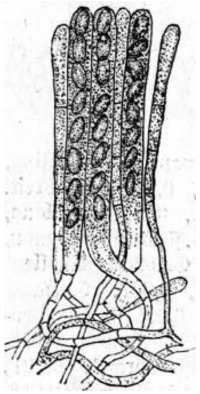
ASCOMYCOTINA

The ‘Sacfungi’

General character of ASCOMYCOTINA



- **Largest group of fungi** – more than 32,000 speciesin 3,400 genera
- Name derived from Greek word: **askos** – bag orbladder and **mykes** – fungus
- Sexually produced spores (**ascospores**) are contained within a sac (**ascus**)
- Include both **saprophytic** and **parasitic** species
- Some are **symbionts** – about 40% of lichenhave ascomycotina members as fungal partner
- Majority are **terrestrial** but few are **aquatic** – marine and fresh water

Vegetative structure

- Thallus may be **unicellular** (Yeast) or **mycelial**
- Mycelium is well developed with branched andseptate hyphae
- Septa with **simple pore**
- Hyphae compactly or loosely arranged
- Mycelium may be **homokaryotic** – all neclei are genetically similar or **heterokaryotic** – nucleiare genetically different
- Some members (Eg. Xylaria, Claviceps) formhyphal aggregations – Stroma, Sclerotium

Reproduction

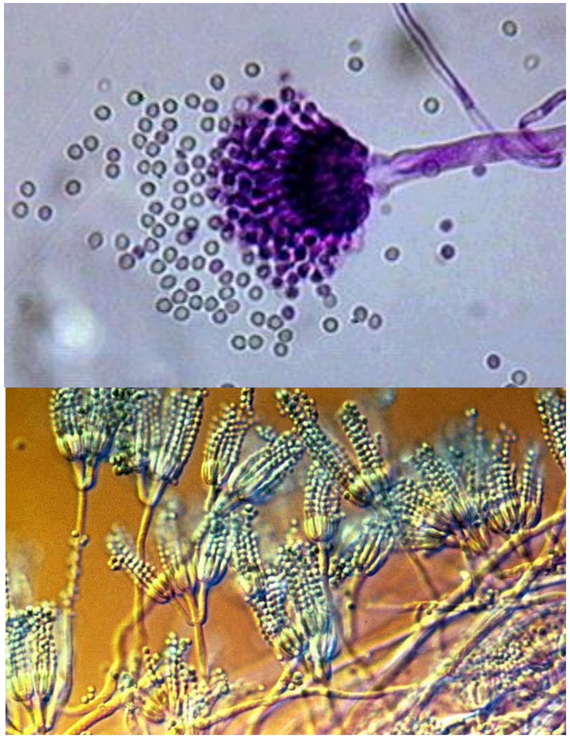
- Asexual or Sexual reproduction

Asexual reproduction

- By formation of spores
- Conidia, Oidia or Chlamydospores

Conidia

- Important mode of asexual reproduction in Ascomycotina
- Exogenous, non-motile spores
- Produced on tip of **conidiophores** – branched or unbranced / unicellular or multicellular
- Single or many chains of conidia are formed on a conidiophore
- Conidia are generally formed basipetally



- Formation of conidia on conidiophore (conidiogenesis) occurs in two ways

– **Blastic conidiogenesis**: conidium develops by blowing out of wall of a cell, usually from the tip of a hypha

– **Thallic conidiogenesis**: conidium develops froma pre-existing hyphae in which terminal or intercalary cells cut off by septa formation

- Conidiophores arise singly or in groups

- If in groups, they may form definite fruiting bodies
  – synnemata, acervulus, sporodichiumor pycnidium

- ***Oidia*** and ***chlamydospores*** are other asexual spores produced in some species
- Fragmentation, fission and budding are shown by some species

Sexual reproduction

- Mycelium is **eucarpic** except in yeast
- Members are either homothallic or heterothallic
- Sexual reproduction is isogamous or heterogamous
- Morphologically distinct sex organs are produced by some species: Male – **Antheridium**; Female –**Ascogonium**

- Initial step in sexual reproduction is fusion of two protoplasts (**plasmogamy**) which bring togethertwo compatible nuclei in a single cell (**dikaryotic cell**)
- Common methods of plasmogamy in ascomycotina are;
  - Gametangial copulation
  - Gametangial contact
  - Spermatization
  - Somatogamy
  - *Autogamy* (Nuclei within the ascogonium arrange themselves into functional pairs without plasmogamy, Penicillium)
  - *Hologamy* (Fusion between two mature somatic cells

    functioning as gametangia, Yeast)

Post - plasmogamy changes

Plasmogamy initiates a new phase in life cycle

- Beginning of dikaryotic phase
- Dikaryotic mycelium produce sac like sporangium called ascus
- Nuclear fusion occurs within the ascus
- Asci are formed in two ways
  - Direct method of development
  - Indirect method of development

Direct development of ascus

- Seen in lower ascomycotina members
- **Plasmogamy** results in a fusion cell with twocompatible, haploid nuclei
- The **fusion cell** enlarges and function as **ascus mother cell**
- Within ascus mother cell, the **two nuclei fuse** to form a diploid nucleus (**zygote**)
- Diploid nucleus immediately undergo a meiotic division

followed by a mitotic division resulting in **8 haploid nuclei**

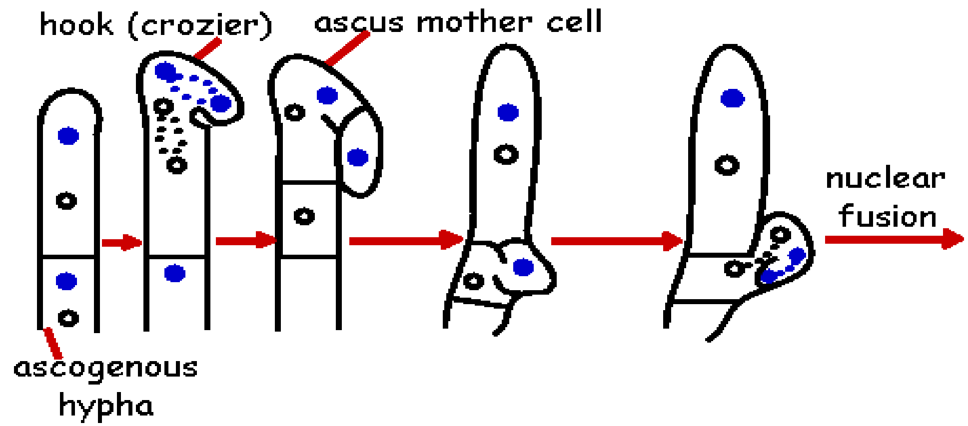
- Each nuclei accumulate cytoplasm, secrete a wall aroundit develop into an **ascospore**
- Ascus mother cell enlarges and develop into an **ascus**

containing 8 haploid ascospores

Indirect development of ascus

- Occurs in higher members of Ascomycotina
- **Plasmogamy** results in **dikaryotisation** of ascogoniumor female hypha
- Male and female nuclei in dikaryotic hyphae **donotfuse immediately**
- Several papillae like outgrowths (hyphae) arise fromthe ascogonium or dikaryotic cell
- These are called **ascogenous hyphae**
- Ascogenous hyphae are asceptate initially but crosswalls develop later
- Two nuclei undergo severalconjugate division and each cell of ascogenous hyphae become dikaryotic
- **Asci** develop from terminal or sub-terminal cell ofascogenous hyphae

Development of ascus



- Asci develop from the **tips of**

  branches
- The dikaryotic tip cell curls over to form a **hook** or **crozier**
- Both nuclei of the hook divide to form **4 nuclei** – onein extreme tip, two lie in the arch and one near the basal septum of crozier
- Septa are formed resulting a *terminal uninucleate cell, binucleate arch cell and a uninucleate stalk or ante penultimate cell*
- These cells compose the characteristic crozier of higher Ascomycotina

- Arch cell contains two nuclei – one male and otherfemale
- It acts as the **ascus mother cell** and enlarges to form the **ascus**

  Two nuclei within the ascus fuse (karyogamy) and form a synkaryon (diploid nucleus)
- Diploid nucleus within the ascus undergo a meiotic division and a mitotic division producing 8 haploid nuclei
- The nuclei gather some cytoplasm and secrete a wall around it resulting in **8 ascospore within an ascus**
- The asci are variable in form – globose, oval, club shaped or cylindrical
- Ascus wall may be single layered (**unitunicate**) or two layered (**bitunicate**)

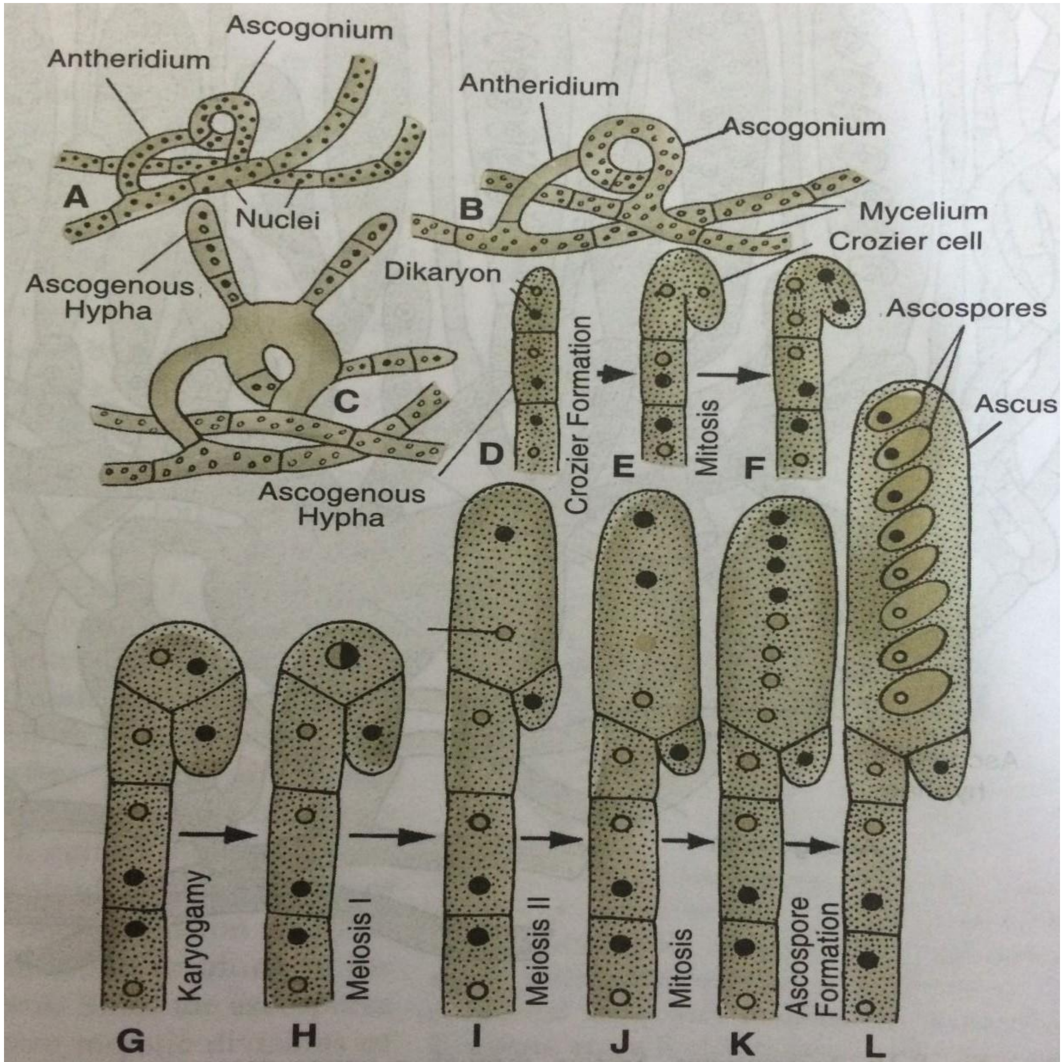


Fig. 8.15 (A-L). Stages in the development of Ascus and Ascospores.

Formation of ascocarp

- The asci and ascogenous hyphae get surrounded by a pseudoparenchymatous mass of sterile hyphae
- The entire fructification is called **ascocarp**
- Ascocarp contains ascogonium, ascogenous hyphae, mass of asci with ascospores, paraphyses and enveloping sheath
- The ascocarp may be of different types – **Ascostroma, Cleistothecium, Perithecium or Apothecium**

Release of ascospores

- When mature, asci dehisce to release the ascospores
- Mode of dehiscence of asci is variable –
  - Apical pore (ascal pore)
  - Lid or operculum
  - Slit
  - In bitunicate ascus, inner wall layer with ascospores protrude through a pore

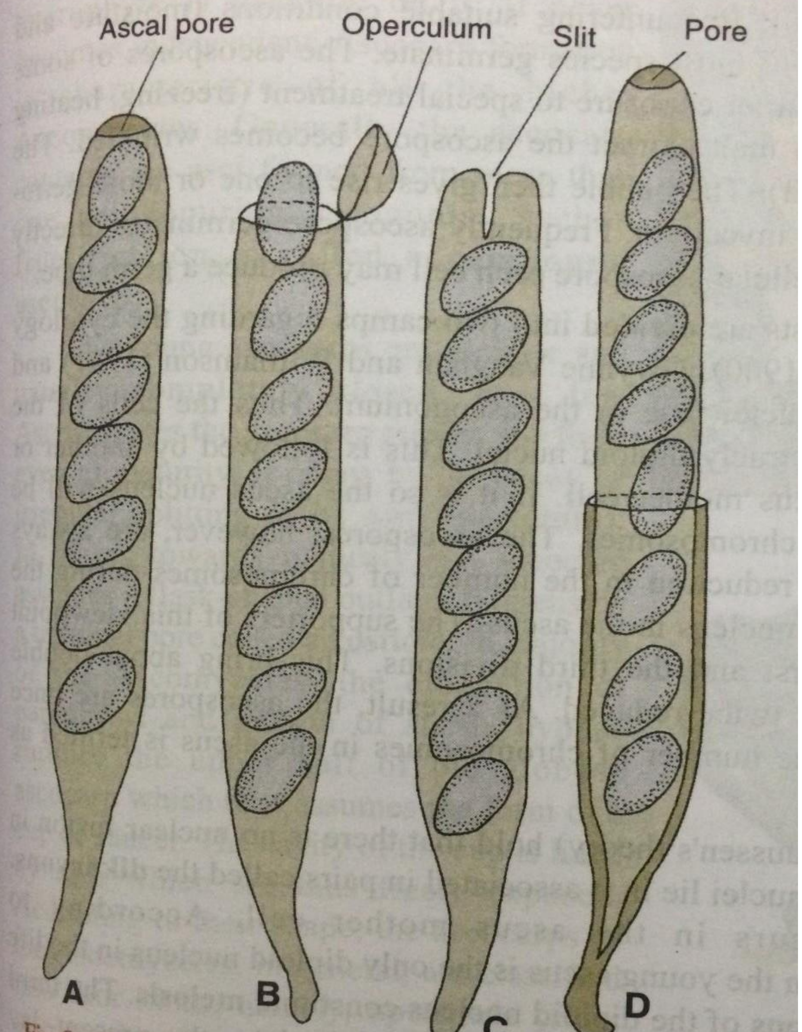


Fig.8.19 (A-D). Ascomycetes. Various types of ascal dehiscence.

(*Aspergillus*) the

Ascospore germination

- Ascospores may be **elliptical** or **spherical**
- It has **dense cytoplasm**, wall may be single layered or double layered. Outer layer is thick if double layered
- Generally **unicellular** and **uninucleate**
- Ascospores germinate under favourable conditions by producing a **germ tube**
- The germ tube later develop into a septate, monokaryotic mycelium

Classification of Ascomycotina

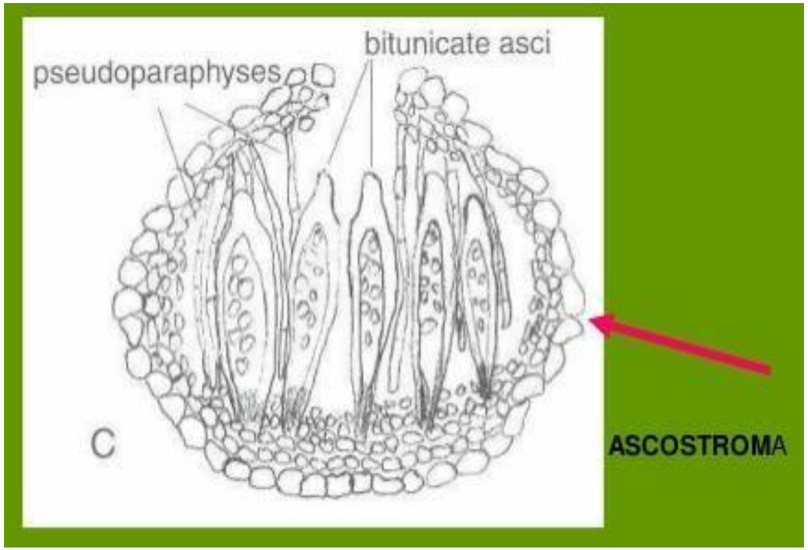
- Ascomycotina is divided into six classes by Ainsworth
  - Hemiascomycetes
  - Loculoascomycetes
  - Plectomycetes
  - Laboulbeniomycetes
  - Pyrenomycetes
  - Discomycetes

Hemiascomycetes

- **Mycelium** is either **poorly developed** or **absent**
- **Direct development of ascus** without formation of ascogenous hyphae
- **No ascocarp formation**
- Asci borne directly on mycelium or from a specialized ascogenous cell
- Eg. Yeast

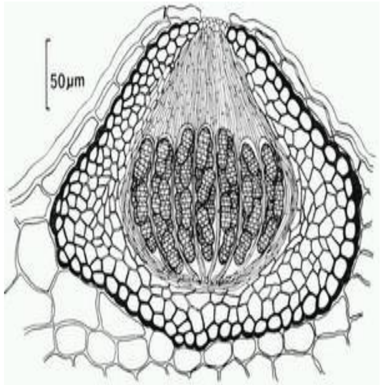
Loculoascomycetes

- Thallus is **mycelial**
- **Produce ascogenous hyphae and ascocarp**
- Asci are produced in a cavity (locule) within a mass of sterile tissue (stroma)
- Ascocarp is **ascostroma**
- **No definite ascocarp wall**
- Ascus is bitunicate
- Eg. Sporormiella



Laboulbeniomycetes

- **Thallus is reduced**
- Members are **exoparasites** on arthropods
- Ascocarp is **perithecium**
- Asci are arranged within ascocarp in regular or parallel layers
- Asci inoperculate
- Eg. Pleospora



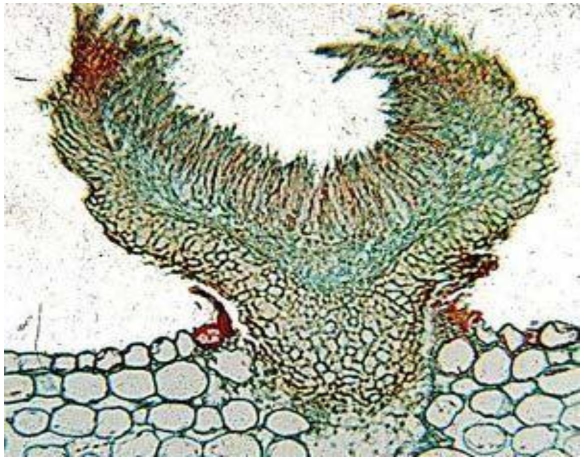
Plectomycetes

- Mycelium is **well developed**, branched and septate
- Ascogenous hyphae develop from ascogoniumafter plasmogamy
- Asci are **unitunicate**
- Ascocarp may be **cleistothecium** or **perithecium**
- **Asci** are globose or oval in shape and **scattered** within the ascocarp
- There is a tendency towards gradual reduction in sex organs especially antheridium
- Eg. Aspergillus, Penicillium

Pyrenomycetes

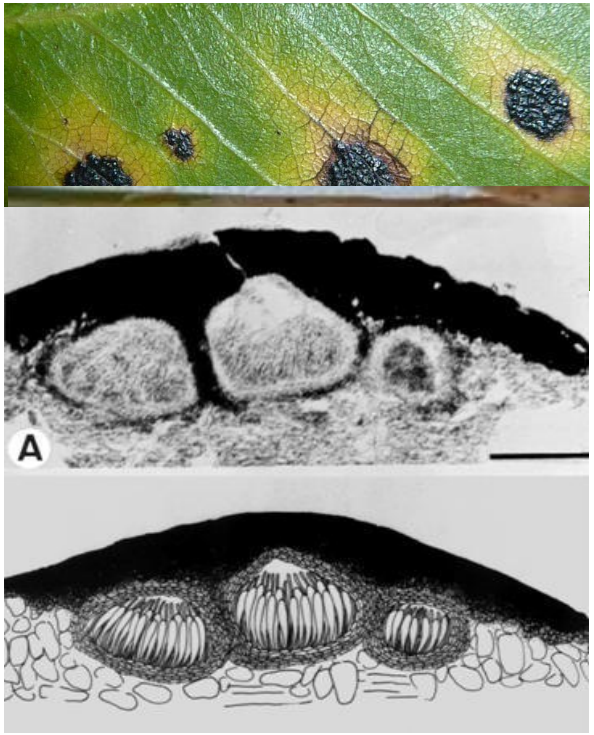
- Mycelium **well developed** and septate
- Ascogenous hyphae and ascocarp are produced
- **Ascocarp is perithecium**
- Asci are arranged regularly in a palisade like layer (**hymenium**)
- Asci are unitunicate and inoperculate with an apical pore or slit
- Eg. Xylaria

Discomycetes



- Well developed **mycelium**
- **Sex organs are lacking**, sexual fusion by **somatogamy**
- Produce ascogenous hyphae and ascocarp
- Ascocarp is **apothecium**
- Asci are arranged in hymenium
- Asci are inoperculate or operculate
- Eg. Peziza

Phyllachora



- Obligateparasiticfungiknowas“tar fungi”
- Causes **tar spot** or **black spot** disease on angiosperms
- Not very harmful to host
- Produce branched septate mycelium into host tissue
- Fruiting body is **perithecium**, produced near leaf epidermis
- Ascospores are liberated by wind or rain splashes

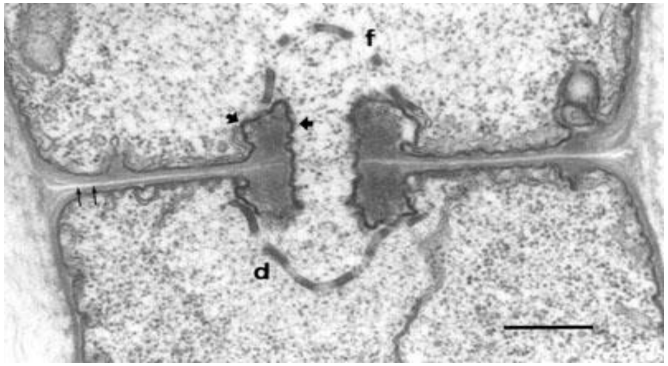
BASIDIOMYCOTINA

General Characters OF BASIDIOMYCOTINA

- Most advanced group of all fungal classes
- Comprises of about 500 genera and 15,000 species
- Includes both saprophytic and parasitic species (Mushrooms, Puffballs, Toad stools, Rusts, Smuts etc.)
- Parasitic genera spread on stem, leaves, wood or inflorescence (Ustilago, Puccinia, Polyporus,Ganoderma etc.)
- Saprophytic species live in decaying wood, logs, dung, dead leaves and humus rich soil (Agaricus, Lycoperdon, Pleurotus, Cyathus, Geastrum etc.)
- Characteristics spores are **basidiospores**, produced on **basidia**

Mycelium

- Mycelium is branched, well developed and perennial
- Spreading in a fan shaped manner – forming **fairy rings**in mushrooms
- Mycelium spread on the substratum and absorb food
- In few genera mycelium form **rhizomorphs**
- Hyphae are septate, septal pore is surrounded by a swollen rim or crescent shaped cap – **parenthesome** – such septa are called **dolipore septum**
- Not seen in rusts and smuts
- Cell wall is made up of **chitin**

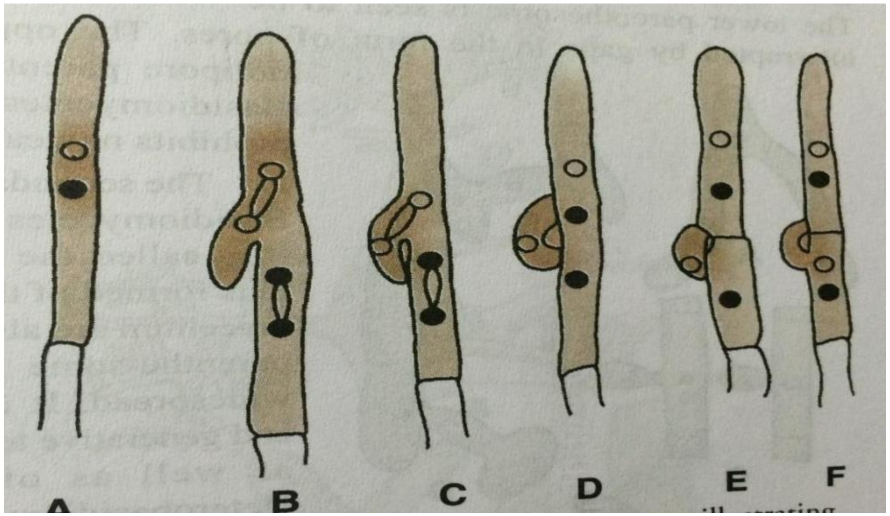


- Mycelium occur in *three* stages
- **Primary mycelium**: **Monokaryotic**, short lived, formedby germination of basidiospores, represent haplophase, does not bear any sex organs
- **Secondary mycelium**: **Dikaryotic**, perennial, formed by the fusion (dikaryotisation) of two dissimilar primary mycelium. Represent dikaryotic phase, produce fruiting bodies and show clamp connections
- **Tertiary mycelium**: In higher members, secondary mycelium get organised into specialized tissues forming fruiting bodies. **Dikaryotic** in nature

Clamp Connections

- Dikaryotic secondary mycelium grow by producing**clamp connections**, unique feature of basidiomycotina
  - Cell divisions are confined to apical cell
  - Dividing cell forms a pouch or clamp during nuclear division
  - The two nuclei of the cell undergo ***conjugate division***
  - One of the four daughter nuclei moves into the pouch/clamp
  - A septum is formed at the base of pouch, separating it
  - Another septum is formed below the clamp connection on parent cell dividing it into two daughter cells, upper cellwith two nuclei and lower with one nucleus
  - Clamp cell grows and fuse with sub apical cell .The nucleus within the clamp migrate to sub apical cell making it dikaryotic
  - Clamps degenerate later

Diagrammatic representation of clamp connection



Fairy rings

- Due to centrifugal growth of dikaryotic mycelium, fruit bodies are formed in a circular ring around the spot where fruit bodies formed in the last year.
- These fruit bodies are arranged in a ring
- Imagined that these rings mark the path of dancing fairies

Fairy rings

Reproduction

- **Vegetative reproduction**
  - *Fragmentation and budding*
- Asexual reproduction
  - Not common, oidia or conidia are produced in some species. Uredospores in rust fungi

Sexual reproduction

- Development of sex organs are absent throughout the group
- Most of the species are **heterothallic** –morphologically similar but genetically distinct
- Involves plasmogamy, karyogamy and meiosis
- Plasmogamy occur either by **somatogamy** or by

  spermatization (exclusively in rust fungi)

- Karyogamy – fusion of dikaryotic nuclei, occurs **withinbasidia**,

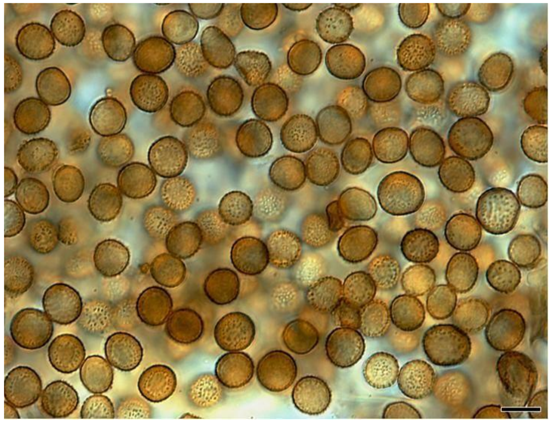
  results in synkaryon, represents a transitory diplophase
- Meiosis –Diploid nucleus within the basidium produce 4 haploid spores, develop into **basidiospores**

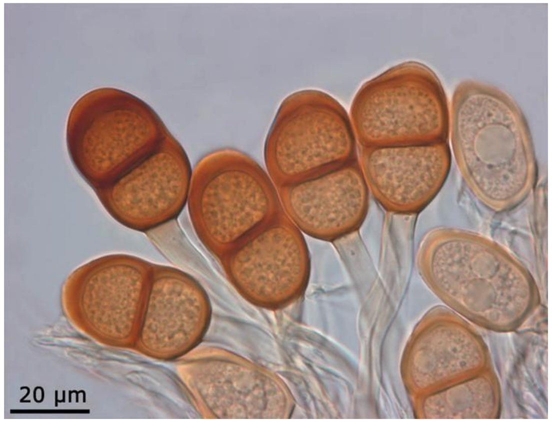
Basidium

- *Basidium is the characteristic reproductive organ of Basidiomycotina where both karyogamy and meiosis occur*
- Produced on dikaryotic mycelium
- Two types of basidium
  – **Phragmobasidium** and **Holobasidium**

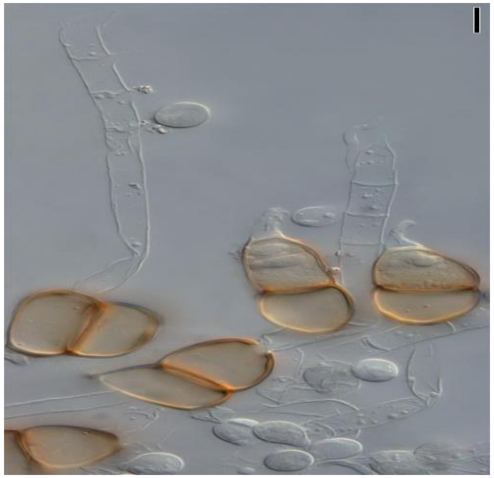
Phragmobasidium

- Typical of rusts and smut fungi, they do not form basidiocarps
- They are **septate** – transverse or vertically
- Formed by the germination of thick walled spores produced from dikaryotic mycelium
- These spores are called **smut** or **brand spores** or **teleutospores**
- Dikaryotic nuclei within the spores undergo fusion to produce a diploid nucleus





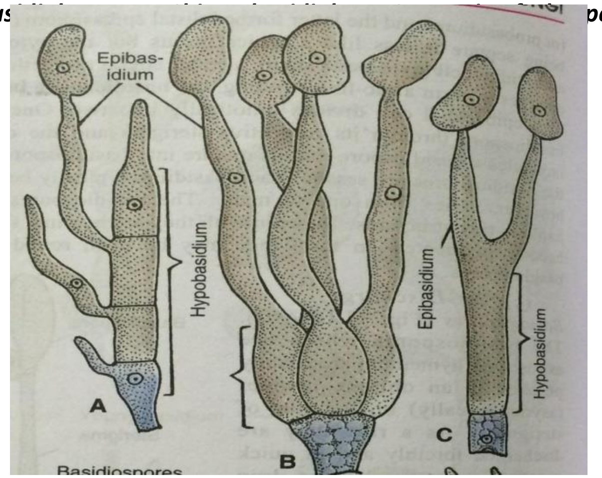
- The spore germinate by producing a germ tube – **epibasidium** or **promycelium**
- Diploid nuclues divide **meiotically**, produce 4 haploid nuclei, nuclei migrate into epibasidium, epibasidium get segmented into 4 uninucleate cells
- Each epibasidial cell produce a small, slender, lateral projection called **sterigmata**
- Haploid nucleus moves into sterigmata, tip of sterigmata enlarges to form a round swelling with nucleus – develop into **basidiospore**

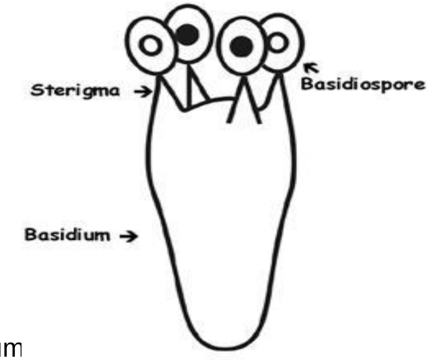


- Phragmobasidium is of three types
  - ***Stichobasidial type***: this type is cylindrical and transversely septate
  - ***Chiastobasidial type***: this type of phragmobasidium is vertically septate
  - ***Tuning fork type***: *Epibasidium is with two long arms resembling a tuning fork. Each arm bears a basidiospore at its tip*

Types of phragmobasidia

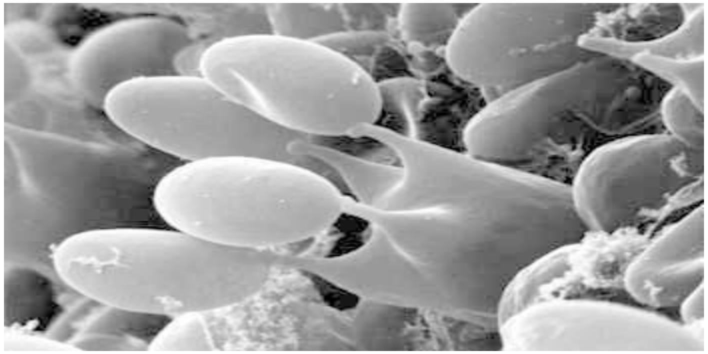
A – *Stichobas* ... ***pe***





Holobasidium

- Characteristic of higher basidiomycetes fungi
- Simple, **club shaped**, **aseptate** with round apex
- Originate from terminal binucleate cell of dikaryotic hyphae – secondary or tertiary mycelium



- Terminal cell elongates, become broader
- Two haploid nuclei fuse to form a diploid nucleus
- Diploid nucleus soon undergo meiosis to produce 4 haploid nuclei

Terminal cell develop into a club shaped basidium

- The club shaped holobaisdium pushes 4 slender projections called **sterigmata**
- Tip of sterigmata swells to form a sac like structure
- A haploid nucleus migrate into each swelling– develop into a basidiospore

- *Protoplast of spore secrete a new wall around it*
- Each basidiospore has a lateral, small outgrowth near the sterigmata –**hilum**
- Each basidium has typically 4 basidiospores that are exogenously produced
- Number of spores/basidium may vary in some species, there may be one, two or more than 4 spores
- **Basidiospores** are unicellular, haploid, oval or spherical
- *They have two layered wall – outer **perispore** and inner*

epispore

Basidiocarps

- In higher basidiomycotina, secondary mycelium form fruiting bodies – basidiocarps
- They are aerial sporophores which bear basidia
- They are of various sizes, types, textures and forms

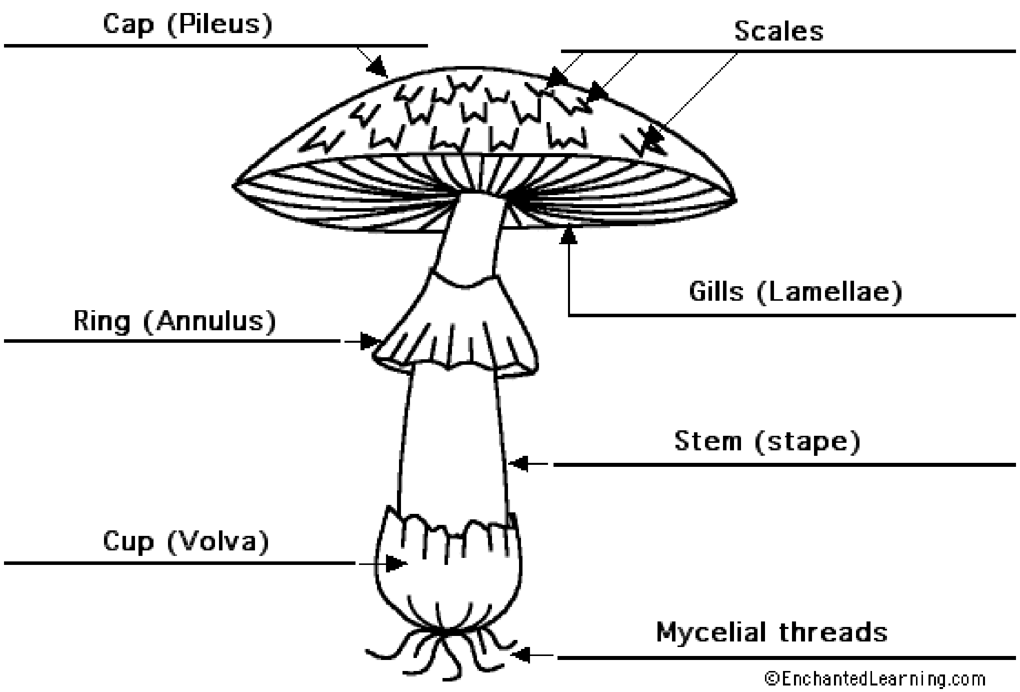
- *Three morphological types of dikaryotic hyphae may be present in basidiocarps*
  - *Generative hyphae*: Present in all basidiocarps, thinwalled, produce basidia and constitute hymenium, give rise to other kinds of hyphae
  - *Skeletal hyphae*: Un branched or sparsely branched,thick walled with narrow lumen, form a rigid frame work
  - *Binding hyphae/ligative hyphae*: Much branched, narrow, thick walled and limited growth. Weave between other hyphae and bind them together

- Different combinations of hyphal types may occur in basdiocarps;
  - **Monomitic basidiocarps**: Basidiocarps made up of only generative hyphae
  - ***Dimitic**: Fruit bodies made of generative hyphae along with any other type of hyphae*
  - **Trimitic**: Fruit bodies consist of all three types of hyphae

Development of Basidiocarp (General)

Basidiocarps arise as hyphal knots fromsub-terraanean mycelial strands – **rhizomorphs**

- Hyphal knots enlarge into round or ovoid structures which break through the surface
- Development of basidiocarps show variations
- In many **hymenomycetes** species, young fruit bodies may be enveloped by a **universal veil**, which is broken as the pileus expands
- This leaves a cup like **volva** at the base of stipe and **broken scales** on cap (Eg. Amanita)

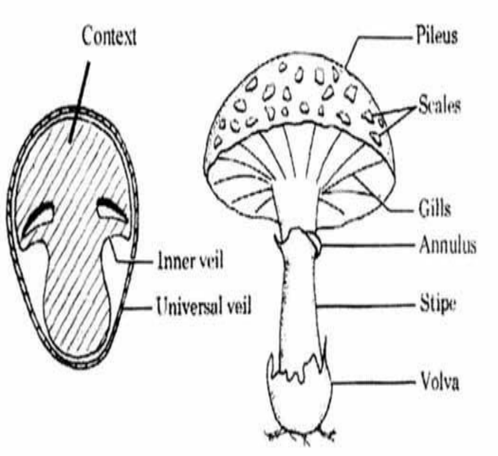


- In some other species, the hymenium is protected during the development by a **partial veil (inner veil/velum)**, extending from the edge of cap to stipe

- Remnants of inner veil persists as a ring on stipe called

Annulus (Eg. Agaricus)

- In many hymenomycetes, basidiocarp has a **stipe** and **pileus**
- Lower surface of pileus has radially arranged **gills**
- The fertile portion of basidiocarp is called **hymenium**
- Arrangement of hymenium show variations



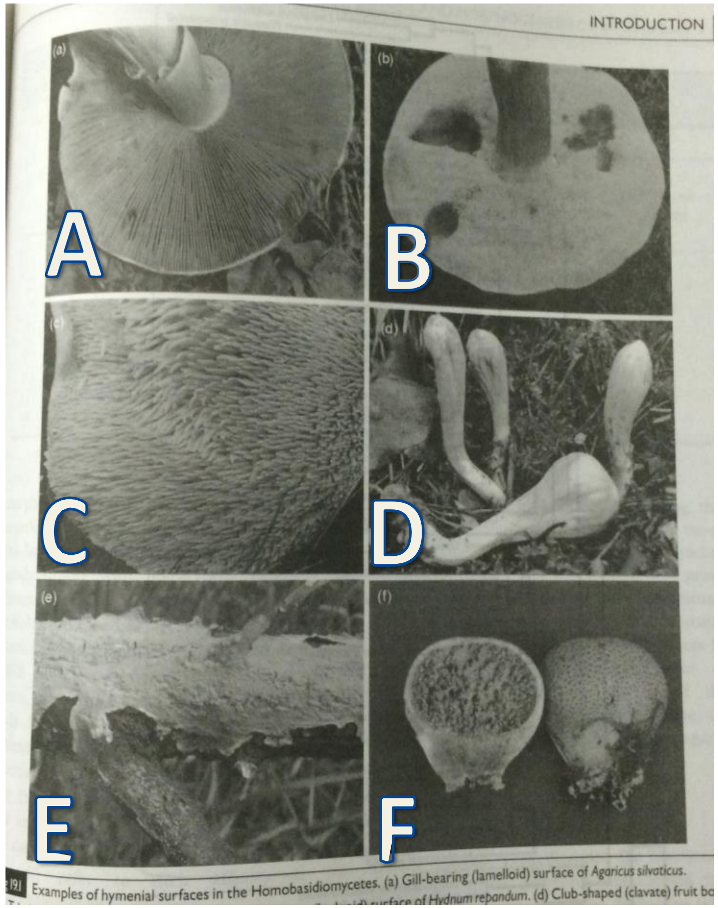
- Agaricoid: hymenium consists of gills/lamellate
- Poroid: Hymenium has pores instead of gills
- Hydnoid: toothed or spiny hymenium
- Clavate: Club shaped or coralloid fruit body ,out side of which is covered by hymenium
- Resupinate: Flattened hymenium, appressed tounderside of solid surfaces
- Gasteroid: Hymenium is enclosed

A – Agaricoid B – Poroid

C – Hydnoid

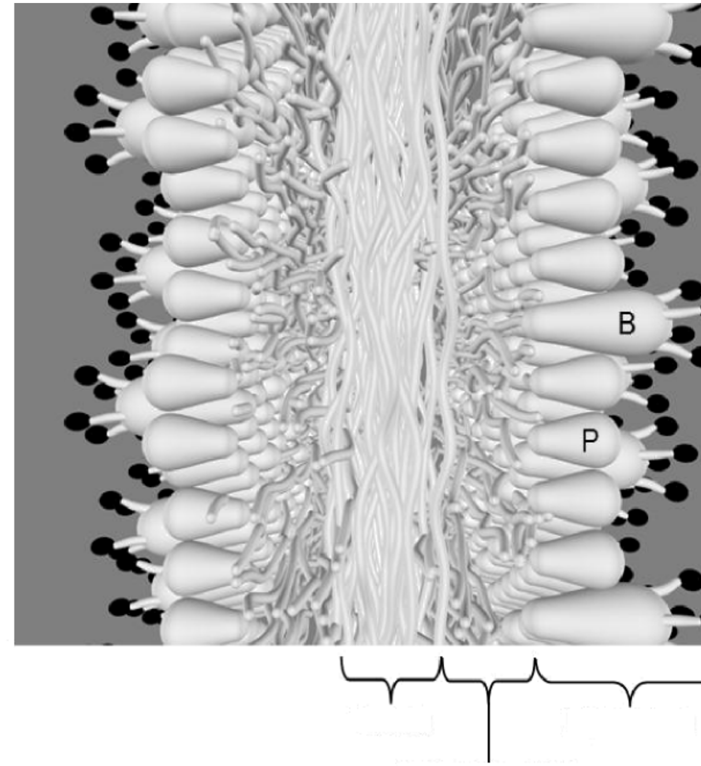
D - Clavate

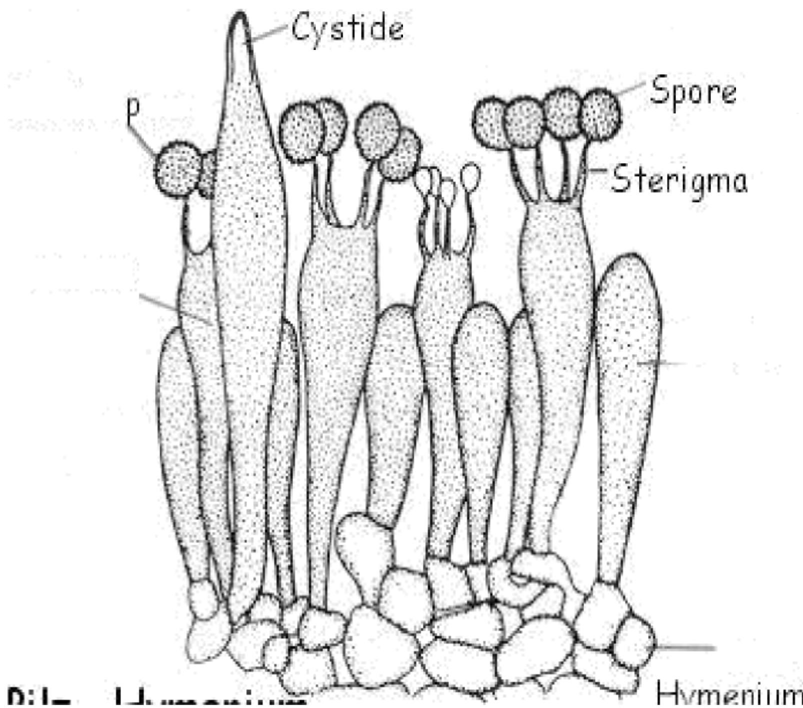
E – Resupinate F - Gasteroid



Structure of hymenium

- *Hymenium is made up of **basidium** bearing basidiospores*
- Sometimes it also bear structures like **cystidia** and **paraphyses**
- Cystidia are conical or cylindrical cells arise with basidium in the hymenium
- Paraphyses are sterile, club shaped hyphae arise from the same hyphae which produce basidia





In gasteromycetes, fruit body is also called gasterocarps

- *Hymenium is never exposed, a recognizable fertile layer is sometimes absent*
- Wall of fruit body is called **peridium**
- *Fertile region within the peridium is called **gleba***
- Basidiospores are non ballistospores
- Spores are released either by disintegration of peridium or by any physical forces, after spores are liberated into the peridium

Basidiospore germination

- Basidiospores are released forcefully in hymenomycetes
- They are released passively in gasteromycetes
- Basidiospores germinate to produce the new haploid primary mycelium

GENERAL ACCOUNT OF DEUTEROMYCOTINA

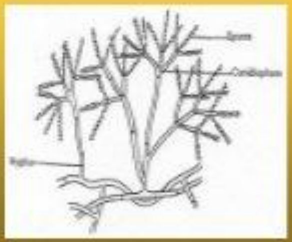
GENERAL CHARACTERISTICS:

- Members ,belonging to this class of Fungi, possess septate mycelium and reproduce by means of asexual spores(conidia) only.
- Hence the name "**fungi imperfecti**"(fungi that lack a perfect or the sexual stage).
- Except the unicellular yeast-like members of blastomycetes, almost all the remaining deuteromycotina have a ***true mycelium***,consisting of well-developed, well-branched, septate hyphae.

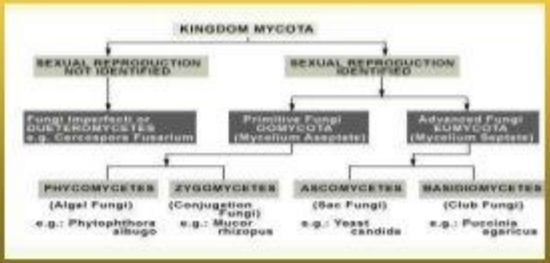
- The mycelium is usually intercellular or intracellular, and each cell contains many nuclei.
- The ***septa*** of all the species resemble largely that of Ascomycotina. A simple central pore is present in each septum.
- ***Sexual reproduction*** is completely absent.
- Reproduction takes place chiefly by the formation of special asexual spores called ***conidia.***
- The conidia are non-motile structures which develop exogenously on the conidiophores, and therefore deuteromycotina resemble ascomycotina.

- The conidia are highly variable in shape, size, colour etc.
- They are hyaline or variously coloured, unicellular or multicellular, and transversely septate or contain both transverse as well as longitudinal septa.
- They may be oval, elongated, spherical, star-shaped, curved, threadlike, disc-shaped, coiled, and of other shape.
- The conidia are produced either directly on the conidiophores or in some special types of fruiting bodies such as *synnemota, acervuli,* sporodochia or *pycnidia.*

- These fruiting bodies are pseudo-parenchymatous structures within which, or on which ,conidia are produced.
- Sutton(1973) recognized only three types of the fruiting bodies, viz., pycnidia, acervuli, and stromata.



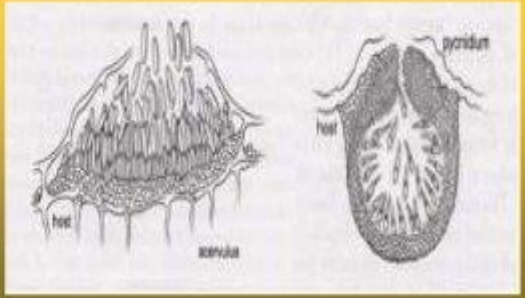
CLASSIFICATION OF FUNGI



PARASEXUAL CYCLE

- It is a process in which plasmogamy, karyogamy and haploidization takes place, but not in particular place in the thallus nor at any specific period during its life cycle.
- FORMATION OF **HETEROKARYOTIC MYCELIUM:**

Heterokaryon formation refers to the condition by which genetically different nuclei are associated in a common cytoplasm.



- More commonly these fungi grow on living and dead plants.
- Some pycnidia and acervuli can be highly complex and be composed of several cavities.

- **Orders:**
- Melanconiales (producing spores in acervuli)
- Sphaeropsidales (producing spores in pycnidia)
- Pycnothyriales (produces pycnothyrial conidiomata.)

Mycorrhiza

Among symbiotic fungi, those that enter into mycorrhizal relationships and those that enter into relationships with algae to form lichens are probably the best-known. A large number of fungi infect the roots of plants by forming an association with plants called mycorrhiza (plural mycorrhizas or mycorrhizae). This association differs markedly from ordinary root infection, which is responsible for root rot diseases. Mycorrhiza is a non-disease-producing association in which the fungus invades the root to absorb nutrients.

Mycorrhizal fungi establish a mild form of parasitism that is mutualistic, meaning both the plant and the fungus benefit from the association. About 90 percent of land plants rely on mycorrhizal fungi, especially for mineral nutrients (i.e., phosphorus), and in return the fungus receives nutrients formed by the plant. During winter, when day length is shortened and exposure to sunlight is reduced, some plants produce few or no nutrients and thus depend on fungi for sugars, nitrogenous compounds, and other nutrients that the fungi are able to absorb from waste materials in the soil. By sharing the products it absorbs from the soil with its plant host, a fungus can keep its host alive. In some lowland forests, the soil contains an abundance of mycorrhizal fungi, resulting in mycelial networks that connect the trees together. The trees and their seedlings can use the fungal mycelium to exchange nutrients and chemical messages.

Pinesaps (*Monotropa hypopitys*) are saprophytes with little photosynthetic tissue. Unlike green plants, saprophytes are unable to manufacture carbohydrates. They rely on their associations with mycorrhizal fungi, which synthesize carbohydrates from the rich organic leaf litter.

There are two main types of mycorrhiza: ectomycorrhizae and endomycorrhizae. Ectomycorrhizae are fungi that are only externally associated with the plant root, whereas endomycorrhizae form their associations within the cells of the host.

Among the mycorrhizal fungi are boletes, whose mycorrhizal relationships with larch trees (*Larix*) and other conifers have long been known. Other examples include truffles, some of which are believed to form mycorrhizae with oak (*Quercus*) or beech (*Fagus*) trees. Many orchids form mycorrhizae with species of *Rhizoctonia* that provide seedlings of the orchid host with carbohydrate obtained by degradation of organic matter in the soil.

Predation

A number of fungi have developed ingenious mechanisms for trapping microorganisms such as amoebas, roundworms (nematodes), and rotifers. After the prey is captured, the fungus uses hyphae to penetrate and quickly destroy the prey. Many of these fungi secrete adhesive substances over the surface of their hyphae, causing a passing animal that touches any portion of the mycelium to adhere firmly to the hyphae. For example, the mycelia of oyster mushrooms (genus *Pleurotus*) secrete adhesives onto their hyphae in order to catch nematodes. Once a passing animal is caught, a penetration tube grows out of a hypha and penetrates the host's soft body. This haustorium grows and branches and then secretes enzymes that quickly kill the animal, whose cytoplasm serves as food for the fungus.

Other fungi produce hyphal loops that ensnare small animals, thereby allowing the fungus to use its haustoria to penetrate and kill a trapped animal. Perhaps the most amazing of these fungal traps are the so-called constricting rings of some species of *Arthrobotrys*, *Dactylella*, and *Dactylaria*—soil-inhabiting fungi easily grown under laboratory conditions. In the presence of nematodes, the mycelium produces large numbers of rings through which the average nematode is barely able to pass. When a nematode rubs the inner wall of a ring, which usually consists of three cells with touch-sensitive inner surfaces, the cells of the ring swell rapidly, and the resulting constriction holds the worm tightly. All efforts of the nematode to free itself fail, and a hypha, which grows out of one of the swollen ring cells at its point of contact with the worm, penetrates and branches within the animal's body, thereby killing the animal. The dead animal is then used for food by the fungus. In the absence of nematodes, these fungi do not usually produce rings in appreciable quantities. A substance secreted by nematodes stimulates the fungus to form the mycelial rings.

Reproductive Processes Of Fungi

Following a period of intensive growth, fungi enter a reproductive phase by forming and releasing vast quantities of spores. Spores are usually single cells produced by fragmentation of the mycelium or within specialized structures (sporangia, gametangia, sporophores, etc.). Spores may be produced either directly by asexual methods or indirectly by sexual reproduction. Sexual reproduction in fungi, as in other living organisms, involves the fusion of two nuclei that are brought together when two sex cells (gametes) unite. Asexual reproduction, which is simpler and more direct, may be accomplished by various methods.

Asexual reproduction

Typically in asexual reproduction, a single individual gives rise to a genetic duplicate of the progenitor without a genetic contribution from another individual. Perhaps the simplest method of reproduction of fungi is by fragmentation of the thallus, the body of a fungus. Some yeasts, which are single-celled fungi, reproduce by simple cell division, or fission, in which one cell undergoes nuclear division and splits into two daughter cells; after some growth, these cells divide, and eventually a population of cells forms. In filamentous fungi the mycelium may fragment into a number of segments, each of which is capable of growing into a new individual. In the laboratory, fungi are commonly propagated on a layer of solid nutrient agar inoculated either with spores or with fragments of mycelium.

Budding, which is another method of asexual reproduction, occurs in most yeasts and in some filamentous fungi. In this process, a bud develops on the surface of either the yeast cell or the hypha, with the cytoplasm of the bud being continuous with that of the parent cell. The nucleus of the parent cell then divides; one of the daughter nuclei migrates into the bud, and the other remains in the parent cell. The parent cell is capable of producing many buds over its surface by continuous synthesis of cytoplasm and repeated nuclear divisions. After a bud develops to a certain point and even before it is severed from the parent cell, it is itself capable of budding by the same process. In this way, a chain of cells may be produced. Eventually, the individual buds pinch off the parent cell and become individual yeast cells. Buds that are pinched off a hypha of a filamentous fungus behave as spores; that is, they germinate, each giving rise to a structure called a germ tube, which develops into a new hypha.

Although fragmentation, fission, and budding are methods of asexual reproduction in a number of fungi, the majority reproduce asexually by the formation of spores. Spores that are produced asexually are often termed mitospores, and such spores are produced in a variety of ways.

Sexual reproduction

Sexual reproduction, an important source of genetic variability, allows the fungus to adapt to new environments. The process of sexual reproduction among the fungi is in many ways unique. Whereas nuclear division in other eukaryotes, such as animals, plants, and protists, involves the dissolution and re-formation of the nuclear membrane, in fungi the nuclear membrane remains intact throughout the process, although gaps in its integrity are found in some species. The nucleus of the fungus becomes pinched at its midpoint, and the diploid chromosomes are pulled apart by spindle fibres formed within the intact nucleus. The nucleolus is usually also retained and divided between the daughter cells, although it may be expelled from the nucleus, or it may be dispersed within the nucleus but detectable.

Sexual reproduction in the fungi consists of three sequential stages: plasmogamy, karyogamy, and meiosis. The diploid chromosomes are pulled apart into two daughter cells, each containing a single set of chromosomes (a haploid state). Plasmogamy, the fusion of two protoplasts (the contents of the two cells), brings together two compatible haploid nuclei. At this point, two nuclear types are present in the same cell, but the nuclei have not yet fused. Karyogamy results in the fusion of these haploid nuclei and the formation of a diploid nucleus (i.e., a nucleus containing two sets of chromosomes, one from each parent). The cell formed by karyogamy is called the zygote. In most fungi the zygote is the only cell in the entire life cycle that is diploid. The dikaryotic state that results from plasmogamy is often a prominent condition in fungi and may be prolonged over several generations. In the lower fungi, karyogamy usually follows plasmogamy almost immediately. In the more evolved fungi, however, karyogamy is separated from plasmogamy. Once karyogamy has occurred, meiosis (cell division that reduces the chromosome number to one set per cell) generally follows and restores the haploid phase. The haploid nuclei that result from meiosis are generally incorporated in spores called meiospores.

Fungi employ a variety of methods to bring together two compatible haploid nuclei (plasmogamy). Some produce specialized sex cells (gametes) that are released from differentiated sex organs called gametangia. In other fungi two gametangia come in contact, and nuclei pass from the male gametangium into the female, thus assuming the function of gametes. In still other fungi the gametangia themselves may fuse in order to bring their nuclei together. Finally, some of the most advanced fungi produce no gametangia at all; the somatic (vegetative) hyphae take over the sexual function, come in contact, fuse, and exchange nuclei.

Fungi in which a single individual bears both male and female gametangia are hermaphroditic fungi. Rarely, gametangia of different sexes are produced by separate individuals, one a male, the other a female. Such species are termed dioecious. Dioecious species usually produce sex organs only in the presence of an individual of the opposite sex.

Sexual incompatibility

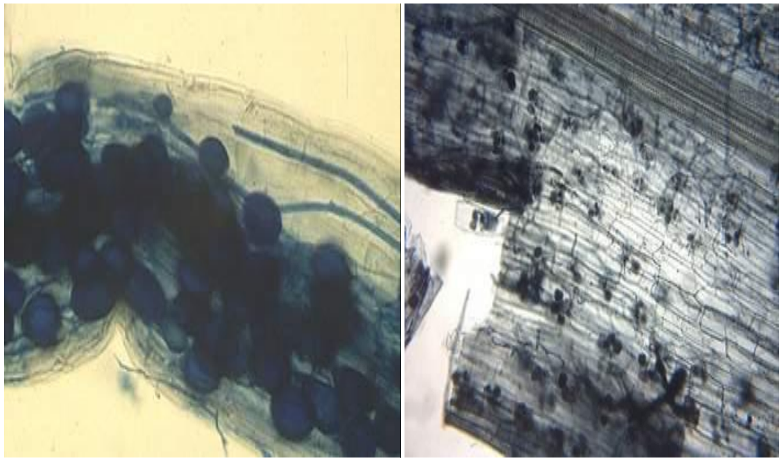
Many of the simpler fungi produce differentiated male and female organs on the same thallus but do not undergo self-fertilization because their sex organs are incompatible. Such fungi require the presence of thalli of different mating types in order for sexual fusion to take place. The simplest form of this mechanism occurs in fungi in which there are two mating types, often designated + and − (or *A* and *a*). Gametes produced by one type of thallus are compatible only with gametes produced by the other type. Such fungi are said to be heterothallic. Many fungi, however, are homothallic; i.e., sex organs produced by a single thallus are self-compatible, and a second thallus is unnecessary for sexual reproduction. Some of the most complex fungi (e.g., mushrooms) do not develop differentiated sex organs; rather, the sexual function is carried out by their somatic hyphae, which unite and bring together compatible nuclei in preparation for fusion. Homothallism and heterothallism are encountered in fungi that have not developed differentiated sex organs, as well as in fungi in which sex organs are easily distinguishable. Compatibility therefore refers to a physiological differentiation, and sex refers to a morphological (structural) one; the two phenomena, although related, are not synonymous.

Sexual pheromones

The formation of sex organs in fungi is often induced by specific organic substances. Although called sex hormones when first discovered, these organic substances are actually sex pheromones, chemicals produced by one partner to elicit a sexual response in the other. In *Allomyces* (order Blastocladiales) a pheromone named sirenin, secreted by the female gametes, attracts the male gametes, which swim toward the former and fuse with them. In some simple fungi, which may have gametangia that are not differentiated structurally, a complex biochemical interplay between mating types produces trisporic acid, a pheromone that induces the formation of specialized aerial hyphae. Volatile intermediates in the trisporic acid synthetic pathway are interchanged between the tips of opposite mating aerial hyphae, causing the hyphae to grow toward each other and fuse together. In yeasts belonging to the phyla Ascomycota and Basidiomycota, the pheromones are small peptides. Several pheromone genes have been identified and characterized in filamentous ascomycetes and basidiomycetes.

Ecto mycorhizae

Endomycorrhizae



Control plants **VAM treated plants**

FUNGI AS BIOCONTROL AGENT

Significance of Biological Control

- Biological control provides protection to the plant throughout its cultivation period. The biological agents **proliferate rapidly** in soil and leave no residue. Being non- toxic, it is **safer for humans and plants**. This approach is not limited for controlling the disease; additionally, it also **enhances the growth** (especially root) and **yield of the crop**. Due to **easy handling and manufacturing**, it can be used in combination with bio-fertilizers. Moreover, it is a **cheap, safe**, and eco-friendly method.

CONTI…

Microbial Biocontrol Agents

- *Aspergillus* spp., *Ampelomyces* sp., *Candida* sp., *Coniothyrium* sp., *Gliocladium* sp., and *Trichoderma* spp. are fungal. Among them, the most versatile fungal agent belongs to *Trichoderma* sp. for controlling the growth of pathogenic fungi.
- Presently, commercial *Trichoderma* products are used as biopesti- cides which amend the soil and increase the plant growth.
- In 1934, Weindling showed the bio- control potential of *Trichoderma lignorum* (viride) against *Rhizoctonia solani*, a fungal pathogen.
- Further, *Trichoderma lignorum* (viride) also showed mycoparasitic activity against *Phytophthora*, *Pythium*, *Rhizopus*, and *Sclerotium rolfsii* (Wells 1988).

CONTI…

Importance of Biological Control

- Chemical pesticides were used to enhance crop yield, but extensive use affects the nontargeted organism and surrounding environment. Thus, the current scenario demands the eco-friendly approach for controlling the pest, as chemical pesticides being not suitable for cultivation of crop. Bacteria, fungi, nematodes, protozoans, and virus have been extensively studied because of advantageous characteristics. Overexploitation of fungicides has resulted in gathering of the toxic molecules which are harmful to the environment and humans, but pathogenic microbes have adapted themselves by getting resistant to it. In order to overcome this global prob- lem related to chemical control, alternative approaches are being exploited. Additionally, this biological control approach is highly effective for sustainable agriculture and is a vital component of integrated pest management (IPM) program.

Conti…..

Efficacy of Microbial Biocontrol Agents

- In addition to properties discussed above, there are few amendments which enhance the efficiency of this method.
- First, inappropriate usage of this technique should be prevented, which is mostly because of improper knowledge.
- Second, one should be able differentiate failure which is cause by low-quality inoculum
- Moreover, inefficacy occurs because the compost/fertilizers containing biocontrol agents are not of superior quality as available in registered plant products.
- To improve the efficiency of the biocontrol agents, the strain should be assessed and verified against the tar- geted disease plus optimum condition should also be noted.
- Specific substrates and carriers also aid in enhancing the efficacy of the agents. Exploration of effective strains will also improve the quality of biocontrol agents and lessen the required amount.

Conti….

Commercial Products of Biocontrol Agents

- Commercially available biocontrol products which control the plant disease are a new prospect.
- But it started in 1979, when ***Agrobacterium radiobacter*** strain **K 84** was enlisted in EPA (United States Environmental Protection Agency) list for controlling crown gall disease in plant.
- Later on, ***Trichoderma harzianum*** ATCC 20476,the first fungal strain, was enlisted in EPA list for controlling the plant diseases.
- Presently, 12 fungi strains have been recorded by EPA which aid in controlling the plant disease (Fravel 2005). The majority of these biocontrol agents are commercially marketed .

CONTI…

Mass Production of Biocontrol Agents

- Mass production of the biocontrol agents is required to meet the commercial demand.
- There is no effective method for the mass production of these biocontrol agents at industrial level, as the production of these biocontrol agents requires continuous resource which should be readily available.
- ***Trichoderma* spp**. have been reported to grow on various solid substrates such as coffee husk, saw dust, sorghum grain, waste of tea leaf, wheat grain and bran, etc.

Conti……..

Commercial Products of Biocontrol Agents

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CONTI…

Fungi as biocontrol agent

- Fungi possess a number of characteristics that make them potentially ideal bio control agents.
- Firstly, many saprophytic species antagonize, representatives of all the pest organisms, including plant pathogenic fungi, weeds and insects.
- Secondly, fungi can be readily grown in culture so that large quantities can be economically produced for release, mainly as spores or mycelial fragments, into the environment.
- These inoculants then germinate or grow to produce active mycelium which can parasitize or otherwise inhibit the pest without damaging the non-target organisms. Fungi also survive for relatively long periods as resting bodies, and can then germinate to grow and control the target population thereby making continual re-inoculation with the bio-control agent unnecessary.

Conti……

Example of Bio Control Agents Used Commercially:

1. **Trichoderma harzianum**—White rot onion
2. **Phlebia gigantean**—Heterbasidion root rot pine
4. **Sporidesmium sclerotivorum**—Lettuce drop lettuce
5. **Talaromyces flavus—**Damping off sugarbeet.

CONTI….

Species	Main target pests
1. *Aschersonia aleyrodis*	White fly
2. *Beauveria bassiana*	Colorado beetle
3. *Beauveria brongniartii*	Cockchafer
4. *Hirsutella thompsonii*	Rust mites
5. *Metarhizum anisopliae*	Beetles, bugs
6. *Nomuraea rileyi*	Caterpillars
7. *Verticillium lecanii*	Aphids, White fly

Conti…….

Fungal compounds involved in induction of plant responses

- Compounds that are released by *Trichoderma* spp. into the zone of interaction induce resistance in plants
- Primarily proteins with enzymatic activity
  - ✓ xylanase, cellulase, swollenin and endochitinase
- Enhance defense, through induction of plant defense-related proteins and peptides that are active in inducing terpenoid, phytoalexin biosynthesis and peroxidase activity.

Role of BCF's

- Reduce the negative effects of plant pathogens and promote positive responses in plant.
- Inoculated plants are sensitized to respond more rapidly to pathogen attack
- Alleviation of abiotic stresses
- Improve photosynthetic efficiency, especially in plants subjected to various stresses
- Increase nutrients absorption and nitrogen use efficiency in plants
- Enhance the growth and yield parameters

Conti…

Mechanisms of Fungal Biocontrol Agents

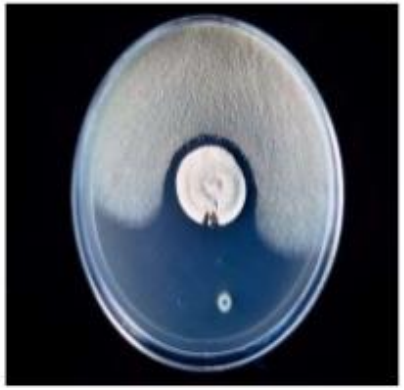
<u>Mycoparasitism</u>

- The term mycoparasitism or "hyperparasitism" has been used to indicate the interrelationships of a parasite and a fungus host. The term mycoparasite refers to organisms that have the ability to parasite fungi, and mycohost means the fungi act as host to be parasitized

Conti….

Antibiosis

" Interactions that involve a low-molecular weight compound or an antibiotic produced by microorganism that has a direct effect on another microorganism"



CONTI…

Competition

- Competition for nutrient and space.
- Biocontrol agent decreases the availability of a particular substance thus limiting the growth of the plant pathogenic agents
- *Trichoderma* spp produce siderophores that chelate iron and stop the growth of other fungi

Conti……

Applications In Plant Disease Control

Coniothyrium minitans

- ***Sclerotinia blight***, caused by the soilborne fungus **Sclerotinia minor Jagger**, is an important disease of **peanut**
- During favorable conditions for *Sclerotinia blight*, peanut farmers can lose up to 50% yield as a result of the disease. Fungicides for control of *Sclerotinia blight* alone can cost producers as much as $104 per hectare for a single application, with up to **three** applications made in a season. Consequently, there is a pressing need to reduce the cost of managing *Sclerotinia blight*.
- A number of microorganisms have been reported to parasitize sclerotia of Sclerotinia spp., including *Coniothyrium minitans*.

Conti…..

Trichoderma species

<u>**Commercial Application**</u>

- Several strains of Trichoderma are commercially available to control plant disease in environmentally friendly agriculture.
- **Fungal Formations**
- **TUSAL** made from T. harzianum and T. viride cultures to prevent the growth of pathogen soilborne fungi responsible for **leaf-falling** disease in several crops

Gliochdium virens

- The efficacy of *Gliochdium virens* (G 1 and G 2) and *Trichoderma longibrachiatum* (T 1 and T 2) as biocontrol agents of economically important soil-borne plant pathogens ***Rhizoctonia solani, Sclerotium rolfsii*** and ***Pythium aphanidermatum*** has been investigated. The *G. virens* isolate G 1 yielded remarkable protection against groundnut root rot (74.4 %), cotton (66.4 %) and tomato (58.4 %) damping-off but only moderately reduced (36 %) the groundnut stem rot incidence, whereas G 2 was much less effective. Of the two *T. longibrachiatum* isolates, T 1 was more potent against groundnut root rot (65.6 %) while against tomato damping-off, T 2 conferred greater protection (49.2 %).

Conti….

Trichoderma species

- Trichoderma species reduces the growth of all the four soil borne pathogens: ***Sclerotium rolfsii, Fusarium solani, Rhizoctonia solani*** and ***Sclerotionia sclerotiorum*** significantly in different level and, therefore, can be incorporated for integrated disease management of soil borne plant pathogens. Hence, Trichoderma species can be used as a potential biocontrol agent against these pathogens. However, its efficacy against *Sclerotium rolfsii*(a fungal Plant pathogen in tobacco plant) was found to be more in comparison to others.
- *Trichoderma* sp. was found to be effective against *Sclerotium rolfsii* causing the damping-off, root rot, and seed rot disease in **mung bean** and **sunflower**, and moreover, it also increased the plant growth.

Paecilomyces lilacinus and *Glomus fasciculatum*

- **Root-knot nematode** (*Meloidogyne incognita*) is a limiting factor causing yield reduction in **FCV tobacco crop**. As an alternative to nematicides of chemical origin, beneficial fungi such as *Paecilomyces lilacinus* and *Glomus fasciculatum* significantly reduced the number of egg masses/g root and final soil **nematode** population.

Ampelomyces quisqualis (Deuteromycetes)

- The fungus *Ampelomyces quisqualis* is a naturally occurring hyperparasite of **powdery mildews**. It infects and forms pycnidia (fruiting bodies) within powdery mildew hyphae, conidiophores (specialized spore-producing hyphae), and cleistothecia (the closed fruiting bodies of powdery mildews). This parasitism reduces growth and may eventually kill the mildew colony.

General account of lichens

Meaning of Lichens:

Lichens are a small group of plants of composite nature, consisting of two dissimilar organisms, an alga-phycobiont (phycos — alga; bios — life) and a fungus-mycobiont (mykes — fungus; bios — life); living in a symbiotic association.

Generally the fungal partner occupies the major portion of the thallus and produces its own reproductive structures. The algal partner manufactures the food through photosynthesis which probably diffuses out and is absorbed by the fungal partner.

Characteristics of Lichens:

1. Lichens are a group of plants of composite thalloid nature, formed by the association of algae and fungi.

2. The algal partner-produced carbohydrate through photosynthesis is utilised by both of them and the fungal partner serves the function of absorption and retention of water.

3. Based on the morphological structure of thalli, they are of three types crustose, foliose and fruticose.

4. Lichen reproduces by all the three means – vegetative, asexual, and sexual.

(a) Vegetative reproduction: It takes place by fragmentation, decaying of older parts, by soredia and isidia.

(b) Asexual reproduction: By the formation of oidia.

(c) Sexual reproduction: By the formation of ascospores or basidiospores. Only fungal component is involved in sexual reproduction.

5. Ascospores are produced in Ascolichen.

(a) The male sex organ is flask-shaped spermogonium, produces unicellular spermatia.

(b) The female sex organ is carpogonium (ascogonium), differentiates into basal coiled oogonium and elongated trichogyne.

(c) The fruit body may be apothecia! (discshaped) or perithecial (flask-shaped) type.

(d) Asci develop inside the fruit body containing 8 ascospores. After liberating from the fruit body, the ascospores germinate and, in contact with suitable algae, they form new lichen.

6. Basidiospores are produced in Basidiolichen, generally look like bracket fungi and basidiospores are produced towards the lower side of the fruit body.

7. The growth of lichen is very slow, they can survive in adverse conditions with high temperature and dry condition.

Habit and Habitat of Lichens:

There is about 400 genera and 15,000 species of lichens, widely found in different regions of the world. The plant body is thalloid; generally grows on bark of trees, leaves, dead logs, bare rocks etc., in different habitat. They grow luxuriantly in the forest areas with free or less pollution and with abundant moisture.

Some species like Cladonia rangiferina (reindeer moss) grows in the extremely cold condition of Arctic tundras and Antarctic regions. In India, they grow abundantly in Eastern Himalayan regions. They do not grow in the highly polluted regions like Industrial areas. The growth of lichen is very slow.

Depending on the growing region, the lichens are grouped as:

1. Corticoles:

Growing on bark of trees, mainly in the sub-tropical and tropical regions.

2. Saxicoles:

Growing on rocks, in cold climate.

3. Terricoles:

Growing on soil, in hot climate, with sufficient rain and dry summer.

Associated Members of Lichens:

The composite plant body of lichen consists of algal and fungal members.

The algal members belong to Chlorophyceae (Trebouxia, Trentepohlia, Coccomyxa etc.), Xanthophyceae (Heterococcus) and also Cyanobacteria (Nostoc, Scytonema etc.) (Fig. 4.111).

The fungal members mainly belong to Ascomycotina and a few to Basidiomycotina. Among the members of Ascomycotina, Discomycetes are very common; producing huge apothecia, others belong to Pyrenomycetes or Loculoascomycetes.

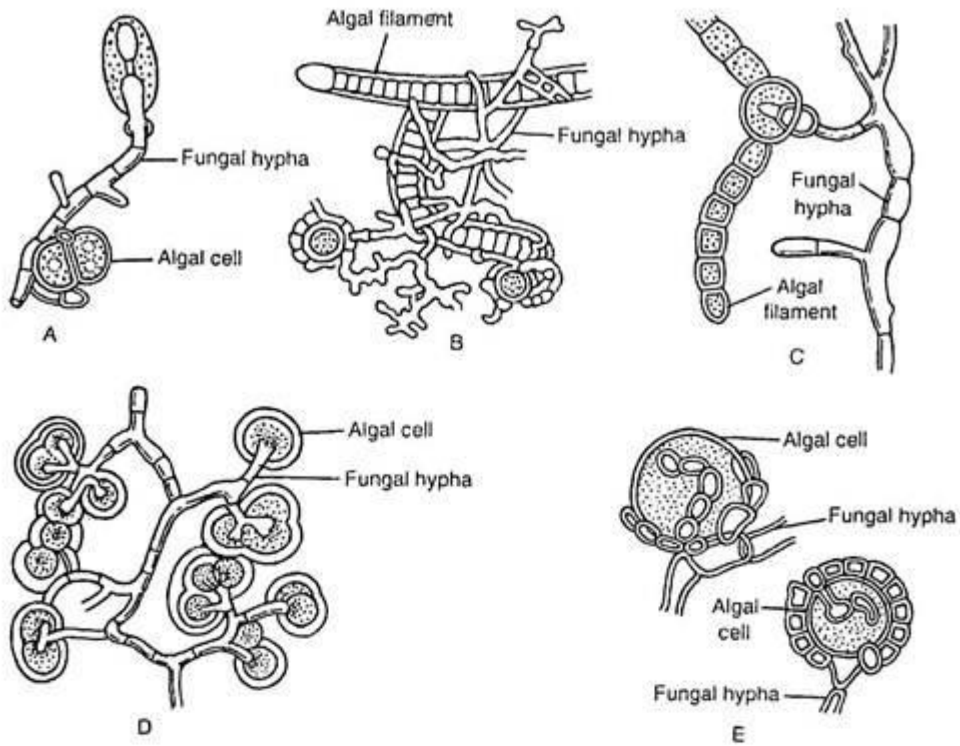


Fig. 4.111 :Lichen-forming Algae : A. *Pleurococcus viridis*, B. *Scytonema* sp., C. *Nostoc* sp., D. *Gloeocapsa* sp., E. *Pleurococcus* sp.

The members of Basidiomycotina belong to Thelephoraceae.

Nature of Association of Lichens:

There are three views regarding the nature of association of algal and fungal partners in lichen:

1. According to some workers, the fungus lives parasitically, either partially or wholly, with the algal components.

This view gets support for the following evidences:

(i) Presence of haustoria of fungus in algal cells of some lichen.

(ii) On separation, the alga of lichen is able to live independently, but the fungus cannot survive.

2. According to others, they live symbiotically, where both the partners are equally benefitted. The fungal member absorbs water and mineral from atmosphere and substratum, make available to the alga and also protects algal cells

3. According to another view, though the relationship is symbiotic, the fungus shows predominance over the algal partner, which simply lives as subordinate partner. It is like a master and slave relationship, termed helotism.

Classification of Lichens:

Natural system of classification is not available for lichens. They are classified on the nature and kinds of fruit bodies of the fungal partner.

Based on the structure of fruit bodies of fungal partners, Zahlbruckner (1926) classified lichens into two main groups:
1. Ascolichens:
The fungal member of this lichen belongs to Ascomycotina.

Based on the structure of the fruit body, they are divided into two series:
(i) Gynocarpeae:
The fruit body is discshaped i.e., apothecial type. It is also known as Discolichen (e.g., Parmelia).

(ii) Pyrenocarpeae:
The fruit body is flask-shaped i.e., perithecial type. It is also known as Pyrenolichen (e.g., Dermatocarport).

2. Basidiolichen:
The fungal member of this lichen belongs to Basidiomycotina e.g., Dictyonema, Corella.

Later, Alexopoulos and Mims (1979) classified lichens into three main groups:
i. Basidiolichen:
The fungal partner belongs to Basidiomycetes e.g., Dictyonema.

ii. Deuterolichen:
The fungal partner belongs to Deuteromycetes.

iii. Ascolichen:
The fungal partner belongs to Ascomycetes e.g., Parmelia, Cetraria.

Structure of Thallus in Lichens:

The plant body of lichen is thalloid with different shapes. They are usually grey or greyish green in colour, but some are red, yellow, orange or brown in colour.

A. External Structure of Thallus:

Based on the external morphology, general growth and nature of attachment, three main types or forms of lichens (crustose, foliose and fruticose) have been recognised. Later, based on detailed structures,

Hawksworth and Hill (1984) categorised the lichens into five main types or forms:

1. Leprose:

This is the simplest type, where the fungal mycelium envelops either single or small cluster of algal cells. The algal cell does not envelop all over by fungal hyphae. The lichen appears as powdery mass on the substratum, called leprose (Fig. 4.112A), e.g., Lepraria incana.

2. Crustose:

These are encrushing lichens where thallus is inconspicuous, flat and appears as a thin layer or crust on substratum like barks, stones, rocks etc. (Fig. 4.112B). They are either wholly or partially embedded in the substratum, e.g., Graphis, Lecanora, Ochrolechia, Strigula, Rhizocarpon, Verrucaria, Lecidia etc.

3. Foliose:

These are leaf-like lichens, where thallus is flat, horizontally spreading and with lobes. Some parts of the thallus are attached with the substratum by means of hyphal outgrowth, the rhizines, developed from the lower surface (Fig. 4.112C), e.g., Parmelia, Physcia, Peltigera, Anaptychia, Hypogymnia, Xanthoria, Gyrophora, Collema, Chauduria etc.

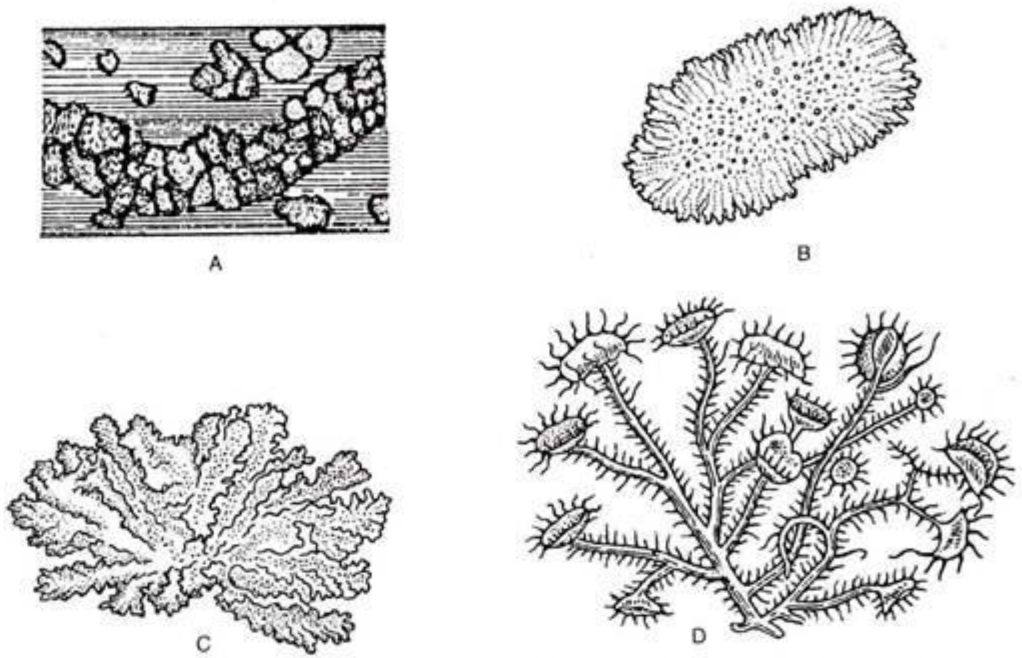


Fig. 4.112 : Different forms of lichen : A. Leprose, B. Crustose, C. Foliose and D. Fruiticose

4. Fruticose (Frutex, Shrub):

These are shrubby lichens, where thalli are well developed, cylindrical branched, shrub-like (Fig. 4.112D), either grow erect (Cladonia) or hang from the substratum (Usnea). They are attached to the substratum by a basal disc e.g., Cladonla, Usnea, Letharia, Alectonia etc.

5. Filamentous:

In this type, algal members are filamentous and well-developed. The algal filaments remain ensheathed or covered by only a few fungal hyphae. Here algal member remains as dominant partner, called filamentous type, e.g., Racodium, Ephebe, Cystocoleus etc.).

B. Internal Structure of Thallus:

Based on the distribution of algal member inside the thallus, the lichens are divided into two types. Homoisomerous or Homomerous and Heteromerous.

1. Homoisomerous:

Here the fungal hyphae and the algal cells are more or less uniformly distributed throughout the thallus. The algal members belong to Cyanophyta. This type of orientation is found in crustose lichens. Both the partners intermingle and form thin outer protective layer (Fig. 4.11 3A), e.g., Leptogium, Collema etc.

2. Heteromerous:

Here the thallus is differentiated into four distinct layers upper cortex, algal zone, medulla, and lower cortex. The algal members are restricted in the algal zone only. This type of orientation is found in foliose and fruticose lichens (Fig. 4.113B) e.g., Physcia, Parmelia etc.

The detailed internal structure of this type is:

(a) Upper Cortex:

It is a thick, outermost protective covering, made up of compactly arranged interwoven fungal hyphae located at right angle to the surface of the fruit body. Usually there is no intercellular space between the hyphae, but if present, these are filled with gelatinous substances.

(b) Algal Zone:

The algal zone occurs just below the upper cortex. The algal cells are entangled by the loosely interwoven fungal hyphae. The common algal members may belong to Cyanophyta like Gloeocapsa (unicellular); Nostoc, Rivularia (filamentous) etc. or to Chlorophyta like Chlorella, Cystococcus, Pleurococcus etc. This layer is either continuous or may break into patches and serve the function of photosynthesis.

(c) Medulla:

The medulla is situated just below the algal zone, comprised of loosely interwoven thick-walled fungal hyphae with large space between them.

(d) Lower Cortex:

It is the lowermost layer of the thallus. This layer is composed of compactly arranged hyphae, which may arrange perpendicular or parallel to the surface of the thallus. Some of the hyphae in the lower surface may extend downwards and penetrate the substratum which help in anchorage, known as rhizines.

The internal structure of Usnea, a fruticose lichen, shows different types of orientation. Being cylindrical in cross-section, the layers from outside are cortex, medulla (composed of algal cell and fungal mycelium) and central chondroid axis (composed of compactly arranged fungal mycelia).

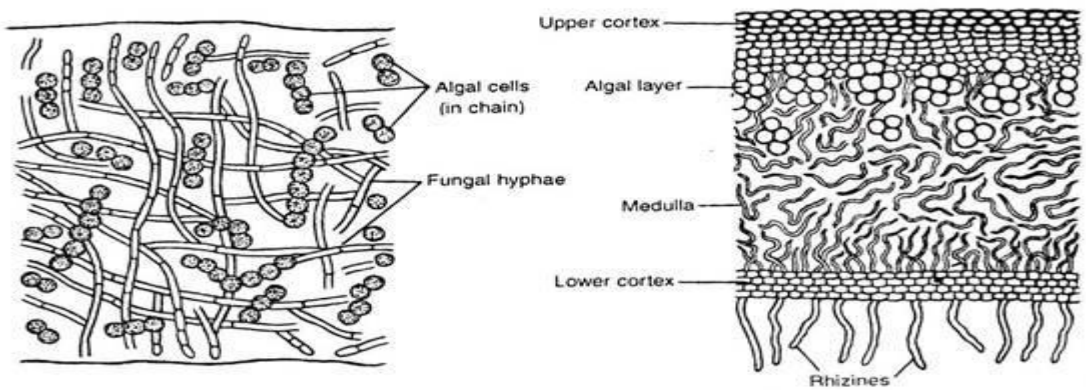


Fig. 4.113 : Internal structure of lichen thallus : A. Homoisomerous thallus, and B. Heteromerous thallus

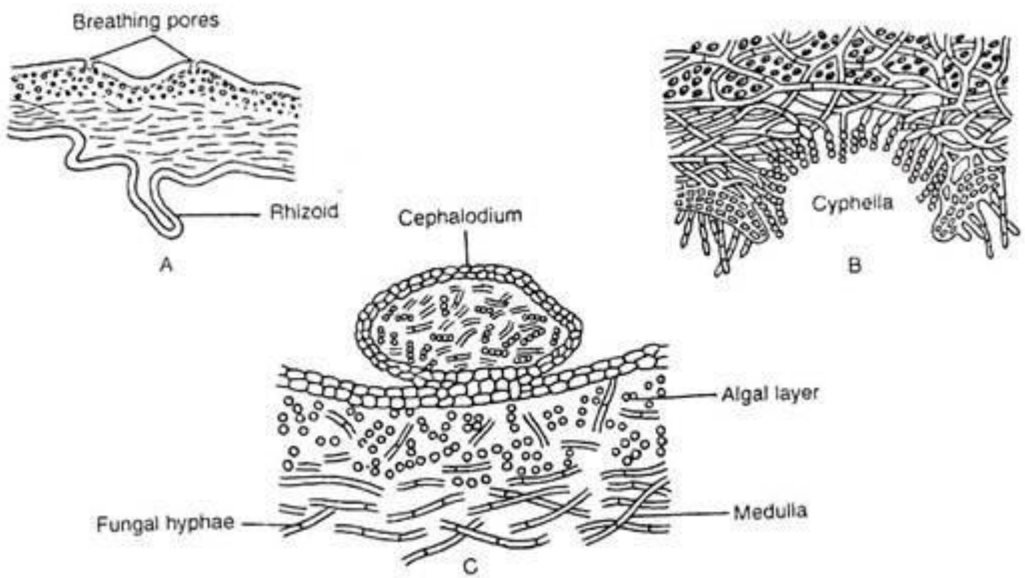


Fig. 4.114 : Specialised structures associated with lichen thallus : A. Breathing pores, B. Cyphella, C. Cephalodium

C. Specialised Structures of Thallus:

1. Breathing Pore:

In some foliose lichen (e.g., Parmelia), the upper cortex is interrupted by some opening, called breathing pores, which help in gaseous exchange (Fig. 4.114A).

2. Cyphellae:

On the lower cortex of some foliose lichen (e.g., Sticta) small depressions develop, which appears as cup-like white spots, known as Cyphellae (Fig. 4.114B). Sometimes the pits that formed without any definite border are called Pseudocyphellae. Both the structures help in aeration.

3. Cephalodium:

These are small warty outgrowths on the upper surface of the thallus (Fig. 4.114C). They contain fungal hyphae of the same type as the mother thallus, but the algal elements are always different. They probably help in retaining the moisture. In Neproma, the Cephalodia are endotrophic.

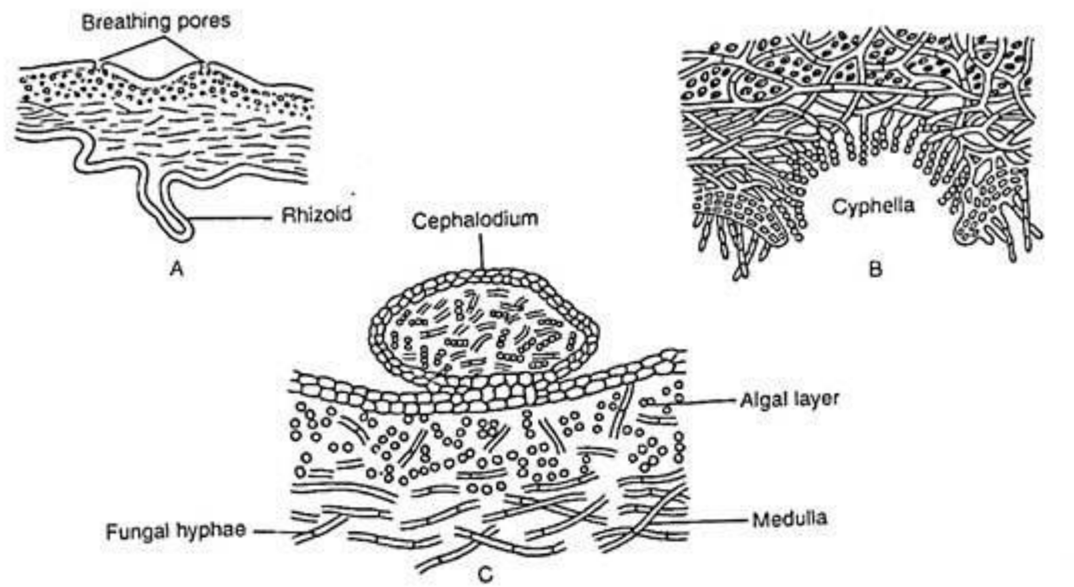


Fig. 4.114 : Specialised structures associated with lichen thallus : A. Breathing pores, B. Cyphella, C. Cephalodium

Reproduction in Lichens:

Lichen reproduces by all the three means, vegetative, asexual, and sexual.

I. Vegetative Reproduction:

(a) Fragmentation:

It takes place by accidental injury where the thallus may be broken into fragments and each part is capable of growing normally into a thallus.

(b) By Death of Older Parts:

The older region of the basal part of the thallus dies, causing separation of some lobes or branches and each one grows normally into new thallus.

II. Asexual Reproduction:

1. Soredium (pi. Soredia):

These are small grayish white, bud-like outgrowths developed on the upper cortex of the thallus (Fig. 4.115A, B). They are composed of one.or few algal cells loosely enveloped by fungal hyphae. They are detached from the thallus by rain or wind and on germination they develop new thalli.

When soredia develop in an organised manner in a special pustule-like region, they are called Soralia (Fig. 4.115D), e.g., Parmelia Physcia etc.

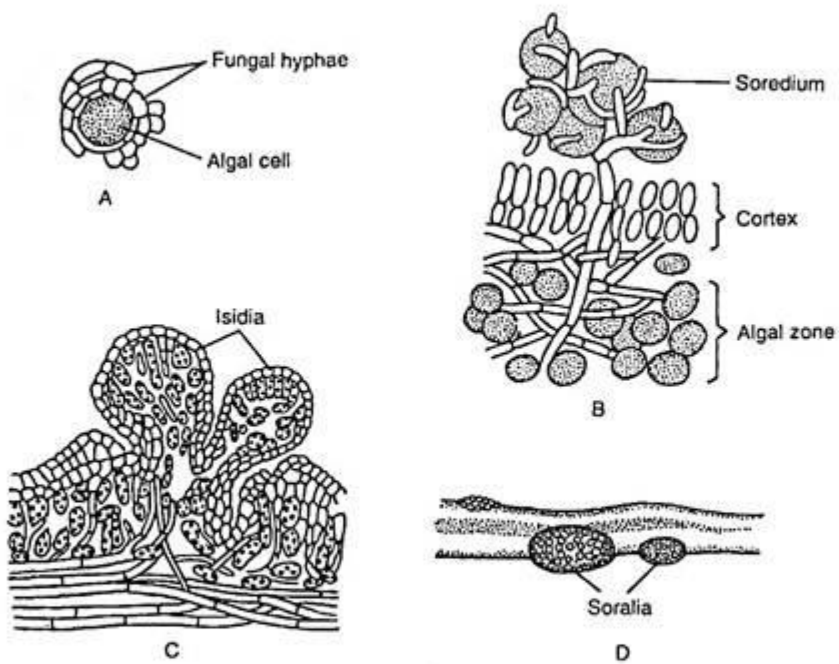


Fig. 4.115 : Asexual reproductive structures : A. Soredium of *Physcia pulverulenta* with single algal cell, B. Soredium of *Parmelia* with many algal cells, C. Isidia of *Peltigera* and D. Soralia on thallus

2. Isidium (pi. Isidia):

These are small stalked simple or branched, grayish- black, coral-like outgrowths, developed on the upper surface of the thallus (Fig. 4.115C). The isidium has an outer cortical layer continuous with the upper cortex of the mother thallus which encloses the same algal and fungal elements as the mother.

They are of various shapes and may be coral-like in Peltigera, rod-like in Parmelia, cigar-like in Usnea, scale-like in Collema etc. It is generally constricted at the base and detached very easily from the parent thallus. Under favourable condition the isidium germinates and gives rise to a new thallus.

In addition to asexual reproduction, the isidia also take part in increasing the photo- synthetic area of the thallus.

3. Pycniospore:
Some lichen develops pycniospore or spermatium inside the flask-shaped pycnidium (Fig. 4.116A).

They usually behave as gametes, but in certain condition they germinate and develop fungal hyphae. These fungal hyphae, when in contact with the appropriate algal partner, develop into a new lichen thallus.

III. Sexual Reproduction:
Only fungal partner of the lichen reproduces sexually and forms fruit bodies on the thallus. The nature of sexual reproduction in ascolichen is like that of the members of Ascomycotina, whereas in Basidiolichen is like that of Basidiomycotina members.

In Ascolichen, the female sex organ is the carpogonium and the male sex organ is called spermogonium (= pycnidium). The spermogonium (Fig. 4.116A) mostly develops close to carpogonium.

The carpogonium is multicellular and is differentiated into basal coiled ascogonium and upper elongated multicellular trichogyne (Fig. 4.116B). The ascogonium remains embedded in the algal zone, but the trichogyne projects out beyond the upper cortex.

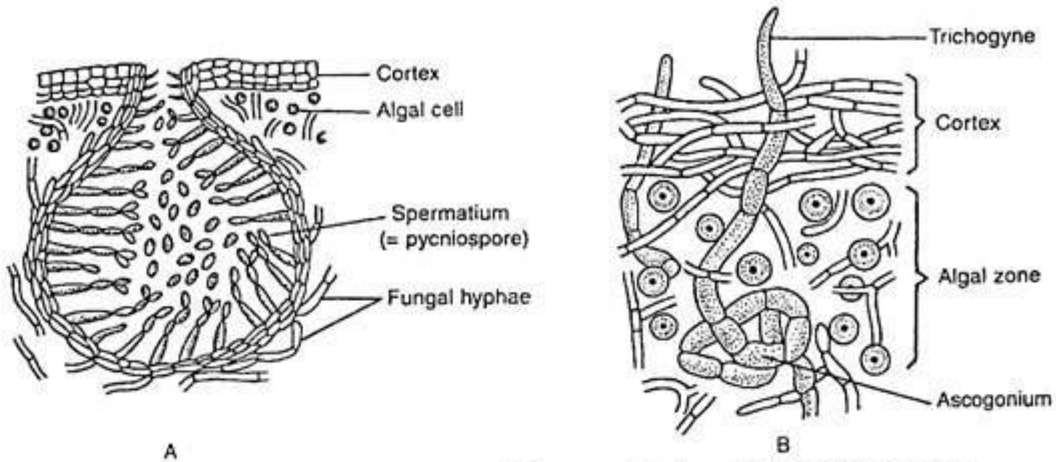


Fig. 4.116 : Sexual reproductive structures : A. Spermogonium (= pycnidium), B. Carpogonium

The spermogonium is flask-shaped and develop spermatia from the inner layer (Fig. 4.116A). The spermatia behave as male gametes. The spermatium, after liberating from the spermogonium, gets attached with the trichogyne at the sticky projected part. On dissolution of the common wall, the nucleus of spermatium migrates into the carpogonium and fuses with the egg.

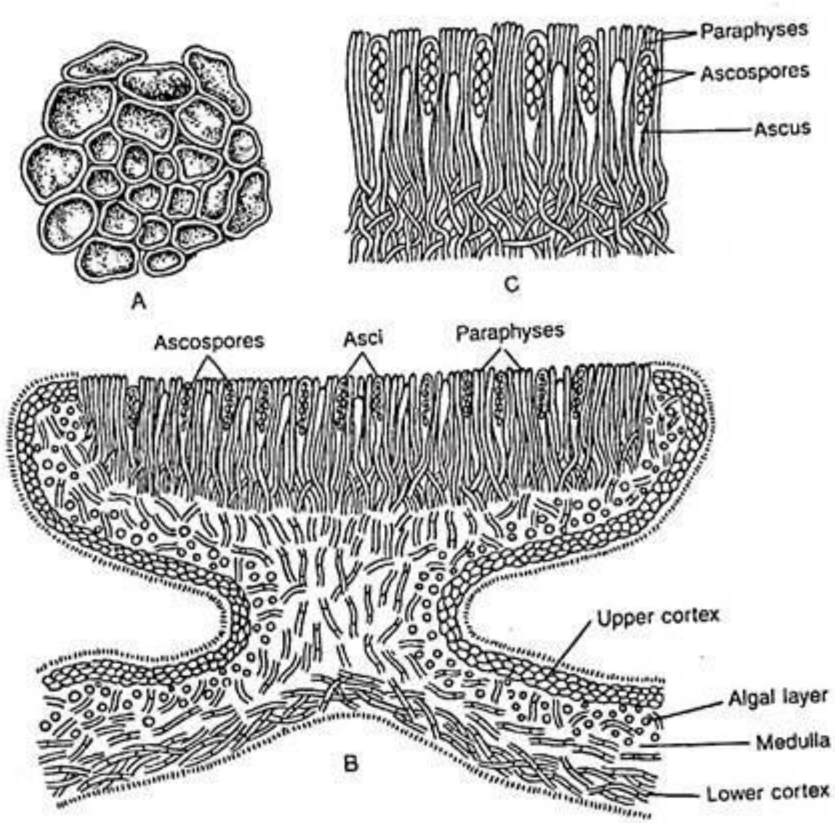


Fig. 4.117 : Structural features of ascolichen : A. Apothecia, B. V.S. of apothecium and C. Portion of hymenial region

Many ascogenous hyphae develop from the basal region of the fertilised ascogonium. The binucleate penultimate cell of the ascogenous hyphae develops into an ascus.

Both the nuclei of penultimate cell fuse and form diploid nucleus (2n), which undergoes first meiotic and then mitotic division — results in eight haploid daughter nuclei. Each haploid nucleus with some cytoplasm metamorphoses into an ascospore.

The asci remain intermingled with some sterile hyphae — the paraphyses. With further development, asci and paraphyses become surrounded by vegetative mycelium and form fruit body.

The fruit body may be ascohymenial type i.e., either apothecium (Fig. 4.117A) as in Parmelia and Anaptychia or perithecium as in Verrucaria and Darmatocarpon or ascolocular type (absence of true hymenium), which is also known as pseudothecia or ascostroma.

Internally, the cup-like (Fig. 4.117B, C) grooved region of a mature apothecium consists of three distinct parts; the middle thecium (= hymenium), comprising of asci and paraphyses, is the fertile zone covered by two sterile zones — the upper epitheca and lower hypotheca. The region below the cup is differentiated like the vegetative thallus into outer cortex, algal zone and central medulla (Fig. 4.117B).

Usually the asci contain eight ascospores (Fig. 4.117C), but the number may be one in Lopadium, two in Endocarpon and even more than eight in Acarospora.

The ascospores may be unicellular or multicellular, uninucleate or multinucleate, and are of various shapes and sizes. After liberating from the ascus, the ascospore germinates in suitable medium and produces new hypha. The new hypha, after coming in contact with proper algal partner, develops into a new thallus.

In Basidiolichen (Fig. 4.118), the result of sexual reproduction is the formation of basidiospores that developed on basidium as in typical basidiomycotina. The fungal member (belongs to Thelephoraceae) along with blue green alga, as algal partner forms the thalloid plant body.

The thallus grown over soil produces hypothallus without rhizines, but on tree trunk it grows like bracket fungi (Fig. 4.118A) and differentiates internally into upper cortex, algal layer, medulla and lower fertile region with basidium bearing basidiospores (Fig. 4.118B, C).

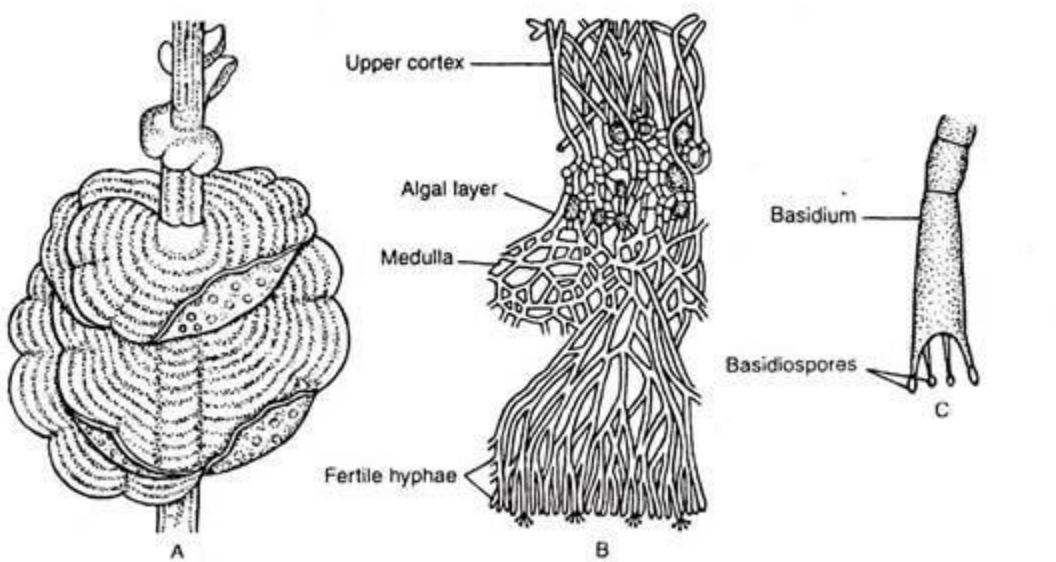


Fig. 4.118 : Structural features of basidiolichen (*Cora pavonia*) : A. Bracket-like thalli, B. Vertical section of thallus (portion), C. Basidium with basidiospores

Importance of Lichens:

A. Economic Importance of Lichens:

The lichens are useful as well as harmful to mankind. The useful activities are much more than harmful ones. They are useful to mankind in various ways: as food and fodder, as medicine and industrial uses of various kinds.

1. As Food and Fodder:

Lichens are used as food by human being in many parts of the world and also by different animals like snail, catterpiliars, slugs, termites etc. They contain polysaccharide, lichenin; cellulose, vitamin and certain enzymes.

Some uses of lichens are:

(i) As Food:

Some species of Parmelia are used as curry powder in India, Endocarpon miniatum is used as vegetable in Japan, Evernia prunastri for making bread in Egypt, and Cetraria islandica (Iceland moss) as food in Iceland. Others like species of Umbillicaria, Parmelia and Leanora are used as food in different parts of the world. In France, some of the lichens are used in the preparation of chocolates and pastries.

Lichens like Lecanora saxicola and Aspicilia calcarea etc. are used as food by snails, caterpillars, termites, slugs etc.

(ii) As Fodder:

Ramalina traxinea, R. fastigiata, Evernia prunastri, Lobaria pulmo- naria are used as fodder for animals, due to the presence of lichenin, a polysaccharide. Animals of Tundra region, especially reindeer and muskox use Cladonia rangifera (reindeer moss) as their common food. Dried lichens are fed to horses and other animals.

2. As Medicine:

Lichens are medicinally important due to the presence of lichenin and some bitter or astringent substances. The lichens are being used as medicine since pre-Christian time. They have been used in the treatment of jaundice, diarrhoea, fevers, epilepsy, hydrophobia and skin diseases.

Cetraria islandica and Lobaria pulmonaria are used for tuberculosis and other lung diseases; Parmelia sexatilisfor epilepsy; Parmelia perlata for dyspepsia. Cladonia pyxidata for whooping cough; Xanthoria parietina for jaundice and several species of Pertusaria, Cladonia and Cetraria islandica for the treatment of intermittent fever.

Usnic acid, a broad spectrum antibiotic obtained from species of Usnea and Cladonia, are used against various bacterial diseases. Usnea and Evernia furfuracea have been used as astringents in haemorrhages. Some lichens are used as important ingredients of many antiseptic creams, because of having spasmolytic and tumour-inhibiting properties.

3. Industrial Uses:

Lichens of various types are used in different kinds of industries.

(i) Tanning Industry:
Some lichens like Lobaria pulmonaria and Cetraria islandica are used in tanning leather.

(ii) Brewery and Distillation:
Lichens like Lobaria pulmonaria are used in brewing of beer. In Russia and Sweden, Usneaflorida, Cladonia rangiferina and Ramalina fraxinea are used in production of alcohol due to rich content of "lichenin", a carbohydrate.

(iii) Preparation of Dye:
Dyes obtained from some lichens have been used since pre- Christian times for colouring fabrics etc.

Dyes may be of different colours like brown, red, purple, blue etc. The brown dye obtained from Parmelia omphalodes is used for dyeing of wool and silk fabrics. The red and purple dyes are available in Ochrolechia androgyna and O. tartaria.

The blue dye "Orchil", obtained from Cetraria islandica and others, is used for dyeing woollen goods. Orcein, the active principal content of orchil-dye, is used extensively in laboratory during histological studies and for dyeing coir.

Litmus, an acid-base indicator dye, is extracted from Roccella tinctoria, R. montagnei and also from Lasallia pustulata.

(iv) Cosmetics and Perfumery:
The aromatic compounds available in lichen thallus are extracted and used in the preparation of cosmetic articles and perfumes. Essential oils extracted from species of Ramalina and Evernia are used in the manufacture of cosmetic soap.

Ramalina calicaris is used to whiten hair of wigs. Species of Usnea have the capacity of retaining scent and are commercially utilised in perfumery. Evernia prunastri and Pseudevernia furfuracea are used widely in perfumes.

Harmful Activities of Lichens:
1. Some lichens like Amphiloma and Cladonia parasitise on mosses and cause total destruction of moss colonies.

2. Lichen like Usnea, with its holdfast hyphae, can penetrate deep into the cortex or deeper, and destroy the middle lamella and inner content of the cell causing total destruction.

3. Different lichens, mainly crustose type, cause serious damage to window glasses and marble stones of old buildings.

4. Lichens like Letharia vulpina (wolf moss) are highly poisonous. Vulpinic acid is the poisonous substance present in this lichen.

B. Ecological Importance of Lichens:

Lichens have some ecological importance.

Some of the activities in this respect are:

1. Pioneer of Rock Vegetation:

Lichens are pioneer colonisers on dry rocks. Due to their ability to grow with minimum nutrients and water, the crustose lichens colonise with luxuriant growth. The lichens secrete some acids which disintegrate the rocks.

After the death of the lichen, it mixes with the rock particles and forms thin layer of soil. The soil provides the plants like mosses to grow on it as the first successor, but, later, vascular plants begin to grow in the soil. In plant succession, Lecanora saxicola, a lichen, grows first; then the moss Crtmmia pulvinata, after its death, forms a compact cushion on which Poa compressor grows later.

2. Accumulation of Radioactive Substance:

Lichens are efficient for absorption of different substances. The Cladonia rangiferina, the ‘reindeer moss’, and Cetraria islandica, the ‘Iceland moss’ are the commonly available lichens in Tundra region. The fallout of radioactive strontium (^{90}Sr) and caesium ($^{137}C_S$) from the atomic research centres are absorbed by lichen. Thus, lichen can purify the atmosphere from radioactive substances.

The lichens are eaten by caribou and reindeer and pass on into the food-chain, especially to the Lapps and Eskimos. Thus, the radioactive substances are accumulated by the human beings.

3. Sensitivity to Air Pollutants:

Lichens are very much sensitive to air pollutants like SO_2, CO, CO_2 etc.; thereby the number of lichen thalli in the polluted area is gradually reduced and, ultimately, comes down to nil. The crustose lichens can tolerate much more in polluted area than the other two types. For the above facts, the lichens are markedly absent in cities and industrial areas. Thus, lichens are used as “pollution indicators”.