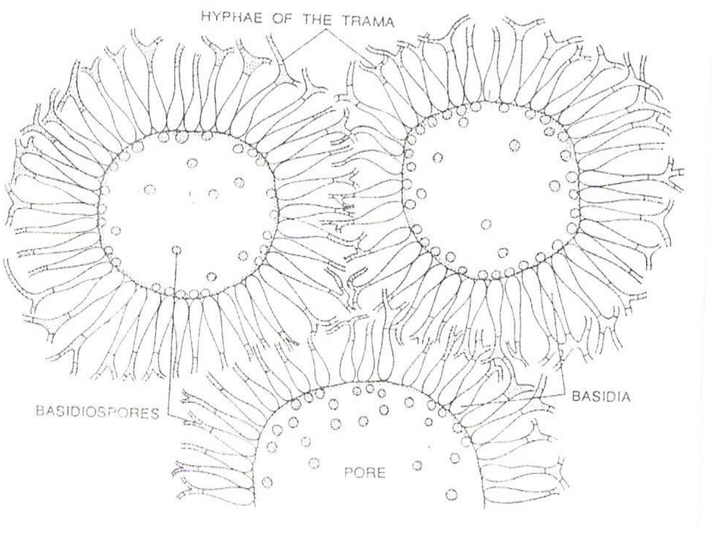


Polyporus sp. V.S. through a part of pileus.



Polyporus. surface of pileus showing pores and hymenia of basidia

The stipe of basidiocarp is 2-6 inches long and brown or dark brown in colour. It consists of immumerable hyphae arranged together in a compact mass. The stipe bears at its apex an expanded structure, the pileus. It is usually brown coloured. The upper surface of pileus is flat and smooth or slightly undulating. The white or brown concentric rings are found in the peripheral region of the pileus. The lower surface of the pileus is smooth and flat. The lower surface does not bear any rediating gills.



Poliporus. Showing hyphae of the trams, basidia and basidiospores.

The pileus bears numerous fine pores. These pores are the openings of many small tubes. These structures give a porous appearance to the under-surface of the pileus. Each pore leads inwards into a hollow tube. The inner surface of this hollow tube is lined by a fertile hymenial layer. this hymenium consists of sterile cells, the **crystidia** and the fertile clavate cells, the **basidia.** The basidia produce basidiospores. They remain projected into the hollow of the tube. The bsidia are somewhat larger in size than that of cystidia. Each basidium bears four basidiospores each on the terminal sterigma.

Basidiospores

The basidiospores are small, oval and whitish or brownish in colour. Millions of basidiospores are produced on a single pileus of fruit body (basidiocarp). They are released through the pores. On the approach of suitable moisture and temperature, the basidiospore germination producing primary haplont mycelium which later on becomes dikaryotic after fusion of hyphae.

NOTES

UNIT - III
BACTERIA

Introduction

Bacteria are microscopic unicellular, prokaryotic microorganisms. The study of bacteria is called ***Bacteriology***. ***Ehrenberg*** (1829) established the genus ***Bacterium***. Bacteria are present everywhere, in the water, in the soil, in the air, on our body and in our body.

Important features of Bacteria

1. They exist everywhere.
2. They are ***unicellular.*** Some exist as colonies.
3. They are prokaryotic.
4. They range in size from 0.4micrometer to 3.0 micrometer.
5. They are in the form of rods, spheres, spirals or filaments.
6. The cell is enclosed in a ***cell envelope*** made up of a ***capsule,*** a cell wall and a ***plasmamembrane.***
7. Nuclear material is represented by a ***nucleoid*** without nuclear membrane.
8. An extra chromosomal DNA called ***Plasmid*** is usually present in the cytoplasm.
9. Cell organelles include ***70 S ribosomes*** and ***mesosomes***. Other organelles such as mitochondria, lysosomes, Golgi complex, endoplasmic reticulum,etc. are absent.
10. They show absorptive mode of nutrition.

Classification

Many systems of classification of bacteria have been brought forward, but more has remained long without revision and enlargement. In 1773, O.F. Muller made the first attempt to classify bacteria and generic name 'Vibrio' was introduced under 'infusoria'. In the period between 1828 and 1838, the German Zoologist, C.G. Ehrenberg added two more generic names, 'Spirillum' and 'Bacterium'. Later more number of bacteria were described and named by Pasteur, Koch and Lister. One of the first scheme for bacterial classification was devised by Cohn in 1872 based almost wholly on morphology. In 1879 Migula devised a scheme based not only on form but on colour and some physiological characteristics such as nitrogen fixation. During the same period (1896), Lehmann and Newmann started their Atlas for Diagnostic Bacteriology.

D.F. Chester, in 1899 and 1901 published the manual of Determinative Bacteriology. Orla-Jensen, in 1909, made up a system based largely on physiological properties. Thus served as a model for all later schemes.

David Bergey was later on entrusted with the work of revising Chester's Manual of Determinative Bacteriology by the Society of American Bacteriologists. Bergey then took up the job and re-revised so as to bring out eight editions of Bergey's Manual of Determinative Bacteriology by 1957.

The 'Bergey's ***Manual of Systematic Bacteriology*'** has four volumes, that contain the internationally recognized names and descriptions of bacterial species. The details of the informations in the above volumes are summarized below.

Vol. I: (Sections 1-11) 1984: Gram- negative bacteria

Vol. II: (Sections 12-17) 1986: Gram- positive bacteria, phototrophic and other specialized bacteria including gliding bacteria.

Vol. III: (Sections 18-25) 1989: Archaeobacteria

Vol. IV: (Sections 26-33) 1991: Actinomycetes and other filamentous bacteria.

Kingdom Prokaryotae

(Prokaryotic organism with primordial nucleus)

Division I. Gracilicutes

(Prokaryotes with thinner cell walls, with a Gram-negative type of cell wall)

Division II. Fimicutes

(Prokaryotes with thick and strong skin, indicating a Gram-positive type of cell wall)

Division III. Tenericutes

(Prokaryotes of liable soft nature, indicative of lack of rigid cell wall)

Division IV. Mendosicutes

(Prokaryotes having faulty cell walls, suggesting the lack of conventional peptidoglycan)

Section 1. The Spirochetes

Order I. Spirochaetales

Family I. Spirochaetaceae e.g. *Spirochaeta*

Family II. Leptospiraceae e.g. *Leptospira*

Section 2. Aerobic/Microaerophilic, Motile, Helical/Vibroid Gram-negative bacteria.

Section 3. Nonmotile (or rarely motile), Gram-negative bacteria.

Family I. Spirosomaceae e.g. *Spirosoma*

Section 4. Gram-negative Aerobic Rods and Cocci

Family I. Pseudomonadaceae e.g. *Pseuomonas*

Family II. Azotobacteriaceae e.g. *Azotobacter*

Family III. Rhizobiaceae e.g. *Rhizobium*

Family IV. Methylococcaceae e.g. *Methylococcus*

Family V. Halobacteriaceae e.g. *Halobacterium*

Family VI. Acetobacteriaceae e.g. *Acetobacter*

Family VII. Legionellaceae e.g. *Legionella*

Family VIII. Neisseriaceae e.g. *Neisseria*

Section 5. Facultative Anaerobic Gram-negative Rods

Family I. Enterobacteriaceae e.g. *Escherichia*

Family II Vibrionaceae e.g. *Vibrio*

Family III Pasteuellaceae e.g. *Actinobacillus*

Section 6. Anaerobic Gram-negative straight, curved and Helical Rods

Family I Bacteriodaceae e.g. *Bacteroides*

Section 7. Sulphur- reducing bacteria

Section 8. Anaerobic Gram-negative Cocci

Family I. Veillonellaceae e.g. *Veillonella*

Section 9. The Rickettsias and Chlamydias

Order I. Rickettsiales

Family I. Rickettisiaceae e.g. *Rickettsia*

Family II. Bartonellaceae e.g. *Bartonella*

Family III. Anaplasmataceae e.g. *Anaplasma*

Order II. Chlamydiales

Family I. Chlamydiaceae e.g. *Chlamydia*

Section 10. The Mycoplasmas

Division Tenericutes

Class I. Mollicutes

Order I. Mycoplasmatales

Family I. Mycoplasmataceae e.g. *Mycoplasma*

Family II. Acholeplasmataceae e.g. *Acholeplasma*

Family III. Spiroplasmataceae e.g. *Spiroplasma*

Section 11. Endosymbionts

A. Endosymbionts of protozoa, ciliates, flagellates, amoebae

B. Endosymbionts of Insects

C. Endosymbionts of fungi and invertebrates other than Arthropods

Section 12. Gram-positive cocci

Family I. Micrococcaceae e.g. *Micrococcus*

Family II. Deinococcaceae e.g. *Deinococcus*

Section 13. Endospore forming Gram-positive rods and cocci

e.g. *Bacillus*

Section 14. Regular, nonsporing, Gram-positive rods

e.g. *Lactobacillus*

Section 15. Irregular, nonsporing, Gram-positive

e.g. *Corynebacterium*

Section 16. The mycobacteria

Family: Mycobacteriaceae e.g. *Mycobacterium*

Section 17. Nocardioforms

e.g. *Nocardia*

Section 18. An oxygenic, phototrophic bacteria

I. Purple bacteria

Family I. Chromatiaceae e.g. *Chromatium*

Family II. Ectothiorhodospiraceae e.g. *Ectothiorhodospira*

Purple non-Sulphur bacteria

e.g. *Rhodospirillum*

II.Green bacteria

e.g. *Chlorobium*

Multicellular, filamentous, green bacteria

e.g. *Chloroflexus*

III.General Incertae Sedias

e.g. *Heliobacterium*

Section 19. Oxygenic Photosynthetic Bacteria

Group I:	Cyanobacteria
Subsection I	Order: Chroococcales
Subsection II	Order: Pleurocapsales
Subsection III	Order: Oscillatoriales
Subsection IV	Order: Nostocales
Subsection V	Order: Stigonematales
Group II:	Order: Prochlorales
Family	Prochloraceae e.g. *Prochloron*

Section 20. Aerobic Chemolithotrophic Bacteria and associated organisms

A. Nitrifying Bacteria

Family Nitrobacteriaceae e.g. *Nitrobacter*

B. Colourless Sulphur Bacteria

e.g. *Thiobacterium*

C. Obligate Chemolithotrophic Hydrogen Bacteria

e.g. *Hydrogenobacter*

D. Iron and Manganese-Oxidising Bacteria

e.g. *Siderocapsa*

E. Magnetotactic Bacteria

e.g. *Aquaspirillum*

Section 21. Budding and/or Appendaged Bacteria

I. Prosthecate Bacteria

A. Budding bacteria

e.g. *Hyphomonas*

B. Bacteria that divide by binary transverse fission

e.g. *Caulobacter*

II. Non-Prosthecate bacteria

A. Budding bacteria

e.g. *Planctomyces*

B. Non-budding stalked bacteria

e.g. *Gallionella*

C. Other bacteria

1.Nonspinate bacteria

e.g. *Seliberia*

Section 22. Sheathed Bacteria

e.g.*Leptothrix*

Section 23. Non photosynthetic, Non fruiting Gliding Bacteria

Order I. Cytophagales

Family I. Cytophagaceae

e.g. *Cytophaga*

Order II. Lysobacteriales

Family I. Lysobacteriaceae e.g. *Lysobacter*

Order III. Beggiatoales

Family II. Beggiatoaceae e.g. *Beggiatoa*

Section 24. Fruiting Gliding Bacteria

Order Myxococcales

Family I. Myxococcaceae e.g. *Myxococcus*

Family II. Arthangiaceae e.g. *Archangium*

Family III. Cystobacteriaceae e.g. C*ystobacter*

Family IV. Polyangiaceae e.g. *Polyangium*

Section 25. Archaeobacteria

Group I. Methanogenic Archaeobacteria

Order I. Methanobacteriales

Family I. Methanobateriaceae e.g. *Methanobacterium*

Family II. Methanothermaceae e.g. *Methanothermus*

Order II. Methanococcales

Family Methanococcaceae e.g. *Methanococcus*

Order III. Methanomicrobiales

Family I. Methanomicrobiaceae e.g. *Methanomicrobium*

Family II. Methanosarcinaceae e.g. *Methanosarcina*

Group II Archaebacterial Sulphate Reducers

Order Archaeoglobales

Family Archaeoglobaceae e.g. *Archaeoglobus*

Group III. Extremely Halophilic Archaeobacteria

Order Halobacteriales

Family Halobacteriaceae e.g. Halobacterium

Group IV. Cell wall less Archaeobacteria

e.g. *Thermoplasma*

Group V. Extremely Thermophilic Sulphate metabolizers

Order I. Thermococcales

Family Thermococcaceae e.g. *Thermococcus*

Order II. Thermoproteales

Family I. Thermoproteaceae e.g. *Thermoproteus*

Family II. Desulfurococcaceae e.g. *Desulfurococcus*

Order III. Sulfolobales

Family Sulfolobaceae e.g. *Sulfolobus*

Section 26. Nocardioform Actinomycetes

e.g. *Nocardia*

Section 27. Actinomycetes with multilocular Sporangia

e.g. *Frankia*

Section 28. Actinoplanetes

e.g. *Actinoplanes*

Section 29. Streptomycetes and related genera

e.g. *Streptomyces*

Section 30. Maduromycetes

e.g. *Actinomadura*

Section 31. Thermomonospora and related Genera

e.g. *Thermomonospora*

Section 32. Thermoactinomycetes

e.g. *Thermoactinomycetes*

Section 33. Other Genera

e.g. *Pasteuria* etc.

Morphology of Bacteria

The bacterial cell represents a typical prokaryotic cell. The size, shape and arrangement of the cells comes under ***morphology*.** The size, shape and arrangement of bacterial cells vary with species to which they belong.

Size

Bacteria owing to their minute size, approximately 0.4 - 3.0 um in diameter, are barely visible even under the light microscope. The smallest bacteria may be 0.1 um in diameter while the large cyanobacteria may have cell 60 um in length.

Shape and Arrangement

Bacteria have definite shapes conferred on them by the rigid cell walls. The shapes may be spherical, rod-like or spiral. The spherical shape bacteria are called ***cocci*** (singular. ***coccus***). The cells may occur in pairs (***diplococci***), in chains (***streptococci***), in groups of four (***tetracocci***), in regular groups (***staphylococci***) or in cubical arrangement of eight or more (***sarcinae***).

The rod like bacteria are called ***bacilli*** (singular. ***bacillus***). The rods may occur in pairs by joining at the ends (***diplobacilli***) or linear chains (***streptobacilli***). Rods that are curved in shape are called ***vibrios*** or ***commas***. A helically curved rod or a spiral bacterium is called ***spirillum*** (plural. ***spirilla***) (Fig.1).

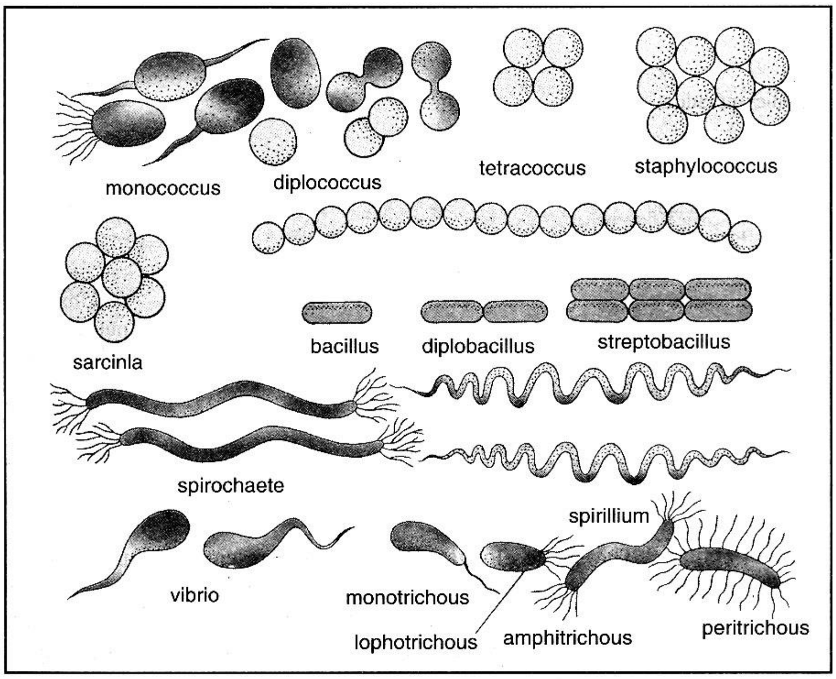


Fig. 1

Different forms of Bacteria

Spirilla are rigid helical bacteria, not to be confused with spirochaetes which are highly flexible. There are some bacteria which can exhibit a variety of shapes and their cells are called ***Pleomorphic***. e.g. ***Rhizobium***. In ***Streptomyces,*** filamentous hyphae are formed due to the linear arrangement of cells, and hence it is placed in a separate section called Actinomycetes.

Structure of Bacterial Cell

The typical bacteria posses a rigid cell wall. Outer to the cell wall are the capsules, flagella, fimbriae and pili, and inside the cell wall occurs the plasma membrane enclosing the bacterial protoplast with its various contents typical of a prokaryotic cell (Fig.2).

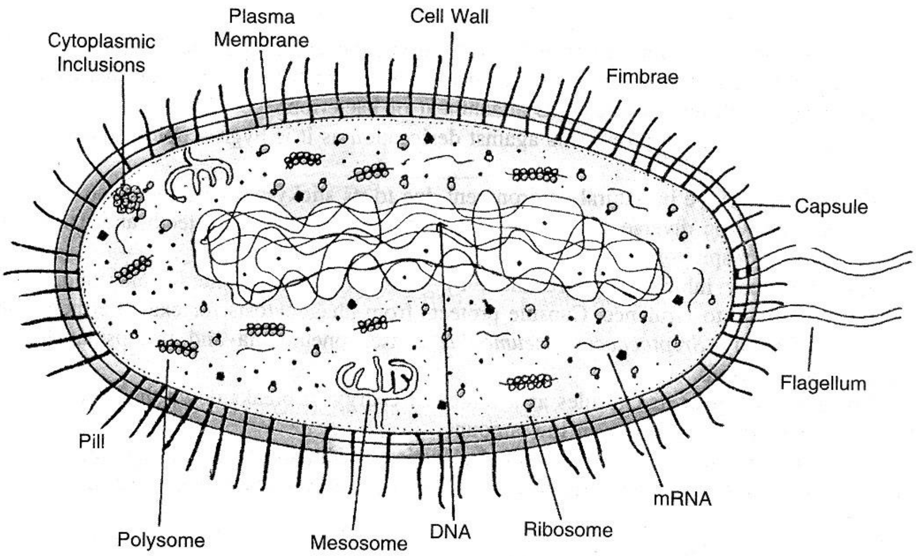


Fig. 2

Structure of a typical bacterial cell

Cell wall

The cell walls of bacteria are generally referred to as outer membranes and the plasma membrane being considered as inner membranes. The cell wall is the dense layer lying above the plasma membrane. It gives shape and rigidity to the cell. The cell wall is formed of strong fibers composed of ***peptidoglycans*** (also called ***murein*** or ***mucopeptide***). Peptidoglycans are glycopeptides. The peptidoglycan consists of alternating units of ***N-acetyl glucosamine*** and ***N-acetyl muramic acid*** (Fig.3).

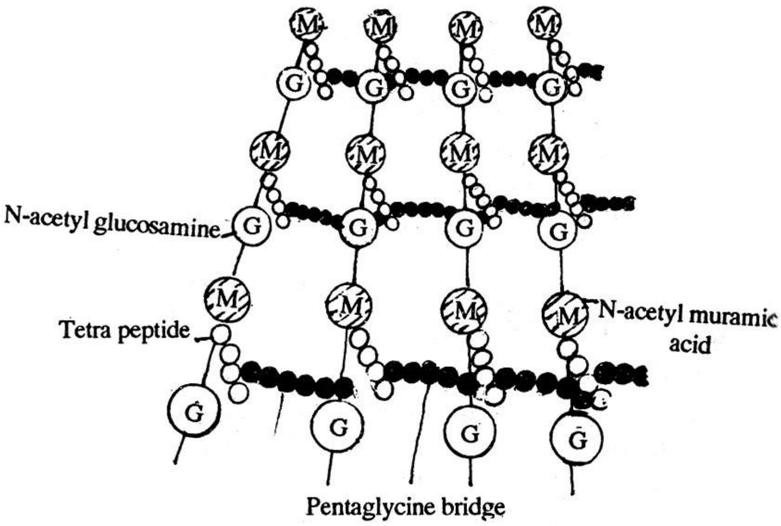


Fig. 3

Structure of glycopeptide of the cell wall of bacteria

The two units are linked by B 1,4 linkages. A tetrapeptide or tripeptide is attached to the N-acetyl muramic acid. There are two types of bacteria. They are ***Gram positive*** and ***Gram negative*** bacteria. Gram positive bacteria retain ***violet*** colour on Gram's staining. Gram negative bacteria appear in ***red*** colour. The Gram positive bacteria have a greater amount of peptidoglycan in their cell walls than the gram negative bacteria. The walls of Gram negative bacteria have an additional outer membrane that surrounds the peptidoglycon layer. The outer membrane is present beneath the capsule. It is an ***unit membrane***. It is a three layered membrane. It is composed of two outer layers of ***phospholipids*** and a middle layer of ***protein***. It serves as a protective barrier against external chemicals and enzymes that could damage the cell. The outer membrane acts as an endotoxin. It bears ***O antigen***. It has small channels of special protein called ***porins.*** The porins serve as pores for the entry of small molecules of nutrients into the bacterial cell. Porins also facilitate signal transduction.

Structures outer to the Cell Wall

Capsule

Some bacterial species have their cells surrounded by a viscous of gelatinous substance outer to the cell wall. This layer can be visualized by microscopy with specific staining technique, and is called ***capsule*** (Fig.4).

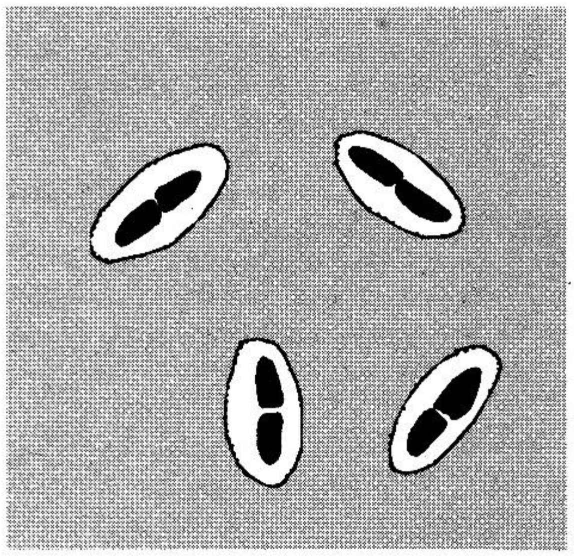


Fig. 4

The Capsule of *Streptococcus pneumoniae*

In some cases this layer is too thin to be seen with a light microscope and is called a ***microcapsule***. If many cells are embedded in a common matrix, the material is called ***slime***. The capsules are generally composed of polysaccharides which may be of a single type (***homopolysaccharides***) or of different types (***heteropolysaccharides***).

Capsules provide protection against drying. They prevent bacteriophages from attaching to the cell wall. They help in proper attachment to surfaces.

Flagella

The ***flagella*** (singular. ***flagellum***) are hair like structures extending through the bacterial cell wall. The flagella may be ***polar*** when it is arranged at one or both ends. When the flagellum is present at one end, it is called ***monotrichous***. When it is present at both ends it is called ***amphitrichous***. If there is a tuft of flagella, it is called ***lophotrichous***. When flagella are uniformly distributed, they are called ***peritrichous*****.** (Fig.1)

Each flagellum consists of three components, namely a ***basal body***, a ***hook***, and a ***shaft.*** The basal body consists of two sets of rings connected by a rod. Each set has two rings and altogether there are four rings. They are named ***M ring*** (M = membrane), ***S ring*** (S = super membrane), ***P ring*** (P = peptidoglycan ring) and ***L ring*** (L = lipoploysaccharide) from the inner to the outside (Fig.5)

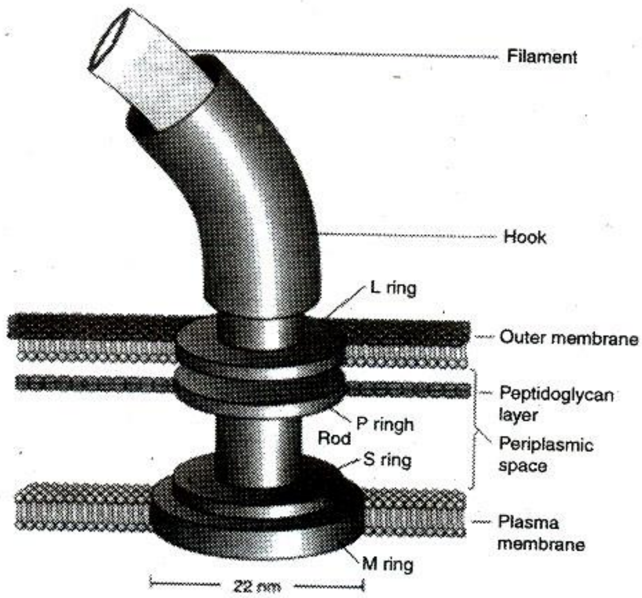


Fig. 5

The structure of a bacterial flagellum

The M ring is embedded in the plasma membrane. The S ring lies in between the plasma membrane and outer membrane. The P ring is attached to the peptidoglycan. The L ring is attached to the lipopolysaccharide of the outer membrane**.** The hook connects the basal body with the shaft. The flagellum is made up of protein subunits called ***flagellin***. They are helically arranged. The flagella are used for locomotion.

Pili and Fimbriae

Pili and fimbriae are hair like appendages found on surface of the bacterial cell wall. The term fimbriae is used for all hair like structure covering the surface of the cell. The number of fimbriae is around 1000. Pili are shorter than flagella and are also much more numerous. They are straight and not hooked. They are found in Gram negative bacteria. Pili arise from the cytoplasm. They are made up of protein sub units called ***pilin*** or ***fimbrin***. The pilin sub units are arranged in a helical manner.

The cells which contain pili are called ***Fim+*** cells and the cells which do not contain pili are called ***Fim-*** cells. Pili are divided into two types, namely ***normal pili*** and ***sex pili.*** Sex pili are hair like structures present on the surface of some bacteria. They are longer than normal pili. They have an axial hole and a knob at the terminal end. They are determined by plasmids.

Internal structure of Bacterial Cell

Plasma membrane

Plasma membrane lies beneath the cell wall. It is an unit membrane. It is made up of proteins and phospholipids. They are arranged in three layers. The two outer layer are phospholipids ad the middle layer is protein. In the phospholipid layer, the heads face outwards and the tail face inwards. The proteins are embedded in between the membrane.

Plasma membrane is selectively permeable. It contains ***permeases*** functioning as transporting system. The plasma membrane in centre of energy production. It does the function of mitochondria. It is the site of electron flow in respiration and photosynthesis. Phosphorylation occurs her. Thus in bacteria plasma membrane functions as the ***energy plant***. The plasma membrane provides a specific site for the attachment of chromosome.

Cytoplasm

The cell membrane encloses the cytoplasm. It is colloidal in nature. The cytoplasm ***does not show streaming movement***. It contains ribosomes, mesosomes, volutin granules, etc. Golgi bodies, mitochondria, lysosomes, endoplasmic reticulum, etc are absent.

Ribosomes

Ribosomes are centre of protein synthesis. They are smaller the ribosomes of eukaryotes. They are called ***70 S***. The 70 S ribosome is made up of two subunits, namely a large subunit ***50 S*** and a small subunit ***30 S.***

The ribosomes are present individually or in a linear series attached to m RNA. Such linear ribosomes are called ***polyribosomes*** or ***polysomes*** (Fig.6).

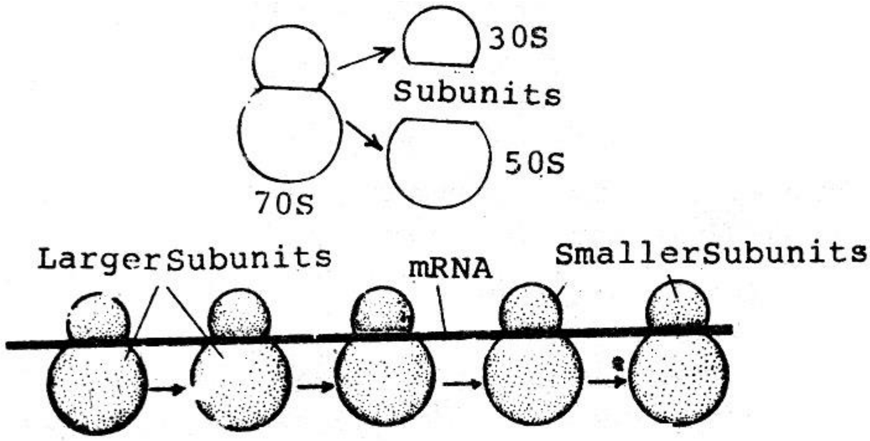


Fig. 6

Structure of 70S ribosomes and polysomes

Mesosomes

Bacteria have specialized invaginations of the cytoplasmic membrane in the form of complex infoldings which increase the surface area of the membrane. They are called ***mesosomes***. They contain vesicles and tubules.

Mesosomes are involved in septum formation during binary fission. They help in DNA replication. They involved in the export of exocellular enzymes. They form a link between the plasmamembrane and the nuclear material (Fig.7).

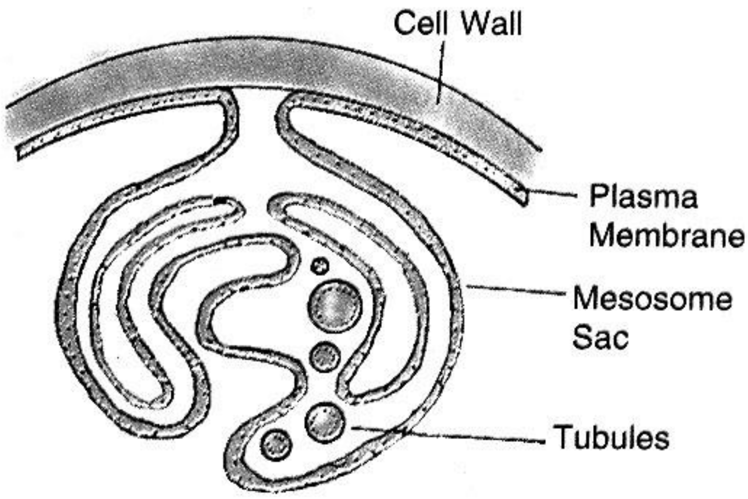


Fig. 7

The bacterial mesosome

Chromatophores

These are pigment bearing membranous structures. They are in the form of ***thylakoids.*** They are involved in photosynthesis. They are found in photosynthetic bacteria.

Nucleoid

The bacterial chromosome remains in a part of cytoplasm. This is not surrounded by a nuclear membrane. The nuclear material without a nuclear membrane is called ***nucleoid***. The bacterial chromosome is made up of a ***single double ended circular DNA***.

Plasmids

Plasmids are small, circular, self replicating, double stranded, DNA molecules present inside the bacterial cell. These plasmids are found in the cytoplasm. Plasmids are ***extrachromosomal genetic*** elements. These vary in size from a few to several hundred kilo bases in length. The chromosome and the plasmids together constitute the ***bacterial genome.*** Plasmids are transferable to other cells and hence are of great use in ***recombinant DNA technology***.

A cell may contain 1 to 100 plasmids. The number of plasmids in a cell is called ***copy number***. When the number is 1 or 2, the plasmid is said to be ***low copy number plasmid*** or ***stringent plasmid***. When the number is 10 to 100, the plasmids are said to be ***relaxed plasmids*** or ***high copy number plasmids***.

Some plasmids are capable of integrating with bacterial chromosome. Such plasmids are called ***episomes***. Plasmids are classified into three main types, namely ***F plasmids*** or ***sex plasmids***, **R plasmids** and ***Col plasmids***. The F plasmids have the ability to transfer chromosomal genes to other cells. It can also transfer itself to other cells. The R plasmid has the gene for resistance to one or more antibiotics. The Col plasmids have the ability to synthesize toxins like ***colicins.***

The plasmids exist in a ***supercoiled form***, or ***open circle*** or ***linear duplex***. Plasmids make toxins. They resist various antibiotics. They can also resist environmental factors (Fig.8).

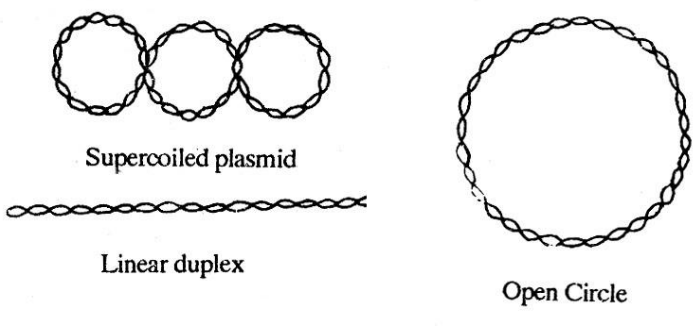


Fig. 8Different forms of plasmids

Bacterial Growth

Bacterial growth refers to the ***increase in cell number*** or ***cell population of bacteria.*** It is brought about by cell multiplication.

Methods of Bacterial Growth

Bacteria grow by the following methods:

Binary fission, Budding, Filamentation and ***Sporulation***.

Binary fission: Binary fission refers to the division of the parent cell into two daughter cells. During binary fission both cytoplasm and nuclei divide. e.g. ***Bacillus.***

Budding: In budding, a Bacterial cell produces a small projection on its surface. It is called bud. It increases in size and separates into a daughter cell. e.g. ***Rhodopseudomonas.***

Filamentation: In filamentous bacteria, the filaments breaks into fragments and each fragment grows into a daughter filament. This process of growth is called filamentation or fragmentation.e.g. ***Nocardia.***

Sporulation: Certain bacteria grow by producing spores. The hypha at its tip produces many spores. The spores separate and develop into new colonies.

e.g. ***Streptomyces.***

Growth Rate

During growth a cell divides into two and the two then divide into four and the four into eight and so on. In this way the cells grow by geometric progression. Growth rate of a cell refers to how rapidly a cell increases in mass. The rate of increase in bacteria at any particular time is proportional to the number or mass.

Generation Time or Mean Doubling Time

The time required by a cell to divide or the time required for the population to double is called generation time. It is denoted by the symbol 'g'. The generation time varies from species to species and it is affected by nutrients, temperature, etc. The generation time for *E.coli* in milk at 37°C in 12 minutes.

Factors affecting Growth

Bacterial growth is influenced by the following factors:

Culture medium, temperature, oxygen, carbon di oxide, pH, light, water, osmotic pressure, etc.

Growth Curve

Growth curve is a *graph obtained by plotting the number of cells against time factor*. A typical growth curve is obtained when a known concentration of bacteria is inoculated into a suitable culture medium (***batch culture***). The bacteria grow by dividing binary fission. The bacterial cells are counted at regular intervals of one hour. The numbers of bacteria are plotted against time.

A typical bacterial growth curve shows four distinct phases, viz., ***lag phase, log phase, stationary phase***, and ***decline phase***. ***Lag phase*** represents an initial period of no growth in terms of increase in cell numbers. In this phase the cells are metabolically active, capable of repairing cell damage and synthesizing enzymes. This phase is followed by a period of rapid growth called ***log phase***. In this phase the bacterial population increases exponentially and is also called ***exponential phase***. Log phase is followed by a ***stationary phase*** during which no new growth occurs. Lastly, there is decline in the viable population in which all bacterial cells die. This phase is called ***decline*** or ***death phase*** (Fig.9)**.**

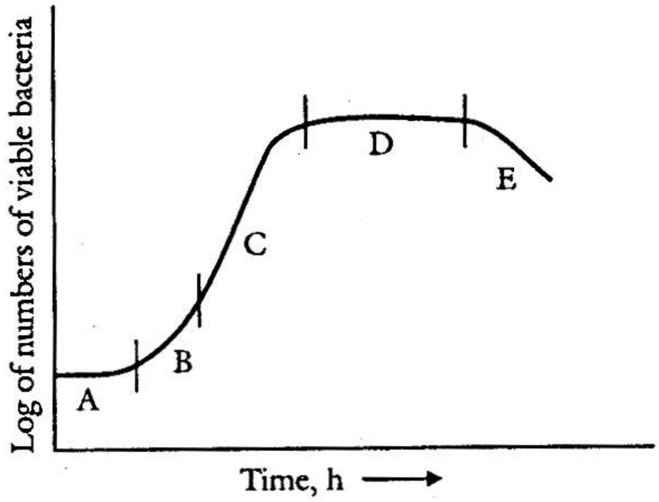


Fig. 9

Typical growth curve of bacteria

A. Lag phase; B. Acceleration phase; C. Log phase;
D. Stationary phase; E. Decline or death phase

When nutrient is regularly added to the culture, the bacteria grow continuously and we get a continuous culture. In continuous culture, the bacterial population remains in the log phase and there will be no stationary and decline phase.

Measurement of Bacterial Growth

Generally growth in bacteria and other unicellular organisms is measured by measuring either increases in numbers or increases in mass in relation to time.

Measurement of Cell Mass

It is an indirect method of measurement of bacterial growth. The cell mass could be measured by an estimate of (a) dry weight of the cells (b) cell volume (c) amount of chemical components of the cell and (d) turbidity of the liquid culture in which bacteria are growing.

Measurement of Cell Number

These are more direct methods. In these methods accuracy declines with increasing concentration of cells that result in crowding of uncountable numbers. By this method we count the total numbers which include both live and dead cells. e.g. Using counting chamber, smear count, membrane filter count, plate count, etc.

Nutrition

Microorganisms, as well as other forms of life, need food to grow and to reproduce. To a biologist food means any substrate that can be metabolized to provide building material and or energy for the cell. To grow organisms must draw from the environment all the substances they require for the synthesis of their cell materials and for the generation of energy. These substances are termed ***nutrients.***

Nutritional Types

Bacteria may be classified into different types based on their nutritional requirements. These classifications may be based on the sources of energy, the sources of carbon, or on both. Sometimes microorganisms are classified based on the mode of ingestion or uptake of nutrients or based on the growth factor requirements.

Classification based on Energy Source:

1). Phototrophs

2). Chemotrophs

Phototrophs:

These are photosynthetic bacteria in being able to use solar energy; these organisms do not release free oxygen. e.g. cyanobacteria and small groups of bacteria.

Chemotrophs:

These are bacteria which rely on chemical compounds for their energy source.

Classification based on Carbon Source:

1). Autotrophs

2). Heterotrophs

Autotrophs:

Autotrophs are bacteria which utilize carbon di oxide as the major source of carbon. e.g. cyanobacteria.

Heterotrophs:

These are organisms which use one or more organic compounds as their carbon source. They cannot utilize CO2.

Based on the Sources of Energy and Electron donor:

1). Lithotrophs

2). Organotrophs

Lithotrophs:

Lithotrophs are organisms which use reduced inorganic compounds as electron donors.

Organotrophs:

Organotrophs are organisms which use organic compounds as electron donors.

Based on the Requirements of Growth Factors:

1). Prototrophs

2). Auxotrophs

Prototrophs:

These are organisms which derive all carbon required from the principal carbon source. These need no additional growth factors. These can grow in the minimal medium.

Auxotrophs:

These are organisms which require, in addition to the principal carbon source, one or more organic nutrients or growth factors. These cannot grow on minimal medium.

Based on Ecological Relationships:

1). Saprophyte

2). Parasite

Saprophyte:

This is one of the types of heterotrophic nutrition. Bacteria act as scavengers in decomposing or recycling dead organic matters.

Parasite:

These bacteria enter and damage the substances inside the living cells or tissues.

Nutritional requirements

Microorganisms can use atmospheric nitrogen, inorganic nitrogen compounds such as nitrate, nitrite or ammonium salts or amino acids for their nitrogen.

Oxygen is obtained from water, from component atoms of various nutrients or molecular oxygen.

Sulphur is required in the form of organic sulphur compounds. Some utilize inorganic sulphur compounds; some use elemental sulphur.

Phosphorus is supplied in the form of phosphates and it is an essential component of nucleotides, nucleic acids, phospholipids and other compounds.

Trace elements are obtained as contaminants of other components of culture media in amounts sufficient to support bacterial growth.

Generally vitamins are synthesized from other compounds. Few others will not grow without the supply of required vitamins.

Water is needed much for the microbes, for all nutrients be in aqueous solution before they can enter the cells.

Culture Medium

Any nutrient preparation in which microorganisms or any other cells are cultivated is called a ***culture medium***. The primary aim of constructing a culture medium for any microorganisms is to provide a balanced mixture of the required nutrients, at concentrations that will permit good growth. A culture medium can be prepared as ***liquid (broth)*** or ***solid medium***.

A typical culture medium is prepared by mixing beef extract, peptone, sodium chloride and water. This medium is liquid in nature and it is called ***nutrient broth***.

Beef extract	-	3g
Peptone	-	5g
Sodium chloride	-	5g
Water	-	1litre

When agar (15g) is added to the above components the medium becomes solid and is called ***nutrient agar***.

It is a complex medium for the growth of heterotrophic bacteria.

Types of Culture Medium

The culture media are classified various types. Based on consistency, the culture media are classified into the following three types.

1. Liquid medium or broth
2. Semisolid medium
3. Solid medium

Liquid medium or broth:

Broth is a ***liquid culture*** medium. During preparation of the medium, the solidifying agent is not added. The broth medium is used to study the growth rate of bacterial cells.

Semi solid medium:

The semisolid medium remains in the semisolid condition and it is prepared by adding small amount of agar ***(0.5%).*** It is used to study bacterial motility.

Solid medium:

The solid medium is solid in consistency. It is prepared by adding large amount of agar ***(2%).*** It is used for colony characterization, colony identification, isolation of bacterial cells.

Reproduction of Bacteria

Asexual method:

Bacteria can reproduce by a variety of mechanisms. The Actinomycetes form long filaments which split into living fragments by the process of ***fragmentation***. Each fragment is capable of giving rise to a new filament. The *Streptomyces* develops spores at their tips. Once released, these spores can give rise to a new colony of microorganism. This process is called as ***sporulation***. A few bacteria are capable of ***budding***, production new smaller cells from the surface of a single organism. The majority of bacterial cells, however reproduced by ***binary fission*** or **transverse fission**. All these methods of reproduction do not involve any sex and hence known as ***asexual methods***

of reproduction. Most bacteria normally reproduced by asexual mean and sexual reproduction, if any, is mainly concerned with exchange or transfer of genetic material from one cell to the other. The mode of reproduction in bacteria is also used to characterize bacterial groups.

Binary Fission

Most of the bacteria reproduce commonly by transverse binary fission. This is the most important mode of cell division in the usual growth cycle of bacteria. This mode of reproduction involves division of single bacterial cell into two cells by the formation of a transverse septum. Each time a cell divides by binary fission and it forms a new generation of two cells. Each cell of the new generation is capable of further division by fission. The next division finds these two cells becoming four and four cells becoming eight and so on. Each generation has twice the number of cells as the preceding generation. Thus, during active growth, the population size is increasing at an exponential rate. The number of bacteria that are present at any time depends on the size of the initial population, and the number of generations that have been produced.

Budding

The genera *Pasteuria*, *Blastobacter*, *Seliberia* and *Plantomyces* are generally known as budding bacteria. These are all gram negative, chemoorganotrophs and reproduce either by longitudinal fission or by budding of spherical or ovoid cells at the free end.

Budding involves development of a small protuberance (bud) at one end of the cell. This enlarge and eventually develops into a new cell which separates from the parent. This type of budding has been observed in *Rhodopseudomonas acidophila*.

Fragmentation

Bacterial genera such as *Saprospira*, *Vitreoscilla*, *Simonsiella* and *Leucothrix* are filamentous in nature. They usually reproduced by fragmentation of filament. In the first three genera reproduction occurs by random fragmentation of the filaments whereas in *Leucothrix* it occurs by the breaking off of ovoid cells, singly or in short chains, from the apical end of the filament. These reproductive cells are often referred to as ***gonidia*** and are capable of gliding movement.

Endospore formation

Spore formation is limited almost entirely to two genera of rod- shaped bacteria; *Bacillus* and *Clostridium*. Sporulation is not a process to increase bacterial numbers because a cell rarely produced more than one spore. Hence, spore formation or endospore formation is not considered as a method of reproduction in its strict sense, though it involves asexuality.

Endospores are bodies produced within the cells of a considerable number of bacterial species. They are more resistant to unfavorable environmental conditions such as heat, cold desiccation, osmosis and chemicals than the vegetative cells.

Spores may be spherical, ellipsoidal or cylindrical in shape. The position of the spore in the cell may be central, sub- terminal or terminal. Each species has it own characteristic size, shape and position of the spore.

Sexual Method

Most bacteria reproduce by asexual methods. However sexual reproduction is also met with in a few bacterial groups. When sexual reproduction occurs a temporary diploidy of chromosome is brought in. Sexual reproduction in bacteria in its broad sense, can be defined as a unidirectional passage of genetic material or DNA from a ***donor cell*** to a *recipient cell*. This is achieved by three methods viz., 1) transformation, 2) transduction and 3) conjugation.

Transformation

In this method, the donor bacterium liberates the DNA by the dissolution of the cell and the DNA is absorbed from the medium by the recipient bacterium. Hence the recipient bacterium is transformed into another strain. This is called transformation. Transformation is described by Griffith (1928) in ***Pneumococcus pneumoniae***.

Griffith in 1928 carried out a series of experiments with *Pneumococcus*. There are two types of *Pneumococcus* bacteria, namely virulent and avirulent. Virulent strains have smooth carbohydrate capsules and give smooth colonies. Avirulent strains have no capsules and give rough colonies. These two strains also differ in their antigenic properties and virulence for the disease pneumonia. Virulence is determined by genetic factors. When virulent strains are injected into mice, they kill them with pneumococcal infection. When mice are inoculated with avirulent bacteria there was no ill effect. Then mice are injected with virulent bacteria after killing with heat. In this case noill effect is produced and the mice survive. Finally, mice are injected with a mixture of avirulent and heat killed virulent bacteria. In this experiment the mice die due to pneumococcal infection. The analysis of dead mice shows that it contains virulent bacteria. The heat killed virulent bacteria are responsible for the transformation of avirulent bacteria into virulent smooth bacteria. Something from the heat killed (dead) virulent bacteria was apparently transferred to the live avirulent bacteria (Fig.10).

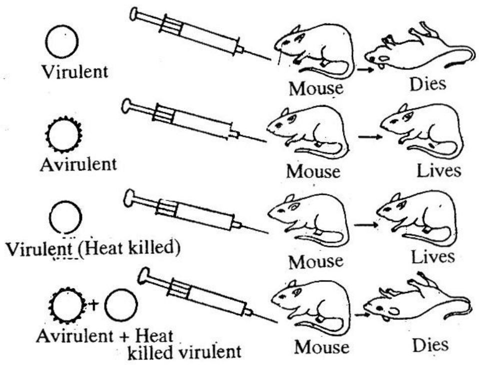


Fig. 10

Griffiths experiment to explain bacterial transformation

This phenomenon is known as ***Griffith effect*** or ***Bacterial transformation***.

Avery, Mac Leod and ***Mc Carthy*** (1944) experimentally proved that the transformation of a avirulent form to virulent form is due to the transmission of a chemical substance. When finely ground virulent bacterial extract is added to cultures of avirulent bacteria, the culture after few hours, contains avirulent as well as virulent bacteria. When the extract is treated with ***DNA***ase (an enzyme destroying DNA), the transforming property is lost. But when the extract is treated with protease the transforming ability is retained. Thus it is confirmed that the genetic material is DNA. The transmission of genetic material from one cell to another by adding DNA extract of the cell in the culture is called transformation.

Transduction

The transfer of genetic materials from one bacterium to another through bacteriophages is called transduction.

Conjugation

In this method two bacteria join together and a portion of DNA of donor is transferred to the recipient.

F+ and F- cells join together and a ***conjugation tube*** is formed. Now a nick is made in one strand of the plasmid of F+ cell. The 5'end of the broken strand is inserted into the F- cell through the conjugation tube and in a few minutes the complete strand is transferred to the F- cell. The single strands of F+ and F- cells now synthesize a complementary strand and produce double stranded circular plasmids. After this, the conjugants separate. Now each exconjugant is provided with a plasmid. Thus the F-cell is transformed into F-cell by conjugation.

Conjugation also occurs between ***Hfr*** cells and F- cells. ***Hfr*** cells, the plasmid remain integrated with the bacterial chromosome. During conjugation the ***Hfr*** cell transfers the plasmid with a portion of bacterial chromosome (Fig.11 & 12).

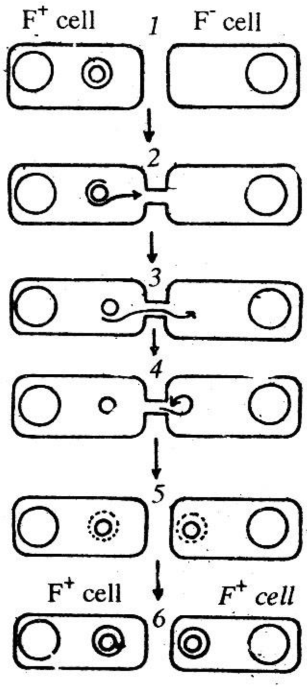


Fig. 11 Conjugation

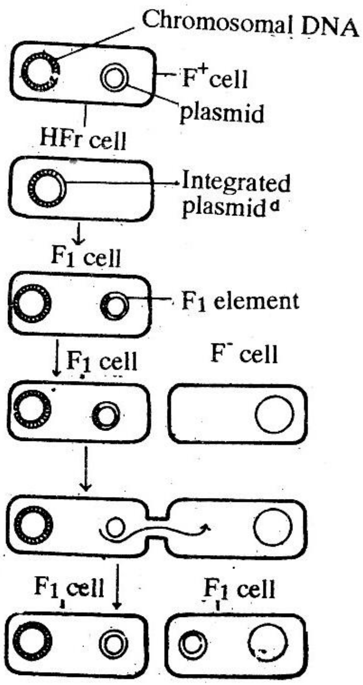


Fig. 12 Sexduction

The F- cell receives not only the genes present in the plasmid, but also a set of chromosomal genes

Economic Importance of Bacteria

Bacteria are useful in several ways to mankind. They are ubiquitous in our environment. Some of the important applied areas are discussed briefly here.

In soil and agricultural improvement

Most of the bacteria live saprophytically on dead organic matter of the soil. They decompose complex organic matter into simpler ones and make it available for plants. Thus they play an important role in the formation of humus. They also prevent leaching of many inorganic compounds.

Cyanobacteria like *Nostoc, Anabaena* etc. are employed to convert a waste land into a productive land.

Bacteria like *Rhizobium, Azospirillum, Azotobacter* etc. fixes atmospheric nitrogen and increase the soil fertility.

Certain bacteria such as *Bacillus thuringiensis, B. papillae* etc. are kill a wide range of insects and protect the plants from pathogenic microbes, insects, pests etc.

In food and dairy industry

Tobacco and tea leaves are fermented to give flavor and taste. This type of fermentation is known as curing. It is brought about by the bacteria *Micrococcus candisans.*

The bacteria, *Streptococcus lactis* convert lactose, the milk sugar, into lactic acid. The production of lactic acid gives the milk a sour taste and in turn causes the precipitation of casein (milk protein).

Dairy products like Butter, Yogurt, Cheese etc. are produced by *Lactobacillus lactis, L. bulgaricus, Leuconostoc* sp. etc.

Bacteria like *Zymomonas mobilis, Lactobcillus vermiformis* are used in Alcohol industries. In Vinegar production industries, *Acetobacter* sp. and *Gluconobacter* sp. are used.

Corynebacterium glutamicum and *Brevibacterium flavum* are used in the production of Glutamic acid.

In pharmaceutical industry

Antibiotics are chemical substances secreted by some microorganisms which inhibit the growth of other microbes. Most of them are produced by bacteria. *Streptomyces aureofaciens, Nocardia* sp. are involved in the production of Tetracycline.

Streptomycin produced by *Streptomyces griseus. Corynebacterium hydrocarboclastus* is used in the production of Corynesin.

Vitamin B12 (Cyanocobalamine) is synthesized by *Propionibacterium shermanii* and *Pseudomonas* sp. *Clostridium acetobutylicum* and *Mycobacterium* sp. are used in the production of Vitamin B2 (Riboflavin).

In Biodegradation

Biodegradation is a microbial process where complex polymers broken down into less harmful forms, and in turn used by them as a source of energy.

It is an important process now-a-days used for abatement of pollution.

Pseudomonas putida have the ability to decompose oil and oil products. It is otherwise called super bug.

Silicates are complex and hard materials. These are degraded by silicate bacteria called *Proteus mirabilis*.

NOTES

UNIT - IV

LICHENS

INTRODUCTION:

Lichens are a peculiar type of plants,their body being made up of algal(phycobiont) and fungal(mycobiont) components, living together in an intimate symbiotic relationship. The plant body resembles neither an algae nor fungi. The word lichen is derived from Greek. The term lichen was first used by **Theophrastus** to denote a superficial growth on bark of trees. Lichens were first discovered by **Tulsane** in 1852.

The branch of botany which deals with Lichen is called Lichonology.

DISTRIBUTION:

Lichens are widely distributed and universal in appearance 400 genera and 17000 species are distributed throughout the world. In India Lichens are in abundant in eastern Himalayan ranges. Distribution of lichens is controlled by climate and substratum. They are adapted to survive under great extremes of heat, cold and drought. Direct light, moderate temparature or cold temperature, constant moisture and pure atmosphere favours lichen growth. Polluted, smoky atmosphere found in industrial area are not favourable for growth.

SYSTEMATIC POSITION:

Linnaeus classify Lichens among Algae.Some authors put lichens under Mosses and Livervorts.Mycologists like **Vaino, Link, Halbrukner, essey, Bold** placed lichens in Fungi.(Eumycophyta)

Bessey assigned lichens to the order Leconarales of Ascomycetes.

Smith viewed that Lichens should be treated as a distinct group.

Bold placed lichens in Mycophycophyta, because of dual algal and fungal nature of the thallus.

CLASSIFICATION:

I.Based on growth forms, **Hue**(1899) classified lichens into three forms:

i.Crustose or Crustaceous.

ii.Foliose or Folioseous.

iii.Fruticose.

II.**Zahlbruckner(1926**) :

Based on fungal components in the thallus ,divided lichens into:

1.Ascolichens(fungal component Ascomycotina)

Further divided into tow series

a) Gymnocarpeae – frutification is apothecium(=discolichen) example-*Parmelia.*

b) Pyrenocarpeae - frutification is perithecium(=pyrenolichen) Ex.*Dermatocarpon.*

2.Basidiolichens-(fungal component belongs to Basidiomycotina.

ExDictyonema,Corella.

III.**Alexopoulos and Mims**(1979) classified lichens into three groups;

1.Basidiolichens

2.Deuterolichens.

3.Ascolichens.

Lichens:Habitat

Lichens are noticed in varied habitats. Usually the lichens are pioneers in succession on barren rocks or burnt-over area.Found growing on leaves,the bark of trees,on decaying wood,on rocks on soil.Few species grow in aqatic habitats in sea water,freh water,standing and running water.*Varrucaria maura* is a marine lichen.in damp forests of the tropical and sub-tropical region they hang in long festoons from trees.In arctic zones they form cushion shaped masses over the grounds.Some lichens are noticed in snows.Lichens are also noticed on turtles and weevils.

Lichonologists divide the lichens into the following catogeries based on habitat like Saxicolous,Terricolous,Corticolous,omnicolous and arboreal.

Lichens which grow on rocks are called Saxicoles.Those grow on barks of trees are called corticoles. Terrestrial lichens are called Terricoles. Those exist on bones, leather, iron are called omnicoles.

Fossil lichens:

Earliest record of lichens is from Mesozoic (*Ramalinites lacerus and Opegrapha*). Lichens like *Ramalina tertiaria, Lichen dichotomous, Opegrapha thomsiana, Cladonia rosea, Parmelia lecunora* are reported from Coenozoic.

GENERAL CHARACTERS OF LICHENS:

1. Lichens have a composite thalloid structure,formed by the association of algae and fungi.
2. Algal and fungal partners form a symbiotic relationship.The fungus always envelops the algal component.
3. The algal component of lichens prepares carbohydrates by photosynthesis which are utilized both by algal and fungal components. The fungal component provides the body of the organisms and absorption and retention of water.

Geitler is of opinion that the relationship being of parasitism,the fungus being parasitic on alga.Lichen thallus is considered to represent an idyllic marriage,a consortium between the fungus and alga.Some consider as helotism(master & slave),Fungus(master) has an upper hand over algae in the association.

4. Lichens are able to withstand extremes of temperature and desiccation.
5. They are not having any special organs like roots,leaves like that of higher organisms.

6. As compared with higher plants ,the rate of photosynthesis is much lower.
7. Respiration is much less as compared with angiosperm leaf.
8. The dry weight of thalli varies with seasons.
9. The lichens are the slowest growing of all plants.
10. Lichens are highly sensitive to atmospheric pollution and thus they will not grow near large industrial town.
11. Lichenic acid found in some lichens are not found in any other plant.The lichen acids are important from taxonomic point of view.
12. Lichens play a prominent role in soil formation.
13. Based on structure ,lichens are of three kinds i) crustose ii) foliose iii)fruticose
14. Internally the thallus is divisible into three or four regions.
15. Asexual reproduction takes place by spores like oidia and pycnidia.
16. Sexual reproduction is entirely by fungal component.
17. The female sex organ is called carpogonium,which is a coiled multicelluar filamentous structure. Carpogonium is divisible into basal coiled ascogonium and an elongated multicelluar trichogyne.
18. The male sex organs are flask shaped spermagonia and are noticed in the upper surface of the thallus. They produce non-motile male gamete spermatia.
19. The fruiting bodies of lichens are disc shaped apothesia or flask shaped perithesia.
20. Each ascus produce eight ascospores,Ascospores may be simple or septate.The hyphae produced by the germination of ascospore,when comes in contact with a suitable alga, then only it forms a new lichen thallus.

STRUCTURE OF LICHEN THALLUS:

Lichens are of different forms and colours.

Size:

Range in size from minute to large and conspicuous forms and some are several feet.

Colour :

Vary greatly in colour.Greyish-green,white,orange,yellow,yellowish-green,brown or black.The colour is due to translucent fungal or gelatinous covering over the algal constituents.

External morphology:

Based on their external appearance or morphology three types of lichens have been recognized.

i) **Crustose lichen:**

The thallus is small in size.Thallus is flat,thin without any distinct lobes.They form a crust adpressed to the substrate partly or wholly embedded in it.The surface of the thallus is divided into more or less hexagonal areas called areolae.

Examples: *Graphis scripta, Haematomma, Lecidia, Lecanora, Rhizocarpon, Strigula, Verrucaria.*

ii) **Foliose lichen**:

Thallus is flat,much lobed and leaf like.Often resembles crinkled and twisted leavesThallus has distinct upper and lower surface.The edges of the thallus are usually curled up.Usually attached to the substrate by a short rhizoid like rhizenes.

Examples: *Xanthoria, Peltigera, Physcia, Parmelia, Gyrophora,*

iii) **Fruiticose lichen:**

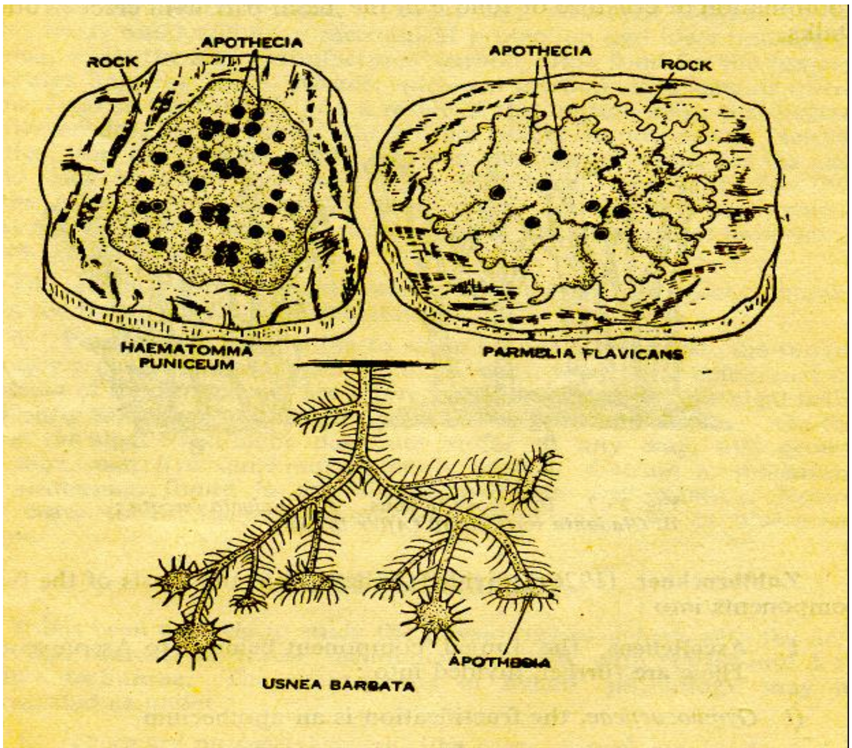
Much branched and either bushy and erect (Evernia,Cladonia) or pendent (Usnea).

Branches may be cylindrical or flattened.Grow erect or hang from the substratum.The plant body is attached to the substratum by a mucilaginous disc.The thallus shows no differentiation into upper and lower surfaces.

Examples: *Alectonia, Cladonia, Letharia, Usnea, Ramalina.*

iv)**Squamulose lichen**:

Thallus is scale like and composed of small lobes.



INTERNAL STRUCTURE;

The internal structure of lichens is very complex.The thallus is composed of algal and fungal components.The major portion of the thallus is composed of closely interwoven hyphae of the fungus in association with the algal components.Such a type of thallus is known as consortium.Algal component comprises about 26 genera of which 80% of lichens belong to green algae, the remaining being blue-green and yellow-green.*Trebouxia* is the commenest green alga.Fungal partner is generally Ascomycetes. Only two or three genera belong to Basidiomycetes.

Foliose lichen:Vertical section.

A vertical section of foliose lichen shows four distinct regions namely upper cortex,algal layer,medulla and lower cortex.

i)**Upper cortex**:

It is the outermost thick and protective zone composed of compactly interwoven fungal hyphae.The hyphae are arranged at right angles to the surface of the thallus.Intercelluar spaces are generally absent and if present they are filled with gelatinous material.In some foliose lichens(*Parmelia*) there are many irregularly arranged breathing pores on the outer surface .The pores help in gaseous exange.

ii**)Algal layer or Gonidial layer.:**

The algal layer occurs just below the upper cortex.The algal zone comprises loosely interwoven hyphae intermingled with algae.In some species (*Collema,Leptogium*),algal cells and fungal hyphae are distributed more or less uniformly throughout the thallus and such thallus is called Homoiomerous.In some like *Parmelia* and *Physcia* ,the algal cells form a distinct layer within thethallus and such are called Heteromerous.The algae which are found commonly are *Nostoc*, *Gloeocapsa*, *Rivularia* (Myxophyceae) or Green algae like *Protococcus Cystococcus, Pleurococcus, Cladophora*,*Tretepholia* and *Trebouxia.*

iii)**Medulla:**

Present below the algal zone and is the central part of the thallus is medulla.It is composed of loosely interwoven hyphae with large spaces between them.This pseudoparenchymatous region is known as plectenchyma.

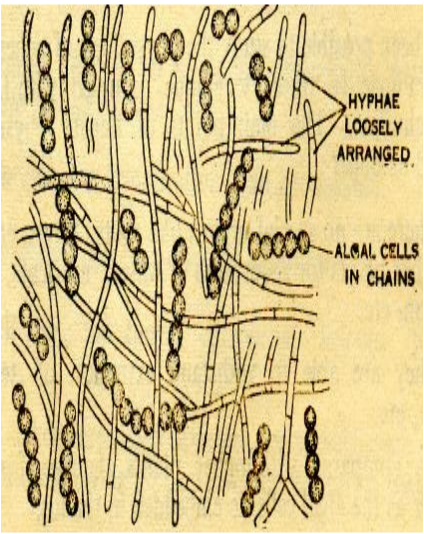
iv)**Lower cortex**:This zone is composed of compactly arranged hyphae.Hyphae are parallel or perpendicular to the surface of the thallus.From its underside arise special hyphae called rhizines which help to attach the thallus to the substratum.

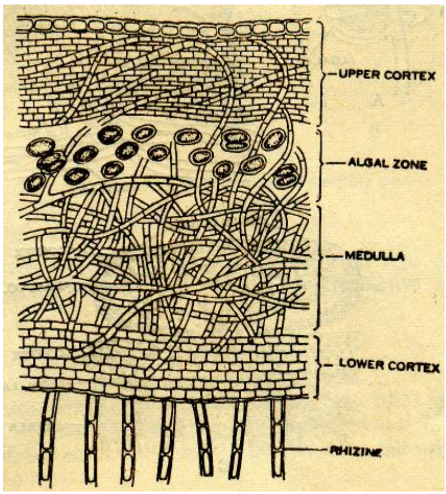
Crustose lichen:vertical section.

Thallus is very poorly formed.Different layers not so complete like that of foliose.

Fruticose lichen:

Due to cylindrical nature ,the thallus not differentiated into upper and lower surfaces.Medulla forms the central part of the axis.Thallus is attached to the substratum by a definite basal portion composed of strands of densely packed hyphae.





Lichen:V.S. of Homoiomerous thallus. Lichen:V.S.of Heteromerous thallus.

Specialised structures of lichen thallus:

1.Aeration structures:

For gaseous exange the special structures formed are

i) Breathing pores
ii) Cyphellae
iii) Pseudocyphellae

Breathing porea:

Breathing pores are noticed on the upper cortex at some places where hyphae are loosely interwoven.They may have cone-like elevation or not.Thease are noticed in foliose and fruticose lichens.

Cyphellae:

Thease are noticed in some foliose lichens on the lower cortex. Cyphellae are concave circular depressions with roundish cells.

Pseudocyphellae:

The cortex bursts at some places and form pseudocyphellae. Pseudogyphellae resemble cyphellae in every respect but here margin is not formed.

2.Cephalodia

These are external or internal gall-like swellings.These are dark coloured and consisting of the same fungal hyphaeas in the lichen thallus but the algal component is always different.They do not have any organic connection with the lichen thalli bearing them.

3.Isidia

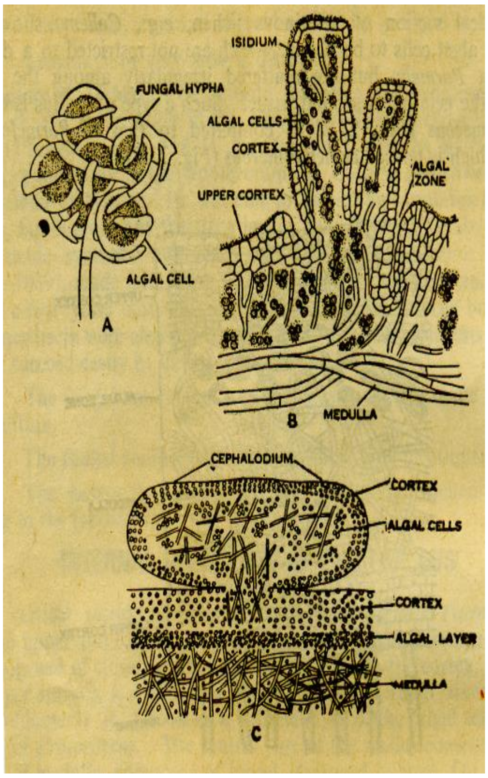
Isidia are coral like blackish papillate outgrowths developed on the surface of the thallus.Composed of external cortical layer of fungal hyphae with an internal algal layer.The algal component is the same as that in the thallus.Help to increase the photosynthetic surface of the thallus.When isidia are detached they behave as reproductive bodies.

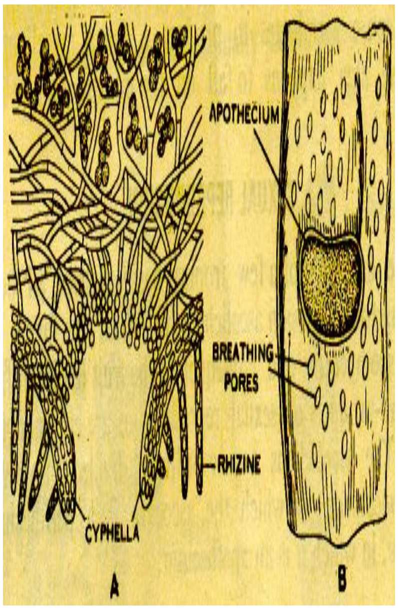
4.Soredia

Soredia are minute ,rounded separable scale like outgrowths.They are composed of algal cells clasped and surrounded by fungal hyphae.Both the fungus and algal components are same as that in the parent thallus.Formed on the surface or margin of the thallus in large numbers.Soredia when desiminated by wind or rain and when fall on suitable substrate germinate into a new lichen thallus.

5.Soralia

Soralia are noticed in fruticose,foliose and few crustose forms.The soredia are noticed in dense compact bodies known as Soralia.





A.Soredia B.Isidia C.Cephalodia. A.Cyphellae B.Brething pores.

REPRODUCTION:

Reproduction takes place by two methods

1) Asexual
2) Sexual

Asexual:

Takes place by vegetative,special structures and asexual spores.

a)Vegetative:

Vegetative reproduction takes place by fragmentation.By the death and decay of the older portions the thallus may be fragmented and the broken-off pieces develop into new thalli if they have both the components of algal and fungal partners.

b)Special structures(propagules):

The structures like Soredia and Isidia when fall on suitable substratum develop into new thalli.

c)Asexual spores:

Conidia or pycnidiospores are produced inside the thallus in cuplike pycnidia.When conidia fall on suitable and favourable conditions, they produce hyphal branches which on coming in contact with appropriate algal cell develop into a lichen thallus.

Sexual method:

Lichens which possess fungal elements belonging to the Ascomycetes,reproduce by ascospores which are produced in asci which are borne in apothesia or perithesia.Fruting bodies like apothesia or perithesia may be embedded in the thallus or be subtended by long stalks.The fruting bodies are produced by fungal hyphae only and algal partner takes no part in the formation of fruting bodies.

Sex organs and reproduction:

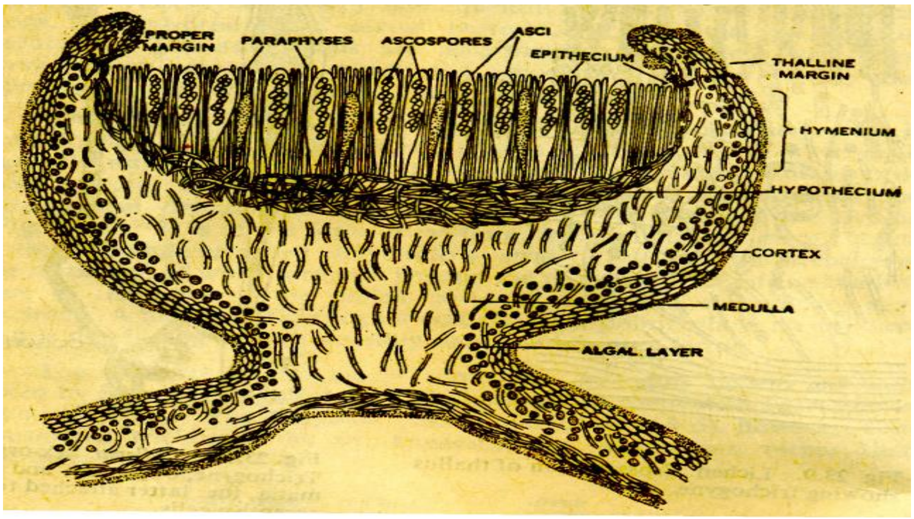
The female sex organ is called carpogonium and develops in the medulla region.The lower portion of carpogonium called ascogonium is many celled and the tip of ascogonium namely trichogyne projects beyond the thallus and receives spermatia.Spermatia are male gametes and are produced in male sex organ called spermagonium.The sperm nucleus gradually passes down the trichogyne to the oogonium where it fuses with the egg nucleus.After fertilization numerous ascogenous hyphae grow out from coiled portion of ascogonium which finally give rise to asci.The ascocarp is lined with a palisade –like sterile hyphae called paraphyses.Each ascus bears eight ascospores.Ascospore may be one celled or two to many celled.

Apothesium structure:

Apothesia are like that of parent thalli in colour and consistency.The apothesia are small elvated cup shaped or disc shaped bodies.The bottom of the cup or surface of the disc is lined by hymenium consisting of up-right asci interspersed with slender paraphyses.The wall of the apothesium is composed of the vegetative part of the thallus consisting of algal and fungal layers or fungal tissue withno algal cells.

Basidio-Lichen:

If a fungal partner belongs to basidiomycetes ,generally is associated with blue-green algae.The thalli look like bracket fungi.There is no cortex in the thallus.The medulla of loose hyphae grows over the lower surface and produce an uneven surface.The spores are exogenous and are borne at the tips of basidia.A continuous hymenial layer is formed.Each basidium bears four sterigmata and basidiospores.Paraphyses similar to basidium are abundant in the hymenium.



V.S.Apothecium.

ECONOMIC IMPORTANCE OF LICHENS:

Beneficial aspects:

I.Used as food:

1)Food for humanbeings.

Lichens contain lichenin,a type of carbohydrate related to starch which is useful to humanbeings.*Cetraria islandica* (Iceland Moss) is used as food by man.Various soups are prepared from this lichen.Egyptians use *Evernia prunastri* in baking.In India a species of *Parmelia* (rock flower) is used as food and source of medicine. Species of *Lecanora* (bread of heaven) is used as food in Western Asia and Northern Africa. In Japan, *Endocarpon miniatum* (Stone mushroom) is used as vegetable.

2)**Food for higher animals.**

Lichens like *Lobaria pulmonaria*,*Evernia prunastri*,*Ramalina fraxinea*,*Ramalina fastigiata* have a carbohydrate lichenin used as fodder for animals.*Cladonia rangiferina* (reindeer moss) is used as food for reindeer,cattle etc.*Alectoria jubata*, *Stereocaulon pchale*,*Cetraasria islandica* are good for horses,oxen,cows and swine.

3)Food for insects.

Some species of lichens like *Aspicilia calcarea* and *Lecanora saxicola* are included in the diets of mites,caterpillars,termites and snails.

II.Medicinal uses:

Lichens are used in the treatment of jaundice, diarrhea, fevers, epilepsy**,** hydrophobia and skin diseases. In Iceland, lichen is used as laxatives.A preparation of *Peltigera carina*(dog lichen) is used to cure hydrophobia.Lichen is used as an ingredient in culture media for bacteria.*Parmelia saxatilis*(skull lichen) can cure epilepsy.Several species of *Pertusaria* ,*Cladonia* and *Cetraria islandica* is recommended for fever.Species of *Usnea* and *Evernia furfuracea* used as astringents in haemorrhages.*Cladonia pyxidata* is valuable in curing whooping cough.*Lobaria pulmonaria* (lungwort)is used for the treatment of lung diseases.*Acarospora smaragdula* possess antibiotic properties.Lichenic acids like Usnic acid has antibacterial activity.Some lichens act as allergens and cause allergy.

III.Industrial uses.

1)Perfumery.

Lichens are used in perfumeries in different ways. *Evernia prunastri*,*Lobaria* pulmonaria are used in perfume making. Powdered thalli of *Usnea* species,*Ramalina calicaris* are used as substitute for starch in perfume industries.In France,certain aromatic substances are extracted from lichens and used in soaps.Lichens are used in perfumes owing to their presence of various oils.

2)Tanning,brewing and distilling industries.

In Russia,Siberia,lichens like *Lobaria pulmonaria* are used in the brewing of beer.The astringent substances extracted from the thalli of *Cetraria islandica* and *Lobaria pulmonaria* are made use of in tanning of leather.*Cladonia rangiferina*,*Usnea florida* and *Ramalina fraxinea* are used in the preparation of alcohol.

3)Preparation of Dyes.

Dyes from lichens are used for colouring fabrics and paints.Orchil,Cudbear are some dyes.Orchil is used for dying woollens and silks.Orcein a purified extract of orchil is used as stain in the laboratories for microscopic preparations.*Roccella tinctoria* yields litmus solution by grinding the thallus from which litmus paper made after soacking in that solution (pH indicator).

4)Indicators of air pollution.

Lichens accumulate quantities of industrial waste materials.When the accumulation reaches toxic level, the lichen dies.The degree of air pollution in an industrial area can be easily estimated by sampling the lichen from the source of air pollution.

5)Mineral production.

Lecanora esculenta, an inhabitant of limestone deserts yields abundant quality of calcium oxalate.

IV.Ecological importance:

1.Pioneer indicators of rock vegetation.

Lichens play as pioneers in colonization of rocky habits by plants.They excrete organic acids which disintegrate rocks,thus forming soil and preparing substrates in which other kinds of plants can subsequently become established.First lichen to appear on rocks is *Lichen candelarius.*

2.Soil formers.

Lichens perform the work of breaking down the hard rock surfaces and preparing a soil on which more highly developed plants can grow.Usually Crustaceous lichens begin to cover the area.When they die,their decaying remains, together with rock particles, form a soil in which other plants may grow.The first successors are generally mosses,but sooner or later vascular plants begin to grow in the soil.

Harmful aspects:

1. Lichens of the genera *Cladonia*,*Amphiloma* cause total destruction to the colonies of mosses by direct parasitic attack.
2. Lichens cause serious damage to the window glasses in old buildings by corroding the glasses with the excretion of acids.
3. *Usnea(*Oldman's beard) being inflammable easily catches fire in nature causing forest fires.Some lichens are radioactive.
4. *Letharia vulpina* used in Scandinavia to poison wolves.

VIRUSES

Introduction:

The name virus is derived from Latin which means a venom or poisonous fluid. **Pastuer**, 1881 used the term virus for the first time.M.W.Beijerinck, a Dutch bacteriologist, demonstrated the infectious nature of tobacco is due to the 'infectious living fluid' and called it as contagium vivum fluidum.**W.M.Stanley** isolated and crystallized Tobacco Mosic Virus.Bawden and Pirie,1936 established nucleo-proteinaceous nature of viruses. d'Herelle 1917,coined the term 'bacteriophage' for bacterial virus.**Shafferman** and **Morris 1**963 discovered the virus of blue=green algae Dienner and Rayner 1967 discoered viroids.

General characteristicsof viruses:

Viruses are non-cellur,ultra-microscopic particles of protein and nucleic acid which grow and multiply only in living cells. They are intracellur obligate parasites.They can live only in living cells.No saprophytic viruses have been discovered so far.Viruses are the smallest of all infective agents.They are not visible with light microscope.They can be observed and photographed with the electron microscope.

Most of viruses have been crystallized.They cause many infectious of animals,human beings,angiosperms,bacteria,fungi and algae.Viruses can not be grown on artificial media.They show growth and mutate.Are capable of forming new strains in nature.They lack pigments,movement and sex organs.They synthesize their proteins with the help of host ribosomes.

Viruses have some living non-living properties.

Living characters of viruses.

1. Possess genetic material DNA or RNA.
2. Can reproduce and mutate.
3. Exhibit specifity of host.
4. Posses antigenitic properties.
5. React to chemicals and radiation.

Non-living characteristics of viruses.

1. Can be crystallized like a non-living molecule.
2. Lack cell wall cell membrane.
3. Lack protoplasm.
4. They are inert like a chemical outside the host.

Size of virus:

The virus particle or virion ranges from size 20-350nm.(1nm= 0.000000001metre)

Shape:

The virions may be spherical,oval,rod like,brick shaped tadpole like.Usually animal viruses are somewhat spherical.The plant viruses may be oval or rod shaped.Based on shape,the plant viruses chiefly fall under three categories:

i) Straight tubular, long, rigid rods with a helical architecture. Ex.TMV, Barley stripe mosaic and Tobacco rattle.

ii) Long flexuous thread like: Ex.Potata latent mosaic, Lettuce mosaic, Wheat streak masaic virus.thread –like.

iii) Polyhedral. Ex.Turnip Yellow Mosaic, Cucumber Mosaic, Tobacco ring spot.

Structure of virus.

A virion consists of a central core of nucleic acid or nucleoid surrounded by a protein coat called capsid.

Nucleoid:

The virus contains only one type of nucleic acid,which may be either DNA or RNA but never both.Viruses containg DNAare called De oxy viruses,those having RNA are called Riboviruses. Generally the animal viruses have DNA, the plant viruses contains RNA.However there are some exceptions.The type of genetic material is variable in different viral types.All plant viruses have single stranded RNA,animal viruses have either single or rarely double stranded RNA or double stranded DNA,bacterial viruses contain mostly double stranded DNA or RNA.,most of insect viruses contain RNA and only a few have DNA.The DNA of several bacterial and animal viruses is circular,whereas in others it is linear.The nucleic acid represents the infectious part of the virus.Avirion contains only a single molecule of nucleic acid.The number of nucleotide pairs in a molecule varies from 1000-250000 pairs.The amount of nucleic acid depends on the size of virion,usually larger the size of virion, the greater is the amount of nucleic acid.

Protein coat(Capsid):

The nucleic acid core is protected by a protein coat called capsid.The capsid is made up of many identical protein units called capsomeres.The number and arrangement of capsomeres in a capsid has been studied by electron microscopy and X-ray diffraction analysis.Based on these studies,the viruses are classified into three symmetry groups,namely

i) cubic symmetry

ii) helical symmetry iii)complex symmetry.

The capsid performs the following functions:

i) it protects the nucleic acid

ii) it helps the entry of nucleic acid into the host cell.

iii) it exhibits antigenic properties.

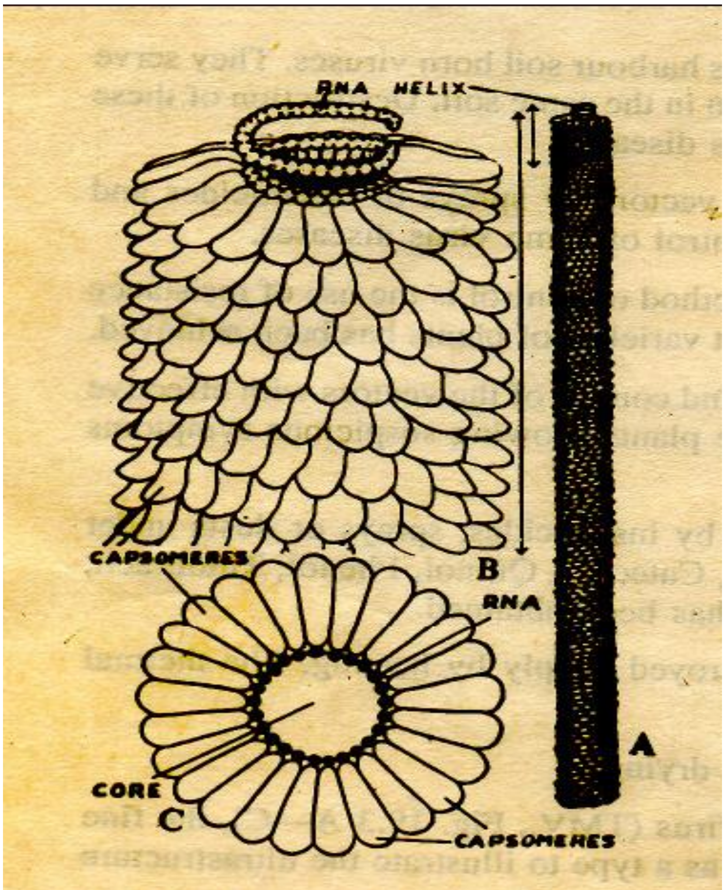
iv) sometimes helps in the synthesis of nucleic acid in some animal viruses.

Envelopes :

Some animal viruses may be covered by a lipid or lipoproteinaous envelope of 100-180A^{o} thickness. Such viruses are called Lipiviruses. A characteristic feature of this envelope is the projections which are called spikes or peplomers.

Structure of Tobacco Mosaic Virus:TMV

More than 100 types of plant viruses are known.Of theseTMV has been studied extensively.This virus was discovered by **D. Iwanovsky** 1892, but its isolation from infected plants and crystallization was done by **W.M. Stanley** 1935. TMV is a hollow, helical, rod shaped virus measuring about 3000 Angstron in length and 175A^{o} in diameter. The capsid is made up of about 2130 capsomeres arranged spirally around an axial hole of 40 A^{o} diameter. The molecular weight of each capsomere is 17300.The genetic material of TMV is RNA. It is single stranded,spirally coiled and remains embedded within the protein monomers.Its molecular weight is about 2.4 million.The protein-nucleic acid ratio of TMV is 94.4:5.6%It was crystallized by **Stanley** in 1935.



A.TMV in surface view.B.Portion of A C.Part of rod.

Common symptoms of Viral infection in Plants:

Symptoms of viral infections can be grouped into three categories;

1. External symptoms
2. Internal symptoms.
3. Physiological symptoms.

External symptoms.

These symptoms appear externally on various parts of the plant,such as leaf,stem,fruit.The external symptoms on leaves may be mosaic, yellowing, rolling or curling of leaves. On stems, the symptoms may be 'witches broom'

Internal symptoms:

Many abnormalities in tissues and cells are noticed.Some intracellular inclusion bodies like lamellar or amoeboid like bodies are formed. Besides, hyperplasia and necrosis of cells and tissues are common in diseased plants.

Physiological symptoms.The functional system of plants become affected directly or indirectly due to virus infection. It leads to accumulation of many metabolic products in the cells. Virus infected cells possibly synthesise certain new proteins which affect their permeability and enzyme system. The chlorophyll contents of diseased leaves are low and it leads to lower rate of photosynthesis.Viruses accelerate the activity of oxidizing enzymes like cytochrome oxidase, peroxidase and the rate of respiration is usually high in diseased leaves.

Transmission of viruses:

The virus moves from one host to another for its survival and in search of a suitable host.For its transmission,the virus depends on external carriers.Some common modes of transmission of plant viruses are i) transmission by vegetative propagation ii) transmission by friction and rubbing iii) transmission through soil and seeds. iv) transmission through pollen grains v) transmission through fungi vi) transmission through insects vii) transmission by infected agricultural tools.

Economic importance of viruses:

Viruses are generally harmful as they produce serious human, animal and plant diseases.

Diseases on Humanbeings:

Chicken pox, Dangue fever, Measles, Rabies, Small pox, Mumps, Yellow fever, Polio, AIDS, Carsinoma.

Diseases in animals:

Foot and mouth disease, Rabies in dogs and cats, Carcinoma in rabbits, cattles and dogs, Influenza in mice, Carsinoma in rabbit, cattles and dogs.

Diseases in Plants:

Tobacco mosaic, Leaf curl of Papaya, Bunchy top of Banana, Bean mosaic, Vein clearing in lady finger, Potato leaf roll, Wheat mosaic.

GENERAL ACCOUNT ON BACTERIOPHAGES:

Viruses which infect bacterial cells are known as bacteriophages or bacterial viruses.

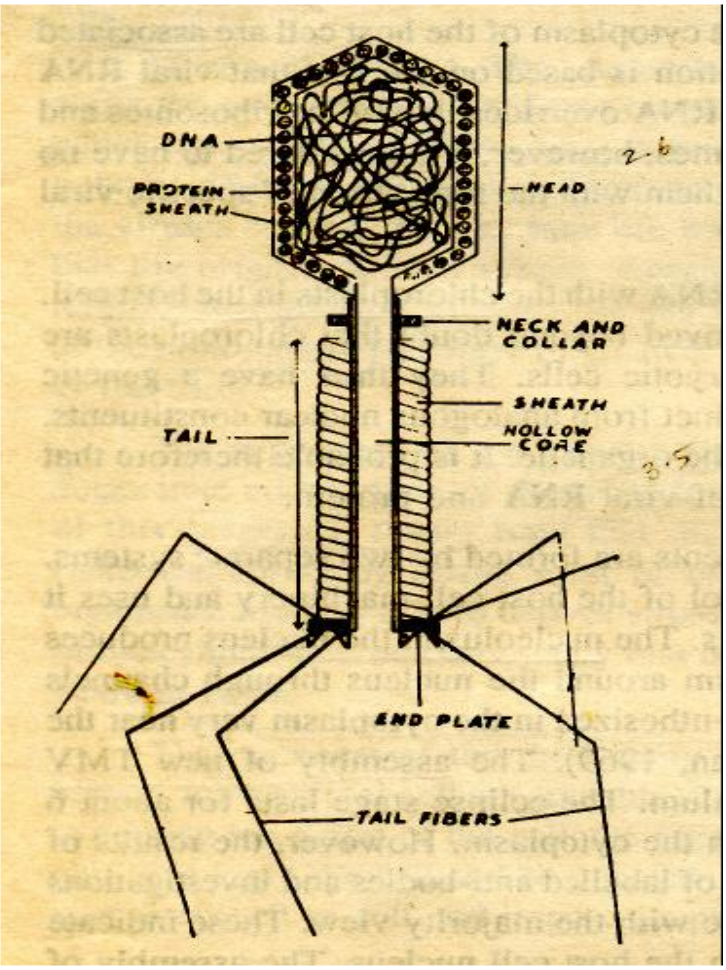
Bacteriophage was discovered by **Edward Twort** and **d'Herelle** independently.

Occurance:

Bacteriophages are obligate parasites and are found in all such habitats where bacteria can survive.Abundant in soil, sewage water, fruits, vegetables, milk and nodules of legumes. In humanbeings phages can be found in intestinal contents, urine, blood, sputum, saliva, pus and nasal exudates.

Structure:

Bacteriophages are very small particles and cannot be separated by bacterial filters.A T-even phage bacteriophage is tadpole like and differentiated into hexagonal head and a helical or cylindrical tail.The size of the head is about 950x650 A^{o} and that of tail is 1150x170A^{o}.The wall of the head is composed of 2000 similar sub-units of proteins.The head encloses a double stranded 50 milli micron long DNA molecule inside. It is variously coiled.It may be single stranded DNA or single stranded RNA.The phage DNA differs from bacterial DNA chemically.The extended part between the head and the tail is called collar.The tail is almost equal to the length of the head and has a diameter of 80A .At the proximal end of the tail is present a hexagonal tailplate or basal plate.The basal plate is approximately 200A thick.It has six tail pins on its under surface ,each about 1500Along.The tail pins help to adsorb bacteriophage on bacterial wall and their enzymes are helpful in the lysis of bacterial cell wall.Long tail fibres(six) are connected to the basal plate along with the pins.The long tail fibres are meant for adsorption and the short pins help the phage in ensuing a better grip of the host during DNA transmission.



Diagramatic representation of a bacteriophage.

Types of bacteriophages:

The bacteriophages attacking Escherichia coli are called as T-type or Coliphages and enumerated asT1 –T7 by Delbruck.Among these T2, T4, T6 have been studied in detail and they are collectively called T-even phages. T1, T3, T7 are called as odd phages.

Depending on the interaction of phages with the bacterial cell, they are distinguished into Virulent or lytic and avirulant or temperate phages.

Life cycle (or) Growth cycle of Bacteriophages.

Lytic cycle:

Lytic cycle has six phases in its life cycle.

Adsorption phase:

The phages first of all adsorb on the specific receptor sites on the cell wall of the host E.coli.Basal plate, tail pins and tail fibres are helpful for adsorption.

Genome transmission phase:

After adsorption, the bacteriophage forms a hole on the host cell wall and plasma membrane by lysozyme secreted by the basal plate and tailpins.The tailsheath now contracts and the phage DNA present in the head is injected into the bacterial cell.After DNA transfer, empty protein shell of the phages are called ghosts and they are discarded.

Genome replication phase:

The phage DNA replicates inside the host cell repeatedly, thereby forming several replica of the genome.

Protein synthesis phase:

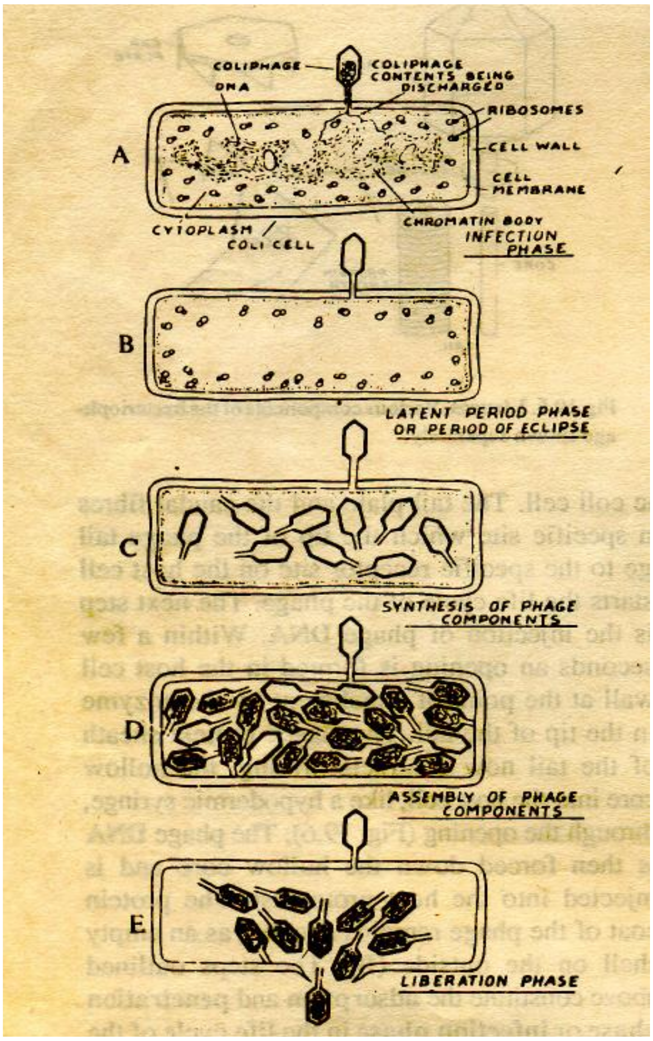
The phage DNA controls the protein synthesizing machinery of the host.The synthesis of proteins of coat occurs later on through the synthesis of viral m-RNA.

Maturation phase (Assemblage of new phage particle):

The DNA and proteins of phages are separately synthesized.The head is assembled first and thereafter the tail is added.The phenomenon of assembling is called maturation.

Release of new phage:

The enzyme formed by the phage now acts upon the host cellwall and the host cell ruptures as a result of lysis and the phage particles are liberated.The entire cycle of phage development is completed in 30-90 minutes .A total of 200 phages are formed in a bacterium.



Bacteriophage: Lytic life cycle.

Lysogenic cycle.

This type of lifecycle is shown by Lambda phages attacking E.coli .Such phages are

Described as temperate phages.During lysogenic cycle the phage particles do not multiply and the host cells do not lyse.

Events of this cycle.

The phages adsorb upon the reseptor sites and their DNA is transmitted to the host cell.Then the phage DNA integrates with the bacterial genome and the integrated state is called 'prophage'.The prophage replicates and multiplies its type.This phenomenon is called lysogeny.

General account on Cyanophages:

Sofferman and **Morris** were the first to report the discovery of viral agent attacks and lysis blue-green algae.The term Cyanophage denotes a viral agent which is capable of infecting, reproducing and lysing a blue-green alga.

Distribution:

Cyanophages are worldwide in distribution.Noticed in fresh water bodies like streams, rivers, lakes, industrial storage tanks, farm and residential ponds also noticed in sewage,ponds and rice-fields.

Ultrastructure of Cyanophage: Cyanophage is head-tail type.The cyanophage virion is differentiated into three regions namely head,tail capital and tail.

i) **Head :** It may be polyhedron or icosahedron.It has many facets.It is differentiated into an outer protein coat which encloses a cavity filled with the genetic material,nucleic acid.The nucleid acid forms the core of the cyanophage head and is the infective agent.This is inert and nongenetic.It is 8-10 nm thick.The nucleid acid is always a DNA molecule.It is a single thread-like,double stranded macromolecule,length of 13.2nm.It fills the cavity of the head capsid.

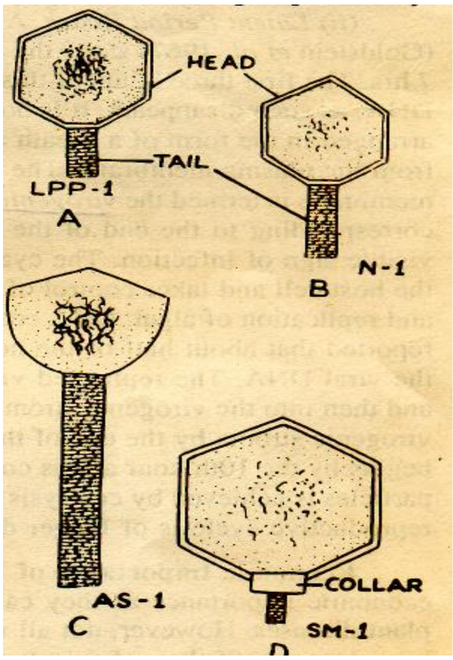
ii) **Tail :** The short, hollow cylindrical tail is 20-25 nm long and 15nm wide.The upper end of the tail is attached to the head capsid and the lower end of the tail produces tail fibres .The tail is non-contractile.It is differentiated into an outer protein sheath called tail sheath which encloses a cavity called tail cavity.The tail sheath is made up of 2-4 rings of six protein subunits each.

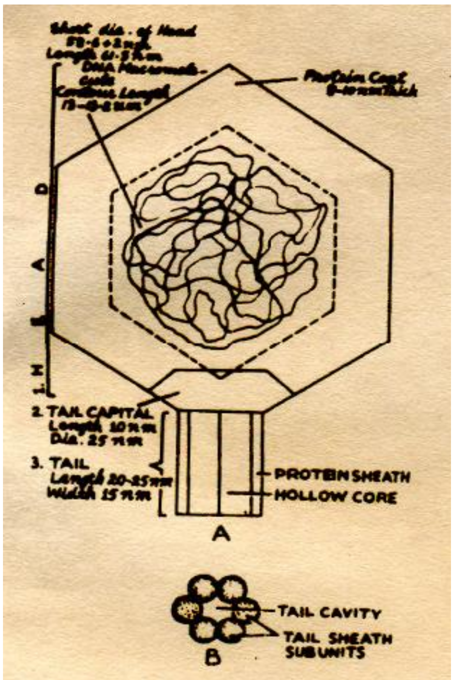
iii) **Tail capital** : Tail capital is present at the junction of the tail with the head capsid.It is about 10nm long and 25nm in diameter.It protrudes into head capsid.The function of the tail capital is uncertain.Propably it serves as a joint to fix the tail to the head capsid.

Life cycle of Cyanophage is more or less like that of lytic bacteriophage life cycle;but,the cyanophage cycle is of longer duration as compared with that of the bacteriophage.

Nomenclature of cyanophages:

Based on host range,cyanophages are named as LPP,SM-1,AS-1,N-1. LPP is named after the genera which attack like **L**yngbya,**P**lectonema and **P**hormidium.Several strains of LPP are LPP-1,LPP-2,LPP-3,LPP-4,LPP-5.Similarly phages infecting *Synecococcus elongates*,*Microcystis* a*eruginosa* are termed as SM group of cyanophages(Strains SM1,SM-2).Those which infect *Nostoc muscorum* is termed as N group of phages.Those infecting *Anacystis nidulans* and *Synecococcus cedrorum* are termed as AS-1.





A,B,C,D.-Different types of Cyanophages. Cyanophage –LPP1 structure.

General account onMycophages.

Mycophages are viruses which attack fungi.Mycophages are also called mycoviruses.So far nearly 5000 fungal species are known to be attacked by mycoviruses.Of these, most species of *Penicillium* and *Aspergillus* are infected with viruses.

Mycophage size ranges from 25-50nm(diametr) and weight from 6-13x10 daltons.The nucleoid part contains double stranded RNA with a molecular weight of 2-8.5x10.

NOTES

UNIT - V

PLANT DISEASES

Plants suffer from number of enemies particularly by pathogenic (disease causing) microorganisms. Pathogenic microorganisms includes some bacteria, fungi, virus etc. cause diseases to the plants.

Bacterial Diseases

Plant pathogenic bacteria have been known since 1882. They are by far the largest group of plant pathogenic prokaryotes cause a variety of disease symptoms.

General Symptoms of Bacterial Diseases

Plant pathogenic bacteria produce many kinds of characteristic symptoms on the plants attacked by them. They cause leaf spots and blights, soft rot of fruits, roots and storage organs, wilts, galls and tumors, scabs and cankers, etc.

Leaf spots

Bacteria invading through leaf stomata cause necrosis of leaf tissues around the substomatal space resulting in the appearance of necrotic lesions on the lamina surface. The dead tissues of the infected area appear water-soaked and the spots generally remain restricted in growth.

Blights

The invasion by the bacterium leads to a very rapid and extensive necrosis of the infected area of plant parts resulting in the scorched appearance of the affected surface.

Soft rots

There is softening of the infected tissue due to dissolution of the middle lamella between cell walls by pectolytic enzymes, thus leading to maceration of tissues. Very often a dirty liquid oozes out of the affected area.

Tumors and galls

Infection causes hyperplasia and hypertrophy of the cells in the invaded tissue, resulting in the development of minute galls or large tumors. *Agrobacterium tumefacines* producing crown gall disease is the best example.

Cankers

These are the rough, warty outgrowth formed on leaves, twigs and fruits. They develop as a result of necrosis of the invaded tissues and production of cork cells by undamaged host cells.

Bacterial Leaf Blight of Rice (BLB)

The disease was first seen by farmers in the Fukuoka area of Japan in 1884 and by 1960 it was observed in all parts of Japan except the Northern Island of Hokkaido. During last 30 years or so the disease spread to all major rice-growing countries in Asia, Australia, several Latin American countries, Malaysia, West Africa, Senegal and recently to U.S.A. Intensive methods of rice cultivation using high-yielding varieties and high doses of nitrogenous fertilizers intensified the severity of this disease in most of the Asian countries.

From India, bacterial leaf blight (BLB) of rice was first recorded in 1960 from Maharashtra. This has become a serious problem especially in Tarai area of U.P. where the environmental conditions are much favourable for its incidence and development.

The damage to the crop is partial or total blight of leaves and complete wilting of the infected tillers resulting into unfilled grains. In Japan, the yield losses range from 20% to 30% in severely affected fields and may go up to 50% in rare cases. In the Philippines and Indonesia losses are higher than Japan. In the tropics, the disease has been very destructive. Losses ranging from 6% to 60% have been reported from India.

Symptoms

The disease occurs rarely in seedbeds. Tiny water soaked spots appear at the margins of fully developed lower leaves of seedlings. Infected leaves turn yellow, dry rapidly and wither as the spots enlarge. The disease (leaf blight phase) infect becomes noticeable in the field after the maximum tillering stage and is conspicuous at the heading stage about four to six weeks after transplanting. In the beginning, water soaked lesions appear a little below the tip of leaves, along their margins, usually on one or sometimes on both sides. The lesions enlarge both in length and width with a wavy margin and turn straw yellow within a few days, covering the entire leaf. Water soaking is seen along such enlarging lesions. (Fig. 1).

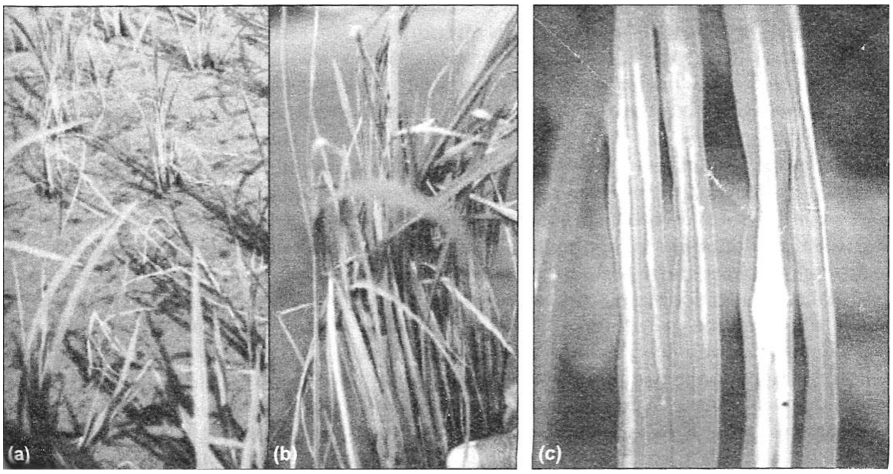


Fig. 1

Bacterial leaf blight (BLB) of rice. A part of infected field (a); a close-up infected plants (b); a close-up of infected leaves

As the disease advances, infected leaves become dry and rolled. Although lesions appear generally at the leaf margins, they may start at anywhere on the leaf blade. When the lesions extented up to leaf sheath and sometimes even culm, the tiller or even the whole clump may die. Milky or opaque bacterial exudates can be seen during morning hours, when the relative humidity is high. The exudates dries up forming pale yellow, small spherical beads on leaf, which are shaken off by wind and drop into the field water. These drops can be washed down by rains. The glumes of young rains also get infected. On the glumes discoloured spots surrounded by watersoaking are conspicuous when the grains are young and green. Infected grains mature earlier than healthy grains.

Another common symptom, sometimes observed in tropics is the pale yellow leaves. Some of the youngest leaves in a clump turn pale yellow or have a yellow or greenish – yellow broad stripe, while the older leaves are green. These leaves later turn yellowish and wither away.

Causal Organism and Disease Cycle

The disease is caused by *Xanthomonas oryzae* pv. oryzae, earlier named as *X. campestris* pv. oryzae, *X. oryzae, Pseudomonas oryzae* and *Bacillus oryzae*. The bacterium is Gram – negative, non-spore-forming, short rod with round ends, measuring 1.0 – 2.0 × 0.8 – 1.0 μm with single polar flagellum. The cells are capsulated, single but aggregating in mass. Colonies are circular with entire margins, whitish yellow to straw yellow later and opaque. The bacterium is strict aerobe, optimum temperature for growth is 25° to 39°C and thermal death point is 53°C. Cultural characteristics are typical of *Xanthomonas* spp with some minor differences.

The sources of primary inoculum and initiation of the disease in the field is not very clearly known. The pathogen survives in dry form and growth form. The dry form is a dormant state found on the diseased plants as an aggregated mass (bacterial exudate) or in xylem of the infected tissue. The pathogen survives for long periods at low humidity and low temperature. When the cells in dry form reach the root zone of host plants and other grasses, they are activated into growth form and serve as primary inoculum. In the growth form the pathogen survives in the rhizosphere of winter crops and perennial wild plants. It infects the susceptible host when cells come in its contact. In Japan, the bacterial cells hibernating in the growth form speed up their multiplication with increase in temperature and become the source of primary infection. In dry form the pathogen can survive for a longer period even under unfavourable conditions.

Infected seeds are known to transmit the disease. The bacteria then growing on root and shoot surfaces eventually become the primary inoculum. The cells present in vascular system of lemma and palea ooze out into soil water at the time of seed germination and through flooding the pathogen is then transmitted from soil water to foliage to bring infection. According to some workers, however, seed is not a source of infection. In the opinion of some Indian workers, infected seeds serve as inoculum from season to season in single cropped areas. The cells ooze out from the germinated seedlings and transmitted to leaves by submergence of seedlings in the seedbeds. Then they establish, multiply and initiate infection under favorable conditions.

Disease Control

Chlorination of field water also reduced the disease. Cellocidin, chloramphenicol, phenylmercury acetate reduced the disease effectively. Nickel dithiocarbamate, dethinone, phenazine and phenazine N-oxide have also been recommended. Sprays of agrimycin – 500, agrimycin – 100 and streptocycline alongwith copper compounds were found effective.

Fungal Diseases

Fungi are generally microscopic, eukaryotic, spore-bearing mycelial heterotrophs. More than 10,000 species of fungi cause diseases in plants. These include biotrophs, such as white rusts, rusts, downy mildews and powdery mildews which grown on live tissues. In the absence of their host plants can survive and even grow and multiply on dead organic matter as saprophytes.

General Symptoms

Different groups of plant pathogenic fungi produce symptoms on the attacked plants which characterize a particular group of the disease.

Rust

Numerous small pustules on leaves or stems, usually of a powdery mass of brown, rusty colour.

Smut

Infected ovaries or galls filled with sooty or charcoal like, dark brown to almost black powdery mass of spores or mycelium of the fungus.

Mildew

Affected areas of leaves, stems, blossoms and fruits, covered with whitish mycelium and the fructifications of the fungus. In downy mildew the areas show a fur-like growth of sporangiophores and sporagia on the undersurface of leaves. In powdery mildews, the area is covered with superficial whitish powdery mass of oidia and oidiophores of the pathogen that gives a dusty appearance.

White rust

Numerous shining white blister like pustules on leaves / stem which break open at maturity exposing powdery mass of spores.

The most common necrotic symptoms are as follows:

Leaf spot

Localised lesions on leaves consisting of dead and collapsed cells. They are of various size and shape. If dead tissue shrinks and separates from the healthy tissue, the condition is known as shot hole.

Streak / Stripe

Elongated, narrow lesions on leaves, usually of brown shade.

Blight

General and extremely rapid and sudden browning and death of leaves, branches, twigs and floral parts or entire seedling / young plant.

Damping – off

Rapid death and toppling down of young seedlings due to disintegration of stem tissues at ground level.

Leaf Spot - Tikka Disease of Groundnut

Leaf spot, also known as Tikka disease is an important fungal disease of the crop and is widely distributed wherever groundnut is cultivated. Due to attack the number and size of the pod are greatly reduced resulting into yield loss. The number and size of the pods are reduced due to severe spotting of leaves, leading to defoliation and general weakening of the plants.

Symptoms

Lesions are commonly dark (reddish) brown to black on the upper surface and light brown on the lower leaf surface. (Fig. 2).

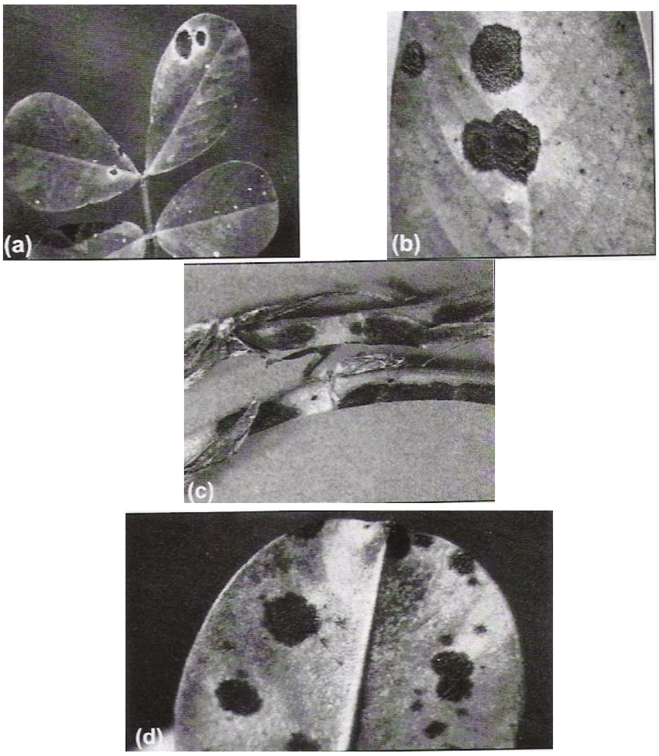


Fig. 2

Leaf spot of groundnut. Symptoms of early leaf spot on leaves (a) and stem (c); close-up of early spot on leaf showing brown and raised appearance (b); late leaf spot showing dark brown to black and rough appearance (d)

Leaf spot on upper surface is commonly surrounded by a yellow chlorotic halo. This is absent or indistinct on lower surface. But the halo is not reliable characteristic for field identification of early leaf spot. Sporulation occurs mainly on necrotic areas of lesions on the upper surface, and they turn to reddish-brown at sporulation stage.

Spots lesions produced by *Cercospora personata* (late leaf spot) are usually smaller and more nearly circular than early leaf spot lesions, 1 to 6 mm in diameter and are commonly dark gray or black on the lower leaf surface. There is no yellow halo around them. Concentric rings of conidia are macroscopically visible on the lower surface. This characteristic is useful for field diagnosis of this pathogen.

Both these pathogens can be distinguished after sporulation. In *C arachidicola*, the conidia are mostly confined to the upper leaf surface, and occasionally on the lower one. They are sparse and not formed in concentric rings. In *C. personata*, conidial production is restricted to the lower leaf surface and conidiophores develop concentric rings. Symptoms also develop on petioles, stipules, stems and pegs.

Causal Organism and Disease Cycle

***Cercospora arachidicola* (Early leaf spot)**

The mycelium is initially intercellular becoming intracellular when the host cells collapse. Haustoria are lacking. Stroma slight to 100 μm in diameter and dark brown. Conidiophores five to many pale golden brown or yellowish brown, darker at the base, mostly once geniculate, unbranched, and 20 – 50 × 3 – 5 μm in size, continuous or with 1 to 2 septa. Conidia are subhyaline, pale, olicaceous or pale yellow, obclavate, often curved, to 12 septate, rounded to truncate at base, tip subacute, and measure 35 – 110 × 4 – 5 μm. (Fig. 3)

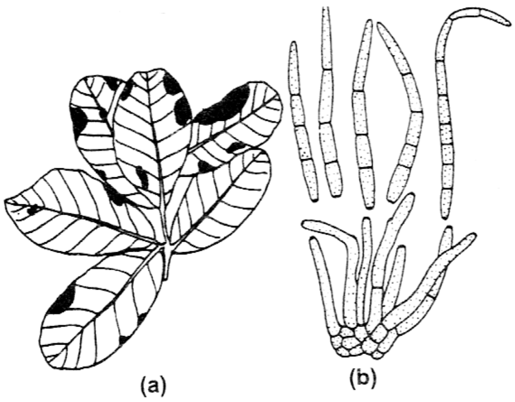


Fig.3

Tikka disease of groundnut caused by *Cercospora arachidicola* (early leaf spot). (a) symptoms, (b) conidiophores, and conidia

***Cercospora personata* (Late leaf spot)**

The fungus has also been named as *Cercospordium personata.* The mycelium is septate, intercellular with branched haustoria in live cells. Stroma dense, pseudoparenchymatous, upto 130 μm in diameter. Conidiophores emerging through ruptured edidermis in dense fascicles, are pale to olivaceous brown, smooth, one to three geniculate or not, 10 – 100 × 3.0 – 6.5 μm in size, septate or continuous, sometimes 1 to 2 septate, usually simple, rarely branched, with prominent conidial scars. Conidia medium olivaceous, cylindrical, obclavate, usually straight or slightly curved finely roughence wall, rounded at the apex, base shortly tapered with a conspicuous hilum, 1-to 9-septate, not constricted, mostly 3-to 4-septate, and measure 20-70 x 4-9 (mostly 30-50 x 6.5-7.5) μm. (Fig. 4).

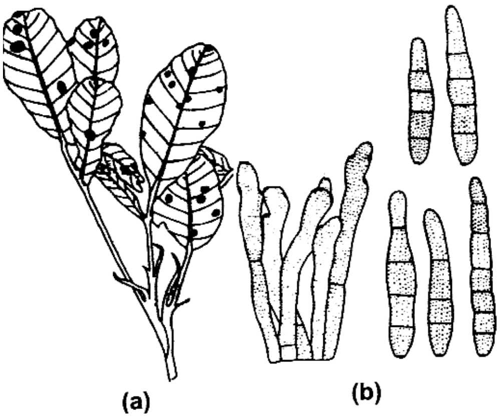


Fig.4

Tikka disease of groundnut caused by *Cercospora personata*.

(a) Infected leaf, (b) conidiophores, and conidia

There is no definite information available on at the source of initial (primary) inoculum. Since the perfect states of both pathogens are rare in nature, ascospores may not be the source of primary inoculum. Conidia present in crop residue are probably the most important the source of primary inoculum. Conidia lying in soil on diseased plant debris and those carried in the shell are the source of initial inoculum.

Disease Control

Several cultural practices may give partial control of the disease. Crop rotation delays the onset of disease and reduces the rate of disease progress. Deep burial of crop residue reduces the load of primary inoculum. Crop management practices may result in modification of environmental conditions that influence disease progress. Seeds with shell should be disinfected with sulphuric acid. Seeds without shell are disinfected by soaking them in 0.5% $CuSO_4$ solution for half an hour or by dressing them with Agrosan GN. Secondary spread of disease through conidia disseminated by wind can be checked by foliage sprays with fungicides. Some most effective ones are, Bordeaux mixture (4:4:50 or 5:5:50), Dithane Z-78 (0.28%), Dithane M-45, Fycol 8E, Cosan and Copper Sulphur Mixture (15 and 25 Ib/acre). Five to six spray are required. Benlate, Bavistin, Brestanol and Cercopin have been found very effective in the Tarai area of U.P.A singly spray of mixture of carbendazim (0.07%) and mancozeb (0.15%), is also very effective.

Viral Diseases

General Characteristics of Plant Viruses

Plant viruses differ greatly from other plant pathogens (fungi, bacteria, etc.) not only in size and shape but also in the simplicity of their chemical and physical structure, methods of infection, multiplication, translocation within the host, dissemination and the symptoms they produce on their hosts.

Symptoms caused by some plant viruses

The most obvious symptoms are usually those appearing on the leaf, but some viruses may cause striking symptoms on the stem, roots and fruit with or without symptom development on the leaves. In almost all viral diseases of plants occurring in the field the virus is present throughout the plant (systemic infection), and the symptoms produced are called systemic symptoms.

The most common types of plant symptoms produced by systemic virus infections are mosaics and ringspots. A large number of other less common symptoms are stunt, dwarf, leaf roll, yellow, streak, pox, enation, tumors, pitting of stem, pitting of fruit and fattening and distortion of stem etc. These symptoms may be accompanied by other symptoms on other parts of the same plant.

Mosaics

These are characterized by light-green, yellow, or white areas intermingled with the normal green areas of the leaves or fruit, or of whitish area intermingled with areas of the normal colour of flower or fruit. Depending on the intensity or pattern of discolorations, mosaic-type symptoms may be described as mottling, line pattern, veinclearing, veinbanding, vein-thckening, chlorotic spotting etc.

Mottles

It is a kind of mosaic, where an irregular pattern of indistinct light and dark areas develops on the leaves. Like mosaics, there are green and white or green and yellow areas.

Yellows (chlorosis)

In extreme cases of mosaics and mottles, the leaf may become almost completely yellow due to chlorosis.

Vein-clearing

There is chlorosis of leaf tissue in close proximity to the veins. The tissue close to veins turns yellow, remaining area appears green. This is very common in bhindi.

Vein-banding

The parenchyma close to the veins is green and rest of the lamina surface shows chlorosis i.e. becomes yellow.

Ringspots

These are chracterised by the appearance of chlorotic or necrotic rings on leaves and sometimes also on fruit and stem.

Leaf-curling or leaf-rolling

These are common in papaya, tomato, potato etc, where leaves become curled and rolled to varying extents.

Stunting

The general growth of entire plant is affected resulting into unusually shorter size of plant.

Tumors

These are gall-like structures developing on roots or stems. In Fiji disease of sugarcane, elongated galls develop on leaves.

Little leaf

Leaves are reduced in size. In fern-leaf, there is much suppression of the lamina.

Bunchy Top of banana

The disease is the most important viral disease of banana. It occurs in most banana growing countries of the world it causes severe losses because infected plants fail to produced fruits. In India, the disease causes huge losses in the banana plantation in Kerala state, the major banana growing areas of the country. The disease was first reported during 1940 from Travancore (Kerala).

Symptoms

The disease appears at any stage of plant growth, on very young as well as adult fruit-bearing plant. In severely infected plant, a tuft of narrower and upright leaves forming a dense rosette at the apex, appears at the top of the plant, hence the name bunchy top. The young infected plants remain stunted with their leaves becoming upright. (Fig. 5).

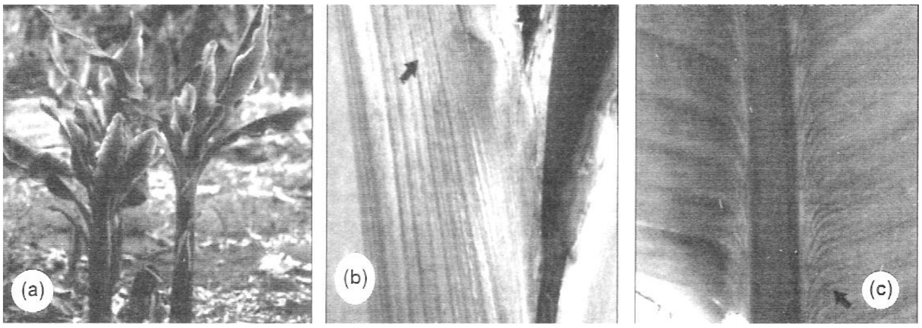


Fig. 5

Bunchy top of banana. Diseased Plants (a);

close-ups of infected leaves (b, c)

New leaves of infected plants develop dark green streaks on secondary veins on the underside of lamina and on the midrib as well as petioles. The streaks are about 1 to 2.5 cm long and 0.75 mm wide. Such streaks (sometimes also as green dots to a continuous dark green line) may begin to appear on emerging or newly emerged tightly rolled leaves as pale whitish streaks along the secondary veins. These streaks become conspicuous dark green along secondary veins of the opening leaves. Older leaves, besides showing these symptoms also become dwarfed, curled and chlorotic along their margins. The leaves gradually become brittle. Depending upon the severity of infection, the inflorescence and fruit bunch either fail to form or fail to emerge from the pseudostem. The fruit bunches are reduced in size. The virus is systemic. The phloem becomes non-functional and its cells infected with the virus produce a fluorescence specific to this disease.

Causal Organism and Disease Cycle

The disease is caused by Banana bunchy top Virus (BBTV). The particles are isometric, small, about 18-22nm in diameter, with multiple (at least six) circular, singly-stranded DNA components.

The virus is not sap transmissible. The main source of primary infection are the diseased suckers used for planting. It the plantation, the disease spreads by suckers produced by a diseased plant. These suckers spread the virus form plantation to plantation. Thus propagative materials as rhizomes suckers or tissue-cultured meristems transmit the virus over long distance. Another means of secondary spread (short distance) are the banana aphid. These aphids occur around the base of the pseudostem at soil level and just below the soil, as well as between the outer leaf sheaths and the pseudostem.

Disease Control

Field sanitation is very important in control of the disease. Destroying all volunteer banana plants and rouging of infected and nearby plants reduces the spread of the virus. Besides following quarantine regulations, use of virus-free propagative material and locating new plantations away from older infected ones help in minimising the virus infection. Aphid control by spraying power kerosene or parathion has also been recommended. It is difficult to develop disease resistant cultivars, as sources of resistance are not yet available.

Plant Disease Control Methods

Methods of plant disease control are as diverse as diseases themselves. Various methods have been categorized in different ways. One way to classify them is (i) **prophylaxis** or **Prevention,** and (ii) **immunization.** Prophylaxis is the protection of the host from exposure to the pathogen; from infection or from environmental or any other such factors favourable to disease development. Immunisation refers to improvement of resistance of the host to infection and to disease development. In plant pathology it is commonly referred to as disease resistance.

Agents of control

On the basis of nature of the agent employed to control the disease, the various methods of disease control are generally classified as physical, chemical and biological methods of disease control.

Physical Methods

The physical agents most commonly used for eradicating or reducing the inoculum of plant diseases are, temperature (high or low), dry air, some light wavelengths and radiations.

Heat treatment

Heat treatments have been used for soil sterilization, disinfection of propagative organs, freeing plants from viruses, and for healing plant products before storage.

Soil Sterilisation

In green house, soil sterilization is done by heat carried in live or aerated steam or hot water. The soil is steam sterilized either in special containers into which steam is supplied under pressure, or on the greenhouse benches in which case steam is piped into and allowed to diffuse. Heat tolerant weed seeds and TMV like pathogens are killed at a temperature between 95 and 100°C. Heat sterilization of soil can also be done by heat produced electrically or supplied by steam or hot water.

Hot-water treatment of seeds and other propagative organs

Hot-water treatment of certain seeds, bulbs and nursery stock is used to kill any pathogens with which they are infected or which may be present inside seed coats, bulb scales, etc.

Hot-air treatment of storage organs

Treatment of certain storage organs with warm air removes the excess moisture form their surfaces and hastens healing of wounds thus preventing their infection by some weak pathogens.

Elimination of Certain Light wavelengths

Plant pathogenic fungi, such as *Alternaria and Botrytis* sporulate only when they receive light in the UV range (below 360nm). It could be possible to control diseases on greenhouse vegetables caused by several fungi by covering or constructing the greenhouse with a special UV-absorbing vinyl film that blocks transmission of light wavelengths below 390 nm.

Refrigeration (Low temperature)

This is probably the most widely used and most effective method to control postharvest diseases of fleshy plant products. Low temperature treatment inhibits or generally retards the growth and activity of all such pathogens. Most perishable fruits and vegetables should be refrigerated soon after harvest.

Radiation

Both, electromagnetic, UV-light, X-rays and γ-rays, and particulate - α particles and β-particles, have been used for their ability to control post harvest diseases of fruits and vegetables by killing the pathogens present on them. Some success could be achieved using γ-rays to control post harvest infections of peaches, strawberries and tomatoes by fungal pathogens.

Chemical Methods

Most chemical methods aim at direct protection of plants form the pathogen, and a few are used to eradicate or reduce the amount of pathogen inoculum.

Direct Protection by chemicals

One of the most commonly known methods of controlling plant diseases in the field and in greenhouse and sometimes in storage is through the use of chemical compounds that are toxic to the pathogens. Such chemicals either inhibit germination, growth, and multiplication of the pathogen or are lethal to the pathogen. The application of chemicals to plants for control of insects and fungi has been practiced for many years.

Chemicals used in plant protection are termed as pesticides and depending on the kind of pathogens they affect, the chemicals are called fungicides, bactericides, viricides, nematicides, insecticides, rodenticides, herbicides an so on. Some chemicals are broad-spectrum, affecting all or most kinds of pathogens, whereas others affect only a few or a singly specific pathogen. Most of the chemicals are used to control diseases of the foliage and other aboveground parts of plants. Others are used to control protect seeds, tubers and bulbs form infection. Still others (insecticides) are used to control insect vectors of some pathogens.

Different groups of chemicals are in used as fungicides. Fungicides are applied to plants in different forms and to various parts of plants. Different terminologies are used for fungicides. These are as follows:

Protective (protectants)

These fungicides kill the pathogen before it attacks the plants. They are thus designed to be present at the infection court in advance of the pathogen in order to prevent infection. While acting in this way, they may also have a direct effect on organisms which have already invaded the host. In this case they act as **eradicants.**

Therapeutic (direct or Eradicants)

These are the fungicides which are applied after attack and kill fungi after they have invaded the plant. They may be fungistatic (fungistat) preventing the growth, or spore suppressants preventing sporulation.

Direct

They kill fungi on plants surfaces, including powdery mildew on leaves and fungi on the seeds coat. Thus these are therapeutic or eradicants in their effect on fungi.

Protective

These are applied before infection occurs.

Contact fungicides

They are aimed at the fungus itself either before or after it has found the host plant.

Residual fungicides

These are applied to the plant before the fungus reaches to it so that chemical forms a protective layer over the plant surface.

Chemicals Used in disease control

There are several hundreds of chemicals developed so far in plant protection as fumigants, seed dressers, sprays, dusts, paints, pastes and systemics. The main groups of chemicals that are in common use are as follows.

Copper compounds

The following formulations are most commonly used:

Bordeaux mixture:

It is the product of reaction of copper sulphate with calcium hydroxide (lime) and is the most widely used copper fungicide. It is effective against many fungal and bacterial leaf spots, blights, anthracnose, downy mildews and cankers. Most commonly used formula is 8:8:100 (copper sulphate (lb): lime (lb): water (gallons).

Inorganic sulphur compounds

These include the following:

Sulphur

Elemental sulphur as s dust, wettable powder, paste or liquid is used mainly for powdery mildews, but also effective against some rusts, leaf blights and fruit rots. It is available under variety of trade names. It is mostly used @ 1-6 lb/100 gallons water.

Lime Sulphur

This is produced by boiling lime and sulphur together. Lime-sulphur, self-boiled-lime-sulphur and dry lime-sulphur are produced.

Organic sulphur compounds (Dithiocarbamates):

They are the most important, most versatile and most widely used group of modern fungicides. They include thiram, ferbam, ziram, nabam, maneb, and zineb, and all are derivatives of dithiocarbamic acid.

Thiram

It is used mostly for seed and bulb treatment for vegetables, flowers and grasses, but also for leaf diseases as some rusts. This is also used as soil drench for control of damping-off and seedling blights.

Ferbam

It is used for many leaf diseases of fruits and ornamentals.

Ziram

It controls foliage diseases of vegetables and ornamentals.

Antibiotics

Most antibiotics are toxic mostly against bacteria, and some fungi. Antibiotics may act on pathogen or on host directly or after undergoing transformation within the host. The most commonly used antibiotics are the following:

Streptomycin

Sold as agrimycin, phytomycin, etc. is used as spray. It is also used as soil drench to control *Xanthomonas* sp.and as a dip or seed disinfectant against bacterial diseases of beans, cotton, crucifers, cereals etc.

Tetracyclines

These are active against many bacteria. Terramycin, aureomycin and achromycin are commonly used and they are injected into tress.

Biological Methods

These methods aim at either direct protection of plants from pathogens or at eradication or reduction of inoculum by using antagonistic organisms, mostly microorganisms. A few biological methods also aim at improving the plant resistance.

Eradication or Reduction of the Pathogen inoculum by Antagonists

Under some situations biological methods can be used to eradicate or reduce the pathogen inoculum. These are as follows:

Suppressive soils

Several soil-borne pathogens, such as *Fusarium Oxysporum* (vascular wilts), *Phytophthora Cinnamomi* (root rot of several fruit and forest tress), *Pythium* spp. (damping-off) cause severe disease in some soils, called **conducive soils.** Whereas they develop much less and cause much milder diseases in other soils, known as **suppressive soils.**

Numerous kinds of antagonistic microbes have been found to increase in suppressive soils; most commonly, however, pathogen and disease suppression has been demonstrated for fungal antagonists, such as *Trichoderma, Penicillium* and *Sporidesmium*, or bacterial antagonists of the genera *Pseudomonas, Bacillus* and *Streptomyces.* Suppressive soil added to conducive soil can reduce the extent of disease by introducing microbes antagonistic to the pathogen.

Antagonistic Plants

Plants like Asparagus and Marigold are antagonistic to nematodes because they release substances in the soil that are toxic to several plant parasitinematodes.

Fungal antagonists

Several fungi have been used in the biocontrol of both, soilborne as well as airborne disease of plants, and also of postharvest diseases.

Soilborne Diseases

Though in several instances, fungal antagonists have been shown to suppress soilborne diseases, there are only few cases where success could be achieved. These are as follows:

Biocontrol of root and butt rot of conifers

This is the classic, most successful story of biological control of a soilborne disease by using a fungal antagonist. *Heterobasidion annosum*

(=*Fomes annosus*), cause of root and butt rot of conifers infects freshly-cut pine stumps and then spreads into the roots.

Diseases of aerial plant parts

Though, no commercial success has so far been achieved in the biological control in phyllosphere, there are instances of effective biocontrols of aerial plant pathogens using fungal antagonists. These are briefly considered below:

Biocontrol of chestnut blight

Chestnut blight, caused by the fungus *Cryphonectrial (Endothia) Parasitica* is controlled naturally in Italy, and artificially in France through inoculation of cankers, caused by the normal pathogenic strains of the fungus, with hypovirulent strains of the same fungus.

Biological control of post-harvest diseases

Post-harvest diseases of several fruits could be effectively reduced by spraying with spores of saprophytic yeasts and filamentous fungi at different stages of fruit development, or by dipping the harvested fruit in the antagonist culture. Yeasts reduced postharvest rotting of peach and apple. Treatment of citrus fruits with *Trichoderma viridae* reduced the green mold disease caused by *penicillium digitatum*.

Bacterial Antagonists

Like fungi, several bacteria also have been successfully used for biocontrol of soilborne, airborne and postharvest diseases of plants.

Soilborne diseases

Though a large number of bacteria have been demonstrated to effectively reduce the soil-borne diseases, only a few of them could so far become available on commercial scale. Some instances of successful biocontrol using bacterial antagonists are given below:

Crown gall of stone fruits

Crown gall of pome, stone, and several small fruits (grapes, strawberries) and ornamentals, caused by the bacterium, *Agrobacterium tumefaciens* is being controlled commercially by treating the seeds, seedlings, and cutting with GaIltrol, a suspension of strain K84 of the related but nonpathogenic bacterium, *Agrobacterium radiobacter.*

Diseases of aerial plant parts

Though none of the biocontrol in phyllosphere could so far be developed on commercial scale, there are several antagonistic bacterial which significantly suppressed the diseases of aerial plant parts. Some such successful cases are described below.

Biological control of bacteria-mediated frost injury of plants

Normally frost-sensitive plants are injured when temperatures drop below 0°C due to ice formation within their tissues. Small volumes of pure water can be supercooled even to -10°C or below without ice formation provided that no catalyst centres or nuclei are present to influence ice formation.

Viral parasites of plant pathogens

Viruses are known to attack all plant pathogens-fungi, bacteria, and nematodes. However, viruses have so far been studied for their potential as biocontrol agents to control bacterial pathogens only. Bacteriophages when mixed with bacterial pathogens, successful control could be achieved in case of several bacterial diseases of plants. However, this tactic is yet to be developed at commercial scale.

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